NUREG-1812

Generic Environmental Impact Statement

Controlling the Disposition of Solid Materials

Draft Report for Comment

U.S. Nuclear Regulatory Commission
Office of Nuclear Materials Safety and Safeguards
Washington, DC 20555-0001

State of Massachusetts
U.S. Department of Energy
U.S. Environmental Protection Agency

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COMMENTS ON DRAFT REPORT

Any interested party may submit comments on this report for consideration by the NRC staff. Comments may be accompanied by additional relevant information or supporting data. Please specify the report number, NUREG-1812 draft in your comments, and send them by ___________ 2005 to the following address.

Chief, Rules Review and Directives Branch
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Electronic comments may be submitted to the NRC by the internet at nrcrep@nrc.gov.

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ABSTRACT

The Nuclear Regulatory Commission (NRC) is considering amending its regulations in 10 CFR Part 20 to include radiological criteria for controlling the disposition of solid materials at nuclear facilities. This Draft Generic Environmental Impact Statement (Draft GEIS) was prepared in compliance with the National Environmental Policy Act (NEPA) and the NRC regulations for implementing NEPA. This Draft GEIS evaluates the potential environmental impacts of the proposed action and its reasonable alternatives. This document also compares the potential environmental impacts resulting from the proposed rulemaking and its alternatives and the costs and benefits associated with those alternatives.

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BACKGROUND

The U.S. Nuclear Regulatory Commission (NRC) is considering whether to promulgate a regulation to control the disposition of solid materials that originate in restricted or impacted areas of NRC/Agreement-State licensed facilities, and have no, or very small amounts of, radioactivity resulting from licensed operations. These solid materials are referred to as "potentially clearable" solid materials. Materials considered by this rulemaking are concrete, metals (including steel, copper and aluminum), trash, soils, and tools and equipment. To support its rulemaking decision, NRC determined that a generic environmental impact statement (GEIS) is required by the NRC National Environmental Policy Act (NEPA)-implementing regulations in 10 CFR Part 51.

Nuclear facilities routinely use different types of solid materials in support of various activities, including operations, production, research and development, maintenance, facility refurbishment, and ultimately decommissioning. In support of operations, materials and items are introduced into areas that contain radioactivity. Once no longer needed, a licensee must decide how to disposition this material. Materials and equipment are surveyed before being taken out of restricted areas. The results of the surveys are used to determine the final disposition of materials or items. Based on the survey results, licensees determine whether it is worthwhile to decontaminate the materials or items or simply dispose of them as low-level waste (LLW).

At present, NRC generally addresses the release of solid material on a case-by-case basis using license conditions and existing regulatory guidance. In each case, material may be released from a licensed operation if the existing guidelines are met. Under the current approach, licensees survey materials to detect the presence of Atomic Energy Act (IAEA) materials above natural background levels. Solid materials with radioactivity below detection limits or below guideline values may be released from control with NRC approval. The process used to identify, survey and disposition solid materials is found in guidance, not regulations. Solid materials with higher levels of radioactivity are required to be disposed of at licensed LLW disposal facilities under NRC's existing regulations in 10 CFR Part 61.

NRC initially considered a proposed rulemaking in 1999. As part of the scoping process, NRC published an issues paper on the release of solid materials. Public comments were received on the preliminary alternatives at public workshops and in written comments. The Commission decided to defer a final decision on whether to proceed with a rulemaking and directed the staff to request that the National Academies conduct a study of alternatives for controlling the disposition of solid materials.

In March 2002, a report issued by the National Academy of Sciences discussed the advantages and disadvantages of various alternatives. The report found that NRC's current approach for controlling the disposition of solid materials "is sufficiently protective of public health that it does not need immediate revamping." However, the National Academies report also stated that NRC's current approach is incomplete and inconsistent and concluded that NRC should therefore undertake a process to evaluate a broad range of alternatives to provide clear risk-informed direction on controlling the disposition of solid materials. The report also recommended that an individual dose standard of 1 mrem/yr provides a reasonable starting point for the process of considering alternatives for a dose-based standard.

Based on these efforts, the Commission decided to proceed with a rulemaking for controlling the disposition of solid materials. In February 2003, the NRC resumed the scoping process by publishing a request for comments on the scope of the proposed rulemaking. The NRC also held a public workshop in May 2003 to solicit additional input on the alternatives being considered.

PROPOSED ACTION

The Proposed Action being considered in this Draft GEIS is to promulgate an NRC regulation that would establish criteria for the disposition of solid materials from NRC-licensed facilities. The Proposed Action would improve the efficiency and effectiveness of the NRC regulatory process for disposing of solid materials. The NRC is guided by the goals of the NRC Strategic Plan (NRC, 2004d) of which the primary goal is ensuring protection of public health and safety and the environment. The proposed rulemaking would result in related rulemakings in the Agreement States.

PURPOSE AND NEED FOR THE PROPOSED ACTION

The NRC agrees with the findings in the National Academies report regarding the need to consider modifying its current approach to provide risk-informed direction on controlling the disposition of solid materials. The purpose of the Proposed Action is to develop an efficient and effective regulatory process that ensures the disposition of these solid materials is controlled in a manner that ensures that NRC's strategic goal of ensuring protection of public health and safety and the environment is met. The Proposed Action should provide a consistent criterion for controlling solid materials, guidance for surficially and volumetrically contaminated materials, and a reduction in the time and resources required to evaluate case-specific applications.

ALTERNATIVES

This Draft GEIS considers alternative amendments to NRC's regulations that would include a criterion for controlling the disposition of solid materials. Based on the input from the scoping process, the following alternatives are studied in detail in this Draft GEIS.

- No Action
- Unrestricted Release
- U.S. Environmental Protection Agency (EPA)/State-Regulated Disposal
- Low-Level Waste (LLW) Disposal/Prohibition
- Limited Dispositions

<u>No Action</u>

This Draft GEIS includes an analysis of the No Action Alternative to provide the decisionmaker with a basis for comparison to the reasonable alternatives. In this case, under the No Action

Alternative, NRC would continue to apply its current approach to determining the eligibility of solid material for unrestricted release in general commerce or disposal. The NRC's current approach is one that employs measurement-based guidelines to determine if solid materials can be released for any use or disposal. In implementation, license conditions and facility-specific procedures require that solid materials that have been used in restricted or impacted areas are surveyed for the presence of radioactivity before being taken out of radiologically controlled areas. Solid materials can currently be released for any unrestricted use or disposal if the survey indicates that the existing guidelines are met. However, 10 CFR Part 20 does not currently specify a numerical level (e.g., dose or radionuclide concentration limits below which the material can be released). Decisions on disposition of solid materials are currently made using levels contained in a set of existing guidelines that are based primarily on the ability of survey techniques to measure the radioactivity level on, or in, the solid material. Under the No Action Alternative, solid material released (at or below guideline levels) for unrestricted release may be recycled and reused in a variety of end products, or it may be sent for disposal. Disposal may take place in an EPA/State-regulated landfill or LLW disposal facility.

Unrestricted Release

The Unrestricted Release Alternative would allow solid materials to be released for any use in general commerce (recycling and/or reuse into consumer products and industrial and construction uses) or for disposal, if they are below a dose-based criterion. All materials to be released would undergo a radiation survey and the measured levels of radiation would be compared against the criterion for unrestricted release. Solid materials with measured radiation levels below the established criterion would be released from licensed control, while solid materials with radiation levels above the criterion would be sent to a LLW disposal site. The proposed rulemaking would include a table of radionuclide concentrations or clearance levels corresponding to the selected dose-based criterion. Solid material released for unrestricted use may follow any disposition path – it may be recycled and reused in a variety of end products, or it may be sent for disposal. Disposal may take place in an EPA/State-regulated landfill or LLW disposal facility. This Draft GEIS considers a range of dose options for allowing the release of solid materials. The allowable dose level that NRC selects would directly impact the amount of solid material released for use in general commerce, with the amount of material released decreasing as the allowable dose criterion decreases. These dose options vary from 0.03 to 10 mrem/yr and include the International Atomic Energy Agency (IAEA) Safety Guide No. RS-G-1.7 dose limit of 1 mrem/yr.

EPA/State-Regulated Disposal

Under the EPA/State-Regulated Disposal Alternative, all potentially clearable solid material below a dose-based criterion would be released to EPA/State regulated landfills and would be prohibited from general commerce (recycling into consumer products and industrial and construction uses). Solid materials above the dose-based criterion would be sent to a LLW disposal site. In the base case, all released solid materials (including tools and equipment) would be disposed of in EPA/State-regulated Resource Conservation and Recovery Act (RCRA) Subtitle D landfills. The Draft GEIS also considers one variation in which all the potentially clearable trash would be incinerated at EPA/State-regulated landfills and the ash disposed of in those landfills. This Draft GEIS considers a range of dose options varying from 0.03 to 10 mrem/yr. Under this alternative, the radionuclide concentrations are higher so a greater amount of activity could be released to landfills than the amount that could be released to general commerce under the Unrestricted Release Alternative. (This is because the public exposure scenarios for landfills differ from those for unrestricted release.)

<u>LLW Disposal</u>

Under the LLW Disposal Alternative, also known as Prohibition, all potentially clearable solid material (including tools and equipment) would be prohibited from general commerce and EPA/State-regulated landfill disposal. All solid material in restricted or impacted areas would be classified as LLW and required to be disposed of under NRC's existing regulations (10 CFR Part 61).

<u>Limited Dispositions</u>

In the Limited Dispositions Alternative, solid material would be released, but NRC would allow only certain authorized dispositions to limit the potential for public exposure. The radionuclide criterion was chosen to be a dose limit of 1 mrem/yr using the IAEA Safety Guide No. RS-G-1.7. The NRC chose to consider a table of radionuclide concentrations accompanying the IAEA Safety Guide that is based on unrestricted release. Use of these concentration levels limits any potential impacts in the unlikely event that these materials were to end up in different dispositions, including reuse and recycling into other products. Solid materials above the radionuclide concentrations associated with the 1 mrem/yr criterion would be sent to a LLW disposal facility.

Based on public comments during the scoping period and on the analyses for the Unrestricted Release and EPA/State-Regulated Disposal Alternatives, the only limited dispositions considered under this alternative are disposal in a RCRA Subtitle D landfill, concrete use in road fill, and reuse of tools and equipment for its original purpose. Licensees would need to demonstrate that the material proposed for release is less than the radionuclide concentrations in the proposed rule.

The following are the components of this alternative.

- For landfill disposal under this alternative, the released solid materials (concrete, metal or trash) at or below the 1 mrem/yr criterion could be disposed of in RCRA Subtitle D landfills.

- Released concrete at or below the 1 mrem/yr criterion could be recycled into roadbed material.

- Tools and equipment that meet the 1 mrem/yr criterion could be reused or disposed of in RCRA Subtitle D landfills.

- Any request to release solid material other than to these limited dispositions or releases at higher radionuclide concentration levels would require case-specific approval from NRC. Disposition of soils would be case-specific.

- To ensure that the material releases are occurring to the pre-approved dispositions, licensees will be required to keep records and these activities would be evaluated periodically during NRC staff inspections at licensed facilities.

<u>Alternatives Eliminated from Detailed Study</u>

One alternative (Conditional Use) and two dose options (both clearance standards) were considered by NRC and eliminated from detailed study. These options are therefore not analyzed in detail in this Draft GEIS.

In the Conditional Use Alternative, solid material would be released, but its further use would be restricted to only certain authorized uses with limited potential for public exposure, such as use in controlled environments. Examples might include industrial uses such as metals in bridges, sewer lines, or industrial components, or concrete use in road fill. Material from these authorized uses may ultimately be reused or recycled into products not authorized under the Conditional Use Alternative. Further, the Conditional Use Alternative would allow a greater amount of activity than the amount released under the Limited Dispositions Alternative. This is because the Limited Dispositions Alternative uses lower, and therefore more restrictive, radionuclide concentrations based on the Unrestricted Use Alternative to establish the 1 mrem/yr dose limit. For this reason, the Conditional Use Alternative was replaced with the more restrictive Limited Dispositions Alternative, which uses radionuclide concentrations based on unrestricted release.

In addition to the dose options being analyzed under the Unrestricted Release Alternative, the 1999 American National Standards Institute (ANSI)/Health Physics Society (HPS) Standard N13.12 was also considered. The ANSI standard presents a screening clearance criterion for unrestricted release of solid materials based on an annual dose limit of 1 mrem. However, the bases for the screening clearance levels in the standard have not been fully documented and the use of the ANSI standard was thus difficult to justify. The standard is due for its first 5-year review cycle in 2004 and may be revised.

An additional international standard considered by NRC as an option under the Unrestricted Release Alternative was the European Commission's (EC's) clearance levels. The EC's standard was rejected because using the more recently adopted IAEA safety guide would provide more consistency in international standards.

COMPARISON OF PREDICTED ENVIRONMENTAL IMPACTS OF ALTERNATIVES

NEPA regulations require a comparison of the environmental impacts of the alternatives, in order to define the issues and provide a clear basis for choice among the alternatives. This section presents a comparison of the environmental impacts of the alternatives. Table 2-1 provides a summary of the impacts.

Some environmental issues are not analyzed in detail in this Draft GEIS because NRC does not anticipate activities that could have the potential to impact these environmental resources. These environmental resources and issues include soils, noise, ecological resources, socioeconomic, historic and cultural resources, environmental justice, visual and scenic resources, and land use.

In the event that there are site-specific construction activities associated with the disposition of solid materials, any such activities would be subject to a site-specific NEPA analysis conducted on a case-by-case basis.

The time period over which impacts are considered includes (1) the operational phase of reactors, during which some materials are expected to be released, (2) the post-shutdown and decommissioning phase of reactors, during which materials will be released as well, (3) and the post-decommissioning time period after which materials that have been released are presumed to have some long-term impacts on the public. The operational phase of reactors takes into account the currently operating and shutdown reactors over the next 50 years. The post-decommissioning phase considers impacts over the next 200 years, while the analysis notes that doses beyond 200 years and out to 1000 years become vanishingly small and contribute very little to the total of collective doses.

Public and Worker Health and Safety

The radiological effects to the General Public, Non-Licensed Facility Workers, and Licensed Facility Workers are assessed in this Draft GEIS in terms of collective dose, in units of person-rem. Even at the highest dose option (10 mrem/year), the effects of exposure on all three categories of exposed groups would be small when compared with background exposure coming from natural, medical, and other sources. However, there is a variation between alternatives.

Table ES-1 presents a summary of the collective dose results discussed in Section 3.2. For the Unrestricted Release Alternative, the dose option chosen for the comparison is the IAEA Safety Guide RS-G-1.7, which is also part of the Limited Dispositions Alternative. The dose option chosen for the EPA/State-Regulated Disposal was 1 mrem/yr. For Licensed Facility Workers, the collective doses associated with all of the alternatives are similar, except that for the LLW Disposal Alternative, the collective dose is lower because there is no decontamination of the solid materials.

For Non-Licensed Facility Workers and the General Public, the highest collective doses are for the No Action and Unrestricted Release Alternatives because for these alternatives the collective dose is dominated by exposure of the General Public to products made from recycled ferrous metal. The lowest collective dose to Non-Licensed Facility Workers and the General Public is for the EPA/State-Regulated Disposal Alternative without trash incineration. Collective dose was not calculated for the LLW Disposal Alternative for Non-Licensed Facility Workers and the General Public, but is assumed to be low, similar to the collective dose for the EPA/State-Regulated Disposal Alternative without trash incineration. The collective dose for the Limited Dispositions Alternative is smaller than the No Action and Unrestricted Release Alternatives.

The collective dose analysis indicates that for all the Alternatives, the exposures to all categories of exposed groups would be small when compared with background exposure coming from other sources. The annual background collective dose to the U.S. population due to natural sources of radiation and radioactivity is estimated to be about 84 million person-rem (Appendix E).

Table ES-1 Summary of Collective Dose Results (person-rem)

Alternative	Collective Dose	
	Licensed Workers	Non-Licensed Facility Workers and General Public
No Action	631	3,996
Unrestricted Release	631	3,429
EPA/State-Regulated Disposal without Trash Incineration	631	2
EPA/State-Regulated Disposal with Trash Incineration	631	1,011
LLW Disposal	323	-
Limited Dispositions	631	112

Transportation

Transportation effects are measured in this Draft GEIS in terms of fatal vehicle accidents and railcar incidents (e.g., derailments) (Table ES-2). These effects are based on statistical information on non-radiological accidents. The effects are highest for the LLW Disposal Alternative, with an estimated 32 fatal accidents over the time period of the analysis (about 50 years) if the material is transported by truck, or approximately 7 accidents if it is transported by rail. This results from the fact that the analysis for the LLW Disposal Alternative assumes that all materials must be transported to a single LLW disposal site in Utah, which is an average trip of 1,544 miles. Transport distances associated with all the other alternatives are significantly shorter, resulting in lower transportation effects. The number of fatal accidents under the No Action Alternative is estimated at 10, which is about double the effect associated with the Unrestricted Release Alternative at 1 mrem/yr. For the EPA/State-Regulated Disposal Alternative, the effect would be even lower due to the large number of Subtitle D landfills located throughout the country resulting in short transportation distances, typically less than 100 miles. The number of fatal accidents under the Limited Dispositions Alternative is estimated at 9.

Water Quality

Impacts to water quality are expected to be small because compliance with EPA and State permits would preclude significant impacts. Water quality effects are primarily associated with point source and area source water discharges from the storage, handling, and processing of solid materials. For the No Action and Unrestricted Use Alternatives, the effects are generated mostly by runoff discharges from rubblization of concrete and runoff and process wastewater discharges from recycling of steel. The incremental quantity of these discharges generated would be small as compared to the overall amount of discharges generated from the total amount of concrete and steel being recycled annually in the U.S., and the impact on water quality would be equally small. Similarly, the quantity of additional leachate and potential effects on ground water associated with disposal of solid materials under the EPA/State-Regulated Disposal Alternative and the LLW Disposal Alternative would be small compared with the overall amount of leachate being generated annually by these facilities. Therefore the overall effects on water quality associated with all of the alternatives would be small.

Table ES-2 Summary of Transportation Impacts (Accident Fatalities)

Alternative	Dose Option (mrem/year)	Vehicle Miles Traveled (millions)	Fatalities	Impact
No Action	not applicable	423	10	small
Unrestricted Release	1	230	5	small
EPA/State-Regulated Disposal	1	88	2	small
LLW Disposal	not applicable	1,402 (truck)	32	moderate
		319 (rail)	7	small
Limited Dispositions	1	405	9	small

Air Quality

Air quality effects are primarily associated with mobile source emissions from transportation of solid materials to recycling and disposal facilities, fugitive dust emissions from rubblization of concrete, process emissions from recycling of steel, and emissions from the incineration of trash. The effects on air quality would be greatest for the EPA/State-Regulated Disposal Alternative trash incineration variation. The air quality effects associated with all other alternatives would be negligible. However, the overall effects on air quality associated with all of the alternatives are small when compared with other sources of emissions.

Waste Management

The resource being evaluated for waste management is disposal capacity. The EPA/State-regulated disposal facilities considered were RCRA Subtitle D landfills. The analysis in Section 3.7 demonstrates that the existing capacity of Subtitle D landfills would be adequate for the disposal of all of the potentially clearable materials that could be released under any of the alternatives.

NRC analyzed disposal capacity at LLW disposal sites for all the alternatives. A summary of the LLW disposal capacity analysis is shown in Table ES-3. A small impact indicates there is currently sufficient LLW disposal capacity and the need to expand existing LLW storage is small. Moderate impact indicates there is currently insufficient LLW disposal capacity and expansion of existing LLW storage capacity would be needed. A large impact indicates the amount of additional low-level waste disposal capacity needed is of such a magnitude that this impact should be avoided.

Under the No Action Alternative, the amount of solid material that would be sent to the Envirocare LLW disposal site (the only site considered in this analysis) is approximately 84 percent of the existing capacity of the site; this is considered a moderate impact. For the Unrestricted Release and EPA/State Regulated Disposal Alternatives, the dose option chosen for the comparison is IAEA Safety Guide RS-G-1.7, which is also part of the Limited Dispositions Alternative. Under the Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives, the amount of potentially clearable solid material that would not be released for unrestricted use, but that would be disposed of at the Envirocare LLW disposal site, would total approximately 11 to 15 percent of the existing LLW disposal capacity of the Envirocare facility; these are considered small impacts. The effects associated with the LLW Disposal Alternative are considered large. Under this alternative, the amount of solid material projected to be disposed of in the Envirocare LLW disposal facility totals more than four times the existing capacity of the facility under its current State licenses and permits.

Table ES-3 Summary of LLW Disposal Capacity Analysis

Alternative	Percent of Estimated Remaining LLW Disposal Capacity That Would Be Filled		Impact
	Hanford, Barnwell and Envirocare	Envirocare Only	
No Action	22	84	moderate
Unrestricted Release	4	15	small
EPA/State-Regulated Disposal	3	11	small
LLW Disposal	112	426	large
Limited Dispositions	4	15	small

Cost/Benefit

The cost/benefit analysis is discussed in Chapter 4 and summarized in Table ES-4 for the dose limit of 1 mrem/yr. The No Action Alternative is the baseline and by definition there are no incremental costs or benefits associated with this alternative. Incremental costs for the other alternatives are those costs above the No Action Alternative costs. In Table ES-4, only the most significant attributes are shown. Public and Occupational Health (Routine) includes collective doses to the public and licensed workers and represents less than 0.5 percent of the total incremental benefit or cost of each alternative. Public and Occupational Health (Accident) includes traffic accidents and represents about 1 percent of the total. Industry Operations includes the cost of surveys, disposal fees, and transportation costs and represents about 99 percent of the total benefits or costs. Environmental considerations include air emissions and reductions in the use of virgin materials due to recycling and represent less than 1 percent of the total. Transportation and disposal costs are the most significant sub-attributes when considering costs and benefits.

The incremental costs and benefits associated with the various alternatives vary greatly. The highest incremental costs are associated with the LLW Disposal Alternative and are estimated to exceed $1.4 billion, primarily from transportation and disposal costs. For the Unrestricted Use and EPA/State-Regulated Disposal Alternatives, the incremental costs and benefits are highly dependent on the dose option selected. For both, benefits are associated with the 1 mrem/yr and 10 mrem/yr dose options, but costs are associated with the 0.03 mrem/yr and 0.1 mrem/yr dose options due to the fact that under the smaller dose options, smaller amounts of solid material are cleared, and larger amounts must be transported and disposed of in LLW disposal sites. For the comparison of alternatives in Table ES-4, IAEA Safety Guide RS-G-1.7 for the Limited Dispositions Alternative. For the Unrestricted Release, EPA/State Regulated Disposal, and Limited Dispositions Alternatives, the total benefits are similar.

Table ES-4 Summary of Net Incremental Benefit (Cost) Associated with Major Attributes by Alternative

	Benefit (Cost) in Millions of Dollars (2003$)				
Alternative	**Public and Occupational Health (Routine)**	**Public and Occupational Health (Accident)**	**Industry Operations**	**Environmental Considerations**	**Total**
No Action	-	-	-	-	-
Unrestricted Release	<1	0	246	1	247
EPA/State-Regulated Disposal	1	0	181	(1)	181
LLW Disposal	1	(13)	(1,378)	(13)	(1,404)
Limited Dispositions	1	0	258	(2)	257

The net benefits of the Unrestricted Release, EPA Disposal and Limited Dispositions Alternatives are largely the result of less LLW transportation and disposal costs for concrete compared to the No Action Alternative. This is because there are many more tons of potentially clearable concrete than steel or trash. Also, there are less benefits for steel recycling because recycling revenue for steel is offset by the fact that the average distance to the steel recycling facilities is greater than the average distance to the EPA/State-regulated landfills.

Summary

As discussed above, the impacts on public and worker health and safety, transportation, water quality, air quality, and waste management were studied in detail. The impacts on public and worker health and safety, water quality, and air quality are predicted to be small for all the alternatives. The transportation effects are highest for the LLW Disposal Alternative, because transport distances associated with this alternative are significantly higher for truck transport, resulting in higher estimated fatal traffic accidents. The effects on waste management associated with the LLW Disposal Alternative are considered large (more than four times the existing LLW capacity at the Envirocare site under its current State licenses and permits). Under the other alternatives, the amount of solid material that would be sent to a LLW facility is less than the existing LLW disposal capacity.

In analyzing the costs and benefits associated with the alternatives, the No Action Alternative is the baseline against which the other alternatives are compared. The highest incremental costs are associated with the LLW Disposal Alternative and are estimated to exceed $1.4 billion, primarily from transportation and disposal operations. For the Limited Dispositions Alternative, with a criterion based on the IAEA standard, the incremental benefit would be $257 million.

CUMULATIVE IMPACTS

Cumulative impacts are those impacts on the environment which result from the incremental impacts of an action (in this case, a rulemaking for disposition of solid materials) when added to the impact of other past, present and reasonably foreseeable future actions (40 CFR 1508.7). The following cumulative impacts were considered: (1) exposure of individuals to multiple sources, (2) disposition of DOE scrap metals with small amounts of radioactivity, (3) industries not licensed by NRC that use or process materials that contain naturally-occurring radioactive materials (NORM), which because of their operations create higher concentrations of radioactivity than that associated with an undisturbed natural setting, and (4) two proposed new uranium enrichment plants which would generate large quantities of LLW. Cumulative impacts to doses to the public are expected to be small due to the low doses considered in the NRC rulemaking.

UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS, SHORT-TERM USES OF THE ENVIRONMENT, AND LONG-TERM PRODUCTIVITY

The radiation doses that would occur as a result of the proposed action are well below NRC regulatory limits and represent a small fraction of the existing background levels of radiation. Unavoidable adverse environmental impacts, short-term uses of the environment, and long-term productivity were previously considered under the activities expected during operation and decommissioning of licensed facilities.

IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

For all but the LLW Disposal Alternative, no resources would be lost because the Proposed Action falls within the activities expected during operation and decommissioning of licensed facilities. For the LLW Disposal Alternative, the amount of LLW would exceed the available LLW disposal capacity, and thus this alternative would result in the commitment of land for additional LLW facilities or the expansion of current facilities. This alternative also represents approximately a 350 percent increase in energy expended for transportation as compared to the No Action Alternative.

The No Action and Unrestricted Release Alternatives would result in recycling of concrete, steel, aluminum and copper. The Limited Dispositions Alternative would result in recycling of concrete but not metals, except by case-by-case determination by NRC. The recycled steel would displace the need for production of new steel, and the production of recycled steel requires less energy and materials than production of new steel. Thus the No Action and Unrestricted Release Alternatives, under which steel would be recycled, would commit fewer resources towards steelmaking than would the EPA/State-Regulated Disposal Alternative or LLW Disposal Alternative, under which no recycling would be conducted. The amount of steel that would be recycled under the Limited Dispositions Alternative cannot be estimated, but would likely be much lower than the amount for the No Action Alternative or Unrestricted Release Alternative.

MONITORING AND MITIGATION MEASURES

All radioactive materials used, possessed, or stored onsite are required to be periodically monitored and inventoried. The monitoring includes the conduct of external radiation and surface contamination surveys. The inventory addresses quantities of radioactive materials as to their physical and chemical forms, uses, and dispositions, including radioactive decay. These requirements are stated in 10 CFR Part 20 and as license conditions stipulated in each license. Accordingly, the radiological status and locations of materials, before being designated for release, fall under the full control of the radiation safety program of each licensee. As a result no additional mitigation measures are anticipated as a result of implementing any of the alternatives. The implementation of the rule will be monitored through inspections, similar to those for releases to sewers.

STAFF ASSESSMENT AND PRELIMINARY RECOMMENDATION

After weighing the costs and benefits of the alternatives and comparing the impacts of the alternatives, the NRC staff, in accordance with 10 CFR 51.71(e), sets forth their preliminary NEPA recommendation regarding the proposed action. The NRC staff recommends that the staff promulgate a regulation for limited dispositions.

The National Academies report indicated that NRC's current approach for controlling the disposition of solid materials (the No Action Alternative) is sufficiently protective of public health; however, the report also indicated that the current approach is incomplete and inconsistent and that NRC's approach should be risk-informed.

Some commenters were in favor of the Unrestricted Release Alternative because disposal of all potentially clearable solid material in a licensed LLW disposal facility is costly to licensees without an accompanying health and safety benefit and would cause a severe economic impact for small licensees (e.g., medical facilities, universities). However, most of the public commenters were concerned that risks associated with unrestricted release of these solid materials are avoidable and involuntary, radiation risks are underestimated, there is a potential for exposures to multiple products, and releases would not be accurately measured and tracked. Also commenters from the steel and concrete industries, who would receive the cleared material, indicated that their potential costs could be very large because consumers could choose not to purchase items made from material recycled from licensed facilities.

We also examined the EPA/State-Regulated Landfill Disposal Alternative. This approach would prevent solid material from licensed facilities from entering general commerce, thus limiting the potential for radiation exposure to the general public. Also, limiting disposal of released solid materials to an EPA/State-Regulated landfill would place a smaller economic burden on licensees than disposal of all potentially clearable solid materials at a licensed LLW disposal site. (Some potentially clearable solid material would still go to a LLW facility if it was above the dose limit.) However, because this alternative would allow higher radionuclide concentrations, a greater amount of activity could be released to landfills than the amount that would be released to general commerce under the Unrestricted Release Alternative.

The next alternative considered was the Low Level Waste Disposal Alternative, also referred to as Prohibition. In this alternative, all potentially clearable solid material would be prohibited from general commerce and would be disposed of in a LLW disposal site. This approach would prevent solid material from licensed facilities from entering general commerce, thus limiting the potential for radiation dose to the general public. However, if all potentially clearable material (which has no, or very small amounts of, radioactivity and which has some economic value) is sent to LLW disposal sites, this would be costly to licensees. Furthermore, there is a large impact on LLW disposal capacity - the solid materials to be generated from the existing commercial nuclear reactors would represent more than the existing LLW disposal capacity.

After assessing the above alternatives, NRC considered the Limited Dispositions Alternative. Under this alternative, potentially clearable solid material (concrete, steel and trash) could be released, if it were below radionuclide concentrations associated with a dose criterion of 1 mrem/yr, but with only certain authorized dispositions to limit the potential for public exposures. Three pre-authorized dispositions are considered in this alternative - RCRA Subtitle D landfill disposal, concrete use in road beds, and the reuse of tools and equipment. Any requests to release material other than the three pre-approved dispositions (for example, soils or industrial uses such as metals in bridges, sewer lines, or industrial components in a factory) or at higher radionuclide concentrations would require case-specific approval.

To limit potential impacts in the unlikely event that released solid materials are recycled into other products, the radionuclide concentrations considered in the Limited Dispositions Alternative are based on the Unrestricted Release Alternative. The IAEA radionuclide concentrations were chosen to be consistent with national and international numeric guidelines. Another economic benefit is that potentially clearable solid materials could be used under certain authorized conditions, rather than using the more costly licensed LLW disposal facilities. As shown in Table ES-1, the collective dose for this alternative is lower than for the No Action Alternative because exposures to the public are more limited. To ensure that the material releases are occurring to the pre-approved dispositions, there would be licensee recordkeeping and these activities would be evaluated periodically during routine staff inspections at licensed facilities. Also enforcement action would be taken if necessary.

Municipal solid waste operators, EPA and the State agencies have the discretion of allowing or refusing disposals in Subtitle D facilities. Even if allowed, EPA and the State agencies might impose additional constraints on such disposals. Accordingly, the implementation of the rule would have to consider EPA and State agency requirements as well as the concerns of the landfill operators. It is envisioned that some landfill operators might not want to receive such materials, but others would, considering economic factors. At this time, however, it is not possible to determine readily which landfill operators and State agencies might find the NRC rule as an effective option.

After considering the costs, benefits and impacts of the alternatives, the staff has concluded that the Limited Dispositions Alternative is NRC's preliminary recommendation. The NRC staff concluded the overall benefits of the proposed rulemaking outweigh the disadvantages based on consideration of the following. The proposed rulemaking would

- provide a risk-informed consistent criterion for controlling the disposition of solid materials,
- allow for a predictable regulatory process that is efficient and effective,
- set a dose criterion well below levels established to ensure adequate protection of public health and safety and the environment,
- be consistent with international numeric guidelines,
- provide limited potential for public exposure,
- address public concerns with unrestricted release of solid materials into general commerce,
- address concerns from the steel and concrete industries that consumers could choose not to purchase items made from materials recycled from licensed facilities,
- provide guidance on materials with surficial and volumetric residual radioactivity, and
- ensure less time and resources would be expended on case-specific applications.

The cooperating agencies (State of Massachusetts, EPA and DOE) are currently reviewing the Draft GEIS and have not expressed a preference regarding the alternatives discussed in the GEIS. The agencies found little difference in the environmental impacts among the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives. Thus they have concluded the Draft GEIS analysis does not provide a compelling basis for selecting the Limited Dispositions Alternative. Also, the cooperating agencies recommend there should be a process for clearing material without residual radioactivity in a restricted area for unrestricted release. The agencies have commented that there could be confusion regarding other nations' imports into the U.S. because the IAEA safety guide recommends unrestricted release, but the Draft GEIS recommends limited disposition.

ACRONYMS AND ABBREVIATIONS

ACBFS	Air-cooled blast furnace slag
AEC	Atomic Energy Commission
AGN	Aerojet General Nucleonics
AISI	American Iron and Steel Institute
ALARA	As Low As Reasonably Achievable
ANSI	American National Standards Institute
APA	Administrative Procedure Act
AS	Agreement State
ATSDR	Agency for Toxic Substances and Disease Registry
BCGs	Biota Concentration Guides
BOF	Blast Oxygen Furnace
BRC	Below regulatory concern
BWR	Boiling water reactor
CAA	Clean Air Act
C&D	Construction & Demolition
CDA	Copper Development Association
CEQ	Council on Environmental Quality
CFR	Code of Federal Regulations
CH_4	Methane
CO_2	Carbon dioxide
COI	Conflict of interest
cosmic	Outer space

CRCPD	Conference of Radiation Control Program Directors
CWM	Chemical Waste Management
D&D	Decontamination and Decommissioning
DCF	Dose conversion factor
DF	Dose factor
DGEIS	Draft Generic Environmental Impact Statement
DNAPL	Dense non-aqueous phase liquids
DOD	Department of Defense
DOE	Department of Energy
DOS	Department of State
DOT	Department of Transportation
DUF_6	Depleted uranium hexaflouride
EAF	Electric Arc Furnace
EC	European Commission
EDE	Effective dose equivalent
EFIG	Emission Factors and Inventories Group
EPA	Environmental Protection Agency
FGR	Federal Guidance Report
FMCSA	Federal Motor Carrier Safety Administration
GEIS	Generic Environmental Impact Statement
GGBFS	Ground granulated blast-furnace slag
GHG	Greenhouse gas
GP	General Public

HAP	Hazardous air pollutant
HLW	High-level waste
HPS	Health Physics Society
HSM	Horizontal Storage Modules
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
ISFSI	Independent spent fuel storage installation
LES	Louisiana Energy Services
LLRW	Low Level Radioactive Waste
LLRWDF	Low-Level Radioactive Waste Disposal Facility
LLW	Low-Level Waste
LNAPL	Light non-aqueous phase liquids
LWR	Light water reactor
MACT	Maximum Achievable Control Technology
MARSSIM	Multi-Agency Radiation Survey and Site Investigation Manual
MCL	Maximum Contaminant Level
MOX	Mixed oxide
mrem/yr per pCi/g	Millirem per year of radiation exposure per picocurie per gram of material
mrem/yr per pCi/cm^2	Millirem per year of radiation exposure per picocurie per square centimeter of material
MSW	Municipal Solid Waste
MSWLF	Municipal Solid Waste Landfill
MVDS	Modular Vault Dry Storage

NAAQS	National Ambient Air Quality Standards
NCRP	National Council on Radiation Protection and Measurements
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NESHAP	National Emissions Standards for Hazardous Air Pollutants
NKBA	National Kitchen and Bath Association
NLFW	Non-Licensed Facility Workers
NPDES	National Pollutant Discharge Elimination System
NPR	Non-power reactor
NPTS	Nationwide Personal Transportation Survey
NRC	Nuclear Regulatory Commission
NTTAA	National Technology Transfer and Advancement Act of 1995
N_2O	Nitrous oxide
OAQPS	Office of Air Quality Planning and Standards
OAS	Organization of Agreement States
OTAQ	Office of Transportation and Air Quality
P&O	Public and occupational health and safety
PM_{10}	Particulate matter
$PM_{2.5}$	Fine particulate matter
POTW	Publicly Owned Treatment Facility
ppm	Parts per million
PWR	Pressurized water reactor
R&D	Research and development

RCRA	Resource Conservation and Recovery Act
RDF	Refuse-derived fuel
Rebars	Reinforcement bars
SDMP	Site Decommissioning Management Plan
SIP	State implementation plan
Smelters	NRC-Licensed Recycling Facilities
SRM	Staff Requirements Memorandum
TEDE	Total Effective Dose Equivalent
TENORM	Technologically Enhanced Naturally Occurring Radioactive Material
terrestrial	The ground
TRIGA	Training, Research, Isotopes, General Atomics
U_3O_8	Uranium oxide
UF_6	Uranium hexafluoride
UO_2	Uranium dioxide
USC	United States Code
USEC	U.S. Enrichment Corporation
VOC	Volatile organic compounds
WWW	World Wide Web

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FOREWORD

This Draft GEIS is organized consistent with the National Environmental Policy Act (NEPA) and the President's Council on Environmental Quality (CEQ) regulations at 40 CFR 1502.10. It is intended to provide clear and concise information on the Proposed Action and Alternatives to agency decision-makers and the public. This Draft GEIS describes the Proposed Action and Alternatives, the affected environment, and potential impacts associated with the Proposed Action and Alternatives. The following is a brief description of the contents of this Draft GEIS.

Chapter 1 - Purpose and Need
Chapter 1 introduces the Proposed Action, describes the background and history of NRC's efforts for controlling the disposition of solid materials, describes the purpose and need for action, and introduces the cooperating agencies. This chapter also describes the scope of the analysis.

Chapter 2 - Proposed Action and Alternatives
Chapter 2 describes the Proposed Action and Alternatives, including the No Action Alternative, that are studied in detail in the Draft GEIS. It also describes the Alternatives that were considered, but eliminated from detailed analysis. Chapter 2 concludes with a summary comparison of the predicted environmental impacts that would result from implementation of the Proposed Action or Alternatives, based on the information and analysis presented in Chapter 3.

Chapter 3 - Description of the Affected Environment and Environmental Consequences
Chapter 3 describes the existing natural and human resources that could be affected by the Proposed Action and Alternatives. It also contains the methodology and results of the analysis of potential environmental impacts associated with the Proposed Action and Alternatives, including the No Action Alternative. The results address direct, indirect, cumulative, short-term, and long-term impacts.

Chapter 4 - Cost-Benefit Analysis
Chapter 4 summarizes the results of the cost-benefit analysis, which is provided in full, including a discussion of methodology, in Appendix K. This chapter presents the costs and benefits associated with the Proposed Action and each of the Alternatives.

Chapter 5 - Staff Assessment
Chapter 5 presents the staff's assessment of the proposed action and other alternatives considering their costs, benefits, and impacts to the public and the environment.

Chapter 6 - List of Preparers
Chapter 6 provides a list of the names and qualifications of the preparers of the Draft GEIS.

Chapter 7 - References
Chapter 7 includes citations of all the published sources of information used in the preparation of the Draft GEIS.

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CHAPTER 1
PURPOSE AND NEED

1.0 THE PROPOSED ACTION

The Nuclear Regulatory Commission (NRC) is considering whether to promulgate a regulation to control the disposition of solid materials that originate in restricted or impacted areas[1] of NRC/Agreement State-licensed facilities, and have no, or very small amounts of, radioactivity resulting from licensed operations. These solid materials, which are referred to as "potentially clearable" materials, can include furniture and ventilation ducts in buildings; metal equipment; steel and copper pipes; wood, paper, and glass; laboratory materials (gloves, beakers, etc); routine trash; site fences; concrete; soil; or other similar materials. Under the current approach, licensees survey materials to detect the presence of radioactivity from Atomic Energy Act materials above natural background levels. Solid materials can currently be released for any unrestricted use if the survey indicates that existing guidelines are met. The process used to identify, survey and disposition solid materials is found in guidance, not regulations.

Other solid materials in these restricted or impacted areas can contain more appreciable levels of radioactivity. However, these materials are required to be disposed of at licensed low-level waste (LLW) disposal sites under NRC's existing regulations in 10 CFR Part 61. Solid materials containing appreciable levels of radioactivity are not the subject of this NRC rulemaking. Also, solid materials not located in restricted or impacted areas, and considered to be free of radioactivity resulting from licensed operations, are not the subject of this NRC effort.

The Proposed Action is to promulgate a regulation to control the disposition of solid materials (metals, concrete, trash, and soil) from NRC-licensed facilities. In the Proposed Action, all materials to be released would undergo a radiation survey and the measured level of radiation (i.e., concentration) would be compared against radionuclide concentration levels for release of solid materials. Solid materials with measured radiation levels below these radiation levels would be released from licensed control. Solid materials with measured radiation levels above the standard would be sent to a LLW disposal facility. NRC regulations in 10 CFR Part 20 would be amended to add a new solid material release standard. A new regulation would provide a clear and consistent regulatory basis for determining the disposition of solid materials. In developing the new regulations, the NRC is guided by the goals of its Strategic Plan (NRC, 2004d) of which the primary goal is protection of public health and safety and the environment. The proposed rulemaking could result in related rulemakings in the Agreement States. (Agreement States are States that signed an agreement with NRC under which the State regulates the use of by-product, source and small quantities of special nuclear material within that State.)

[1] A restricted area is defined in the NRC regulations at 10 CFR 20.1003 as an area to which access is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. An impacted area is defined in 10 CFR 50.2 as an area with some reasonable potential for residual radioactivity in excess of natural background or fallout levels.

To support its decision on the proposed rulemaking, the NRC staff determined that a generic environmental impact statement (GEIS) is required by the NRC National Environmental Policy Act (NEPA)-implementing regulations in 10 CFR Part 51. The Draft GEIS is part of the draft rulemaking package on which the public is asked to comment. This Draft GEIS describes the environment potentially affected by the proposal and evaluates the potential environmental impacts of the Proposed Action, including its reasonable alternatives.

1.1 BACKGROUND

NRC initially considered a proposed rulemaking in 1999. As part of the scoping process, NRC published an Issues Paper on the release of solid materials from licensed facilities in June 1999 in the Federal Register (64 FR 35090) (NRC 1999a) and requested public comments. NRC indicated that it was examining alternatives for controlling the disposition of solid materials. NRC held four public meetings during the fall of 1999 as part of the scoping process to receive comments. Over 800 public comment letters were received during the public comment period in 1999. Comments were diverse in the views expressed, and provided a number of alternatives for controlling the disposition of solid materials.

On March 23, 2000, the NRC staff provided the Commission with a paper (SECY-00-0070) on the diversity of views expressed in public comments received on the Issues Paper. Attachment 2 of SECY-00-0070 (NRC 2000a) provides a summary of views and comments received; summaries of the comments can also be viewed in NUREG/CR-6682, “Summary and Categorization of Public Comments on the Control of Solid Materials” (September 2000) (NRC 2000b). To solicit additional input, the Commission held a public meeting on May 9, 2000, at which stakeholder groups presented their views and discussed alternatives for controlling the disposition of solid materials.

On August 18, 2000, the Commission decided to defer a final decision on whether to proceed with a rulemaking and directed the staff to request that the National Academies conduct a study of alternatives for controlling the disposition of solid materials. The Commission also directed the staff to continue to develop technical information and to stay informed of international and U.S. agency activities in this area.

The National Academies study of alternatives for controlling the disposition of solid materials was initiated in August 2000. As part of the study, the National Academies held three information gathering meetings in January, March, and June of 2001, at which it obtained input from various stakeholder groups. The input received was similar to that presented to the NRC earlier. Based on these meetings, and on its deliberations on this topic, the National Academies submitted a report to the NRC in March 2002 titled *The Disposition Dilemma - Controlling the Release of Solid Materials from Nuclear Regulatory Commission-Licensed Facilities* (National Research Council 2002). The report contains findings and nine recommendations related to the decision-making process, potential approaches for controlling the disposition of solid materials, and additional technical information needs. An important finding in the National Academies report was that NRC’s current approach for controlling the disposition of solid materials “is sufficiently protective of public health that it does not need immediate revamping.” However, the National Academies report also states that NRC’s current approach is incomplete and inconsistent and concludes that NRC should therefore undertake a process to evaluate a broad range of alternatives to provide clear risk-informed direction on controlling the disposition of solid materials. The report notes that broad stakeholder involvement and participation in the NRC's decision-making process on the alternatives is critical as the process moves forward. The report also recommends that an individual dose standard of 1 mrem/yr provides a reasonable starting point for the process of considering alternatives for a dose-based standard. A link to the National Academies report is contained in the Background section of the NRC's web page on controlling the disposition of solid materials.[2]

Following completion of the National Academies report, the NRC staff submitted a paper to the Commission on July 15, 2002 (SECY-02-0133) (NRC 2002a) which contained a set of options for proceeding with a regulatory process for examining alternatives for controlling the disposition of solid materials. Based on its review of the National Academies report and of SECY-02-0133, the Commission, in a Staff Requirements Memorandum dated October 25, 2002, directed the staff to proceed with an enhanced participatory rulemaking to develop specific requirements for controlling the disposition of solid materials.

On February 28, 2003, NRC published a notice in the Federal Register (68 FR 9595) (NRC 2003a) requesting comments on the scope of the proposed rulemaking and announcing its intention to prepare a GEIS to analyze alternatives for establishing requirements for controlling the disposition of solid materials. On April 18, 2003 NRC published another notice in the Federal Register (68 FR 19232) (NRC 2003b) announcing the dates and location of a public workshop to discuss the proposed rulemaking and the scoping process.

1.2 PURPOSE AND NEED FOR AGENCY ACTION

Just as is the case for many industrial operations, there are "solid materials" that are no longer needed or useful at facilities licensed by NRC or otherwise need to be removed from restricted or impacted areas. This can occur, for example, during normal facility operations when: (a) metal equipment and tools become surplus, obsolete or worn; (b) glass, plastic, paper, or other trash-like materials are no longer useful; (c) concrete is removed from a building being renovated; or (d) soil is being excavated from a site and is no longer needed. This can also occur at the end of facility operations when a licensee seeks to terminate its NRC license.

Solid materials can currently be released for any unrestricted use if a survey indicates that existing guidelines are met. Appendix B discusses current guidelines used regarding the release of solid materials from sites for unrestricted use. However, these levels are in NRC guidance and 10 CFR Part 20 does not currently specify the dose or concentration limits below which the material can be released. The disadvantages of the current case-by-case approach are (1) the lack of a consistent criterion for controlling solid materials can result in inconsistent release levels, (2) there is no guidance for volumetrically contaminated materials, (3) there have been some inconsistencies when other types of detectors with different sensitivities are used and still lower

[2] http://www.nrc.gov/materials.html. Click on "Controlling the Disposition of Solid Materials" under "Key Issues."

levels of radioactivity are detected in previously released materials, and (4) additional time and resources are required to evaluate and implement an approach that can vary with each case.

The purpose and need of the Proposed Action is to develop an efficient and effective regulatory process that ensures the disposition of solid materials are controlled in a manner that ensures protection of public health and safety and the environment. The Proposed Action should provide a consistent criterion for controlling solid materials, guidance for surficially and volumetrically contaminated materials, and a reduction in the time and resources required to evaluate case-specific applications.

NRC agrees with the findings in the National Academies report (National Research Council, 2002) regarding the need to consider modifying its current approach to provide specific direction on controlling the disposition of solid materials. The National Academies report indicates that NRC's current approach for controlling the disposition of solid materials (the No Action Alternative) "is sufficiently protective of public health." However, the National Academies report also indicates that the current approach is incomplete and inconsistent and that NRC's approach should be risk-informed. As a result, the National Academies study states that NRC should conduct a process to evaluate alternatives to provide clear risk-informed direction on controlling the disposition of solid materials. This Draft GEIS is part of that process and considers several alternatives for rulemakings.

1.3 SCOPE OF ENVIRONMENTAL ANALYSIS

<u>Scoping Process</u>

The NRC is conducting an enhanced participatory process to evaluate alternative courses of action at NRC-licensed facilities for controlling the disposition of solid materials that have no or very small amounts of radioactivity. As part of NRC's examination of its approach for control of solid materials, including the scope of an environmental impact statement, NRC sought early stakeholder input on the major issues associated with this effort, as described in Section 1.1.

As an additional part of its continuing efforts to solicit stakeholder involvement, NRC published, on February 28, 2003, a Request for Comments on the scope of a proposed rulemaking and notice of a workshop in the <u>Federal Register</u> (68 FR 9595) (NRC 2003a). In this Federal Register Notice, NRC sought stakeholder participation and involvement in identifying alternatives and their environmental impacts that should be considered as part of a rulemaking and analyzed in a GEIS. The NRC also announced in this Federal Register Notice its intent to conduct a workshop to solicit new input with a focus on the feasibility of alternatives that would limit where solid materials could go. The workshop was held at NRC Headquarters in Rockville, MD May 21-22, 2003. A summary of the results of this workshop is available on NRC's website (see footnote 2 on page 1-3).

Over 2,600 written comments were received in addition to the discussion at the workshop. NUREG/CR-6682 Supplement 1 (*Summary and Categorization of Public Comments on Controlling the Disposition of Solid Materials, February 2004*) (NRC 2004a) summarizes the comments received as a result of NRC's request for comments and the workshop discussion.

Comments were received from various stakeholder groups, including environmental and citizen's groups, members of the general public, scrap and recycling companies, steel and cement manufacturers, hazardous and solid waste management facilities, the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), State agencies, Tribal Governments, scientific organizations, international organizations, and NRC licensees and licensee organizations.

The scoping process (as described in Appendix A) helped to determine the scope of this Draft GEIS, including significant issues to be analyzed in depth. For example, in response to comments received during the scoping process, the Draft GEIS includes an alternative where the potentially clearable solid material can only be disposed of in a LLW facility (i.e., Prohibition).

Scope of the GEIS

The issues analyzed in depth in the Draft GEIS include the impacts and costs associated with rule alternatives for controlling the disposition of solid materials at licensed facilities. Information was developed on (a) types and contamination levels of solid materials potentially available for release at licensed facilities; (b) pathways of exposure from, and environmental impacts of, solid materials released from licensed facilities; and (c) regulatory alternatives and methods of approach for analysis of the alternatives.

The Draft GEIS recognizes previous and ongoing reports and analyses related to the control of solid materials, including the National Academies report completed in March 2002. In addition, other scientific organizations are engaged in similar processes. Recognized radiation protection organizations like the National Council on Radiation Protection and Measurements (NCRP), International Commission on Radiological Protection (ICRP), and American National Standards Institute (ANSI) have issued findings about possible criteria for controlling the disposition of solid materials. DOE is preparing a Programmatic Environmental Impact Statement on alternatives for disposition of DOE scrap metals. EPA sets radiation protection standards in the general environment, although it does not currently have a program on controlling the disposition of solid materials from licensed facilities. International agencies (such as the International Atomic Energy Agency (IAEA) and the European Commission (EC)) as well as other individual nations, are in the process of establishing standards or have standards for clearance of solid materials.

NRC's goal in preparing this Draft GEIS is to set forth the impact analyses in a manner which is readily understandable to the public. Decisions and the rationale for those decisions are described and significant impacts discussed in this Draft GEIS. Topical areas whose impacts are less significant are discussed in less detail, with an explanation of why they were found to be less significant. This should allow the readers to focus on issues that were important in reaching the conclusions of the Draft GEIS. The following topical areas and issues are analyzed in the Draft GEIS.

- ***Human Health and Safety.*** The potential human health impacts of the Alternatives on the workers and the general public are evaluated for normal licensee operations and decommissioning of licensee facilities. Potential exposures to radioactive materials and to chemicals are considered. Models, assumptions, and supporting data used to analyze the impacts from these potential exposures are described.

- ***Transportation.*** The transportation impacts of shipping released materials under each alternative are discussed. The Draft GEIS contains an analysis of potential impacts resulting from the transportation of each material type by various types of transport, including truck. The Draft GEIS discusses the quantities of material to be shipped and the vehicle miles traveled for each alternative. The impacts of transportation are evaluated in terms of risk to the population during normal transportation (including truck emissions) and under credible accident scenarios.

- ***Water Resources.*** The Draft GEIS assesses the potential impacts of the alternatives on surface water, groundwater, and drinking water resources.

- ***Air Quality.*** Potential air quality impacts of each alternative are evaluated in the Draft GEIS. The evaluation includes potential impacts resulting from operational activities for both radiological constituents and other priority air pollutants and compares the anticipated air quality impacts with relevant standards.

- ***Ecological Impacts.*** Potential impacts of alternatives on ecological receptors (plants and animals) are considered.

- ***Waste Management.*** The Draft GEIS documents the quantities and types of the various released materials to be disposed for each alternative. The Draft GEIS also considers the disposal capacity impacts associated with the release of these materials for both LLW disposal facilities and EPA/State-regulated landfills.

- ***Cumulative Impacts.*** The Draft GEIS analyzes the potential cumulative impacts of the alternatives when added to other past, present, and reasonably foreseeable future actions. Both DOE and technologically enhanced naturally occurring radioactive material (TENORM) facilities are considered in this analysis.

- ***Unavoidable Adverse Impacts.*** A discussion is included on the potential environmental impacts that could not be avoided if any of the alternatives were implemented.

- ***Short-Term Use Versus Long-Term Productivity of the Environment.*** The Draft GEIS compares the potential adverse impacts on the environment associated with short-term use for the alternatives to the potential adverse impacts on the long-term productivity of the environment.

- ***Irreversible and Irretrievable Commitment of Resources.*** The irreversible and irretrievable commitment of resources, including land use, materials, and energy are discussed.

- ***Mitigation and Monitoring.*** The Draft GEIS assesses whether any monitoring or mitigation measures are anticipated as a result of implementing any of the alternatives.

- ***Cost-Benefit Analysis.*** The Draft GEIS includes a cost-benefit analysis that summarizes the environmental and other costs and benefits of each of the alternatives compared to the No Action Alternative.

Issues raised during the scoping period for the Draft GEIS are summarized in Section 2 of Appendix A. Section 3 of Appendix A discusses the subjects and issues that are addressed in depth in the Draft GEIS. Issues raised during the scoping period have been considered in the preparation of the scoping report. As discussed in Section 4 of Appendix A, certain issues are not addressed in depth in the Draft GEIS. NRC has made a determination that some issues are associated with small or no impacts. The following topical areas and issues are not addressed in the Draft GEIS because no impacts are anticipated for these site-specific issues:

- Soils;
- Socioeconomics;
- Environmental justice;
- Land use;
- Visual/scenic resources;
- Noise; and
- Historical, archaeological, and cultural resources.

Further, the scope of the Proposed Action does not include any activities related to construction of facilities. The scope of the Proposed Action is limited to impacts associated with the release, transportation, recycling, and disposal of solid materials. The potential impacts of any construction of facilities that is proposed would be assessed on a site-specific basis.

The scope of the Proposed Action does not include any solid materials left on site at licensee facilities after license termination. The scope of the Proposed Action is limited to transfer of solid materials off site for either recycling, reuse, or disposal. Solid materials remaining on site at facilities after license termination are subject to existing NRC regulations that would not be changed by the Proposed Action. When an NRC-licensed facility is decommissioned, the licensee must decontaminate the facility site to at least the minimum prescribed criterion prior to the NRC terminating the license (10 CFR 20 Subpart E). This limit pertains to both the facilities' remaining intrinsic structure (e.g., buildings) and site (e.g., soil). The potential impacts to the General Public, Non Licensed-Facility Workers, and Licensed-Facility Workers of the existing NRC regulations applicable to material left on site have already been analyzed through the NRC rulemaking for these regulations. Therefore, solid materials left on site are not included within the scope of the Draft GEIS.

Some commenters asked NRC to collect materials that have been previously released. NRC has no plans to collect these materials because once released, there is no tracking of these materials.

The U.S. imports and exports material that may contain residual radioactivity. The analysis of these imports and exports is outside the scope of the GEIS because this rulemaking only applies to control of the disposition of solid materials from NRC and Agreement State licensed facilities. NRC's requirements in 10 CFR Part 110 already contain requirements for export and import of material that assures that these actions are done in a safe, regulated manner. The proposed rulemaking does not propose to change those requirements or the procedures associated with them. However, this Draft GEIS does consider the use of an international standard (IAEA Safety Guide RS-G-1.7) (IAEA 2004), which would provide more consistency with international numeric guidelines.

1.4 APPLICABLE REGULATORY REQUIREMENTS

The NRC's primary mission is to help ensure that public health and safety and the environment are protected in the many different peaceful uses of nuclear materials. The NRC is responsible for regulating various commercial, industrial, academic, and medical uses of nuclear materials. For example, NRC regulates commercial nuclear power plants, fuel cycle and nuclear waste facilities and nuclear materials used in the diagnosis and treatment of cancer and in smoke detectors. Information about NRC is available at NRC's World Wide Web (WWW) site http://www.nrc.gov. One way the NRC accomplishes its mission is by issuing regulations. The process of developing regulations is called rulemaking. The NRC's regulations are found in Chapter I of Title 10, "Energy," of the Code of Federal Regulations (CFR). These regulations are binding on all persons and organizations who receive a license from NRC to use nuclear materials or operate nuclear facilities.

NRC currently addresses the release of solid materials on a case-by-case basis using license conditions and existing regulatory guidance. Appendix B contains details of the current approach. Solid materials can be released for any unrestricted use if a survey indicates that existing guidelines are met.

Under current NRC regulations, licensees also have the option of proposing disposal methods and procedures that are not otherwise authorized in the regulations. These NRC provisions are contained in 10 CFR Part 20.2002 [3]. Under these provisions, a licensee’s application must provide a description of the waste, including the physical, chemical, and radiological properties, for the purpose of assessing potential doses; methods and manner of disposal of such wastes; location and nature of the environment where such wastes will be disposed of; analyses showing projected doses for the proposed disposal methods, and procedures that will be used to maintain doses ALARA for workers and members of the public. NRC policy and guidance for these dispositions uses a dose criterion of “a few millirem” per year. Agreement States have similar provisions in their regulations. Licensees have used the specific process set out in 10 CFR 20.2002 to seek approval for the unrestricted release of material for disposal.

Regulatory Guide 1.86 titled *Termination of Operating Licenses for Nuclear Reactors* (USACE 1974) is used to evaluate solid materials before they are released. A similar guidance document is Fuel Cycle Policy and Guidance Directive FC 83-23, titled *Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Byproduct, Source or Special Nuclear Materials Licenses* (NRC 1983a). Both documents contain a table of surface contamination criteria which may be applied by licensees for use in demonstrating that

[3] Part 20.2002 - Method for Obtaining Approval of Proposed Disposal Procedures. Before the revision of Part 20 (January 1, 1994), these provisions were contained in Part 20.302 under the same title.

solid material with surface contamination can be safely released with no further regulatory control.

The Agreement States use a variety of practices and criteria for the release of solid materials on a case-by-case basis, including the use of radiation levels that are indistinguishable from background, use of guidelines similar or equivalent to Regulatory Guide 1.86, and the use of dose based analyses.

NRC shares responsibility for radioactive material transport with the U.S. Department of Transportation (DOT). DOT is responsible for regulating safety in transportation of all hazardous materials, including radioactive materials, whereas NRC is responsible for regulating safety in receipt, possession, use, and transfer of byproduct, source, and special nuclear materials. NRC recently amended 10 CFR Part 71 - *Packaging and Transportation of Radioactive Material* to make it compatible with DOT's regulations at 49 CFR and with the latest version of the International Atomic Energy Agency standards in TS-R-1 (*Regulations for the Safe Transport of Radioactive Materials*) (NRC 2004b) and to address the Commission's goals for risk-informed regulations and eliminating inconsistencies with other regulatory approaches. The 10 CFR Part 71 Final Rule was published in the Federal Register (69 FR 3698) (NRC 2004b) on January 26, 2004. DOT published a parallel rule in the Federal Register (69 FR 3632) (DOT 2004) on the same date. Table 1-1 lists the major agencies, acts and activities evaluated in this Draft GEIS.

Table 1-1 Federal Regulations

Agency	Authority	Activity Covered
Nuclear Regulatory Commission	Atomic Energy Act	Licensing Decommissioning Release of Solid Materials
Nuclear Regulatory Commission	National Environmental Policy Act (10 CFR Part 51)	Environmental Impact Statement
U.S. Environmental Protection Agency	Resource Conservation and Recovery Act (RCRA)	Landfill disposal
U.S. Environmental Protection Agency	Clean Air Act	Air Quality Permits
U.S. Environmental Protection Agency	Clean Water Act	National Pollutant Discharge Elimination System Permits
U.S. Environmental Protection Agency	Clean Water Act	National Primary Drinking Water Regulations
U.S. Department of Transportation	49 CFR Parts 171 - 180	Transportation Regulations

1.5 COOPERATING AGENCIES

EPA, DOE, and the State of Massachusetts are cooperating agencies in the preparation of this Draft GEIS, pursuant to the President's Council on Environmental Quality (CEQ) regulations (40 CFR 1501.6).

EPA has an interest in the proposed rulemaking because EPA sets radiation protection standards in the general environment. EPA previously had related rulemaking activities, coordinated with NRC on the development of the technical information bases on controlling the disposition of solid materials, and currently is engaged in rulemaking activities on Resource Conservation and Recovery Act (RCRA) landfill disposal. Cooperating agency status will assist EPA in its own rulemaking process, focused on landfill disposal of materials containing residual radioactivity. EPA's Office of Radiation and Indoor Air serves as the principal point of coordination for the Draft GEIS (Appendix C).

NRC invited DOE to be a cooperating agency in the development of the Draft GEIS because of DOE's experience and efforts in the control and release of property containing residual radioactivity. Participating as a cooperating agency will help DOE stay apprised of the relevant issues and will provide a mechanism for DOE to contribute its expertise to the review process, while ensuring effective communication between NRC and DOE. Cooperating agency status will also assist DOE in its own EIS process involving DOE scrap metal, which is a separate, ongoing effort. The Office of Air, Water and Radiation Protection Policy and Guidance is serving as DOE's principal point of coordination for DOE participation in the Draft GEIS (Appendix C).

NRC asked the Conference of Radiation Control Program Directors (CRCPD) and the Organization of Agreement States (OAS) to assist in the development of the Draft GEIS because the proposed NRC rulemaking would result in related rulemakings in the Agreement States. In a joint decision, CRCPD and OAS appointed the State of Massachusetts to act as a cooperating agency on their behalf. Massachusetts' participation as a cooperating agency in the preparation of the Draft GEIS will keep the Agreement States apprised of the issues associated with controlling the disposition of solid material and provide a mechanism for the States to contribute their expertise to the review process, as well as ensure effective communication between NRC and the States.

CHAPTER 2
PROPOSED ACTION AND ALTERNATIVES

This chapter describes the alternatives for amending NRC's regulations to include criteria for controlling the disposition of solid materials that originate in restricted or impacted areas of NRC/Agreement State licensed facilities. These materials have no, or very small amounts of, radioactivity resulting from licensed operations and are referred to in this Draft Generic Environmental Impact Statement (Draft GEIS) as "solid materials." The alternatives studied in detail are No Action, Unrestricted Release, Environmental Protection Agency (EPA)/State-Regulated Disposal, Low-Level Waste (LLW) Disposal (Prohibition), and Limited Dispositions. In addition, one alternative and two options are presented which were considered but not studied in detail.

2.1 PROPOSED ACTION

The Proposed Action being considered in this Draft GEIS is to promulgate an NRC regulation that would include criteria for disposition of solid materials from NRC licensed facilities. The Proposed Action would improve the efficiency and effectiveness of the NRC regulatory process for disposing of solid materials. The NRC is guided by the goals of the NRC Strategic Plan (NRC, 2004d), of which the primary goal is ensuring protection of public health and safety. The proposed rulemaking would result in related rulemakings in the Agreement States.

2.2 SOLID MATERIALS CONSIDERED UNDER THIS RULEMAKING

Nuclear facilities routinely use different types of materials in support of various activities, including operations, production, research and development, maintenance, facility refurbishment, and ultimately decommissioning. In support of these activities, materials and items are introduced in areas that contain radioactivity. Areas that contain radioactivity include systems that process radioactive process fluid or gas streams, and waste storage and processing areas. Areas where radioactive materials are present are collectively referred to as "radiologically controlled" or "radiologically restricted" areas. Once materials or items are no longer needed or otherwise need to be removed, a licensee must decide how to disposition this material. For equipment and items such as tools, vehicles, and test equipment, the items could be considered for recycle or reuse rather than disposed of in LLW facilities because of their usefulness and value. Materials and equipment are surveyed before being taken out of restricted areas. The results of the surveys are used to determine the final disposition of materials or items. Based on the survey results, licensees determine whether it is worthwhile to decontaminate the materials or items or simply dispose of them as LLW. Materials considered by this rulemaking are described below. Descriptions of licensees and inventories of materials are discussed in Appendix F.

Concrete - Concrete is expected to be generated mostly during the decommissioning phase of facilities, although smaller amounts of concrete could be generated during facility or system modifications or refurbishment while still in operation. Larger amounts of concrete are expected to come from structural concrete, with and without steel reinforcement bars (rebars). Other origins of concrete may vary, ranging from sidewalks or equipment pedestals to building foundations.

Metals - For ferrous metals, this grouping includes carbon steel, stainless steel, forged steel, galvanized steel, cast iron, etc. with no specific distinctions being made as to their relative amounts. For the sake of inclusiveness, copper and aluminum were added to this category. In origin, ferrous metal and aluminum are expected to come from process system components, structural support, system piping and tanks, pumps, heat exchangers, valves, pipe hangers, motors, ventilation ductwork, etc. Copper is expected to come from cabling and wiring, electric motors, power distribution panels, etc.

Trash - The composition of trash is expected to vary widely depending on the type of facility and operations. Generally, trash consists of plastics, paper, cloth, rubber, absorbent materials, wood, glass, filters, and metals (such as cans, wiring, etc.), and non-compactible waste (such as rubble, bricks, etc.).

Soils - Soils are generated during facility operations and remediation activities. Most of the soil volumes are expected to be associated with decommissioning activities at the time of license termination. In broad terms, soils include natural soils, engineered backfill, and process related materials that may be present by themselves or commingled with natural soils. Backfills may consist of a mixture of rocks, gravel, and sand, with some being native to the site or imported from offsite locations. Some process materials that are soil-like materials include sediments, sands, filter cake, sludge, and crushed slag, with all excess water drained. These materials are characterized by a water content and other physical properties that are similar to that of natural soils (NRC 2005b). Soils are not within the scope of this Draft GEIS because they were not analyzed as part of this effort (see Section 2.4.5).

Tools and Equipment - Tools and equipment include a variety of items used during facility operations, maintenance, and routine support activities. Tools may include hand tools and power tools. Equipment may include electronic test equipment, welding equipment and test instrumentation. Similarly, heavy equipment may include forklifts, trucks, backhoes, and cranes. Equipment also includes items used in offices, such as desks, file cabinets, chairs, computers, printers, phones, and copy and fax machines.

Treated process materials, which are materials whose properties have been modified or are unique to the process from which they originate, include spent ion-exchange resins, sludge from spent ion-exchange process systems, microspheres, oily sludge and sediments, spent filters and filter sludge, spent charcoal beds, and incinerator ashes. They also include materials that have been solidified or stabilized, contain chelating agents, pathogenic or infectious biotic agents, and pyrophoric or explosive chemicals. These materials are not within the scope of this Draft GEIS and they were not analyzed as part of this effort. Moreover, radioactive materials present as sealed sources, as sources within devices and equipment, and bulk or discrete amounts of radioactive materials (in any form) are excluded from the provisions of this rule.

2.3 PROCESS USED TO FORMULATE ALTERNATIVES

A set of preliminary alternatives for controlling the disposition of solid materials was first described in an NRC Issues Paper published for public comment in the Federal Register on June 30, 1999 (64 FR 35090) (NRC 1999a). Public comments were received on the alternatives at public workshops and in written comments during the comment period (NUREG/CR-6682 (NRC, 2000b) and SECY-00-0070 (NRC 2000a)).

In March 2002, a report issued by the National Academies (National Research Council 2002) provided additional discussion concerning the advantages and disadvantages of various alternatives. The report found that NRC's current approach for controlling the disposition of solid materials "is sufficiently protective of public health that it does not need immediate revamping." However, the National Academies report also states that NRC's current approach is incomplete and inconsistent and concludes that NRC should therefore undertake a process to evaluate a broad range of alternatives to provide clear risk-informed direction on controlling the disposition of solid materials.

Based on these efforts, the Commission decided in October 2002 to proceed with a rulemaking for controlling the disposition of solid material. The Commission published a request for comments on the scope of the proposed rulemaking and notice of a workshop in the Federal Register on February 28, 2003 (68 FR 9595) (NRC 2003a). NRC held a public workshop on May 21-22, 2003 to solicit additional input on the alternatives being considered. This workshop was attended by a range of stakeholder groups who provided a diverse set of comments on the alternatives. In addition, more than 2,600 letters and e-mails were submitted to the NRC in response to the February 28, 2003 Federal Register notice, also from various stakeholders. A more complete description of the details of the entire scoping process for this Draft GEIS (including a summary of the public comments) is provided in Section 1.3 and the Scoping Summary Report in Appendix A.

NRC has explored the range of all reasonable alternatives suggested during the scoping process and by the National Academies. After considering input from this scoping process, NRC determined the following reasonable range of alternatives for detailed study in this Draft GEIS. The order of the alternatives follows the order in which the alternatives were formulated and analyzed.

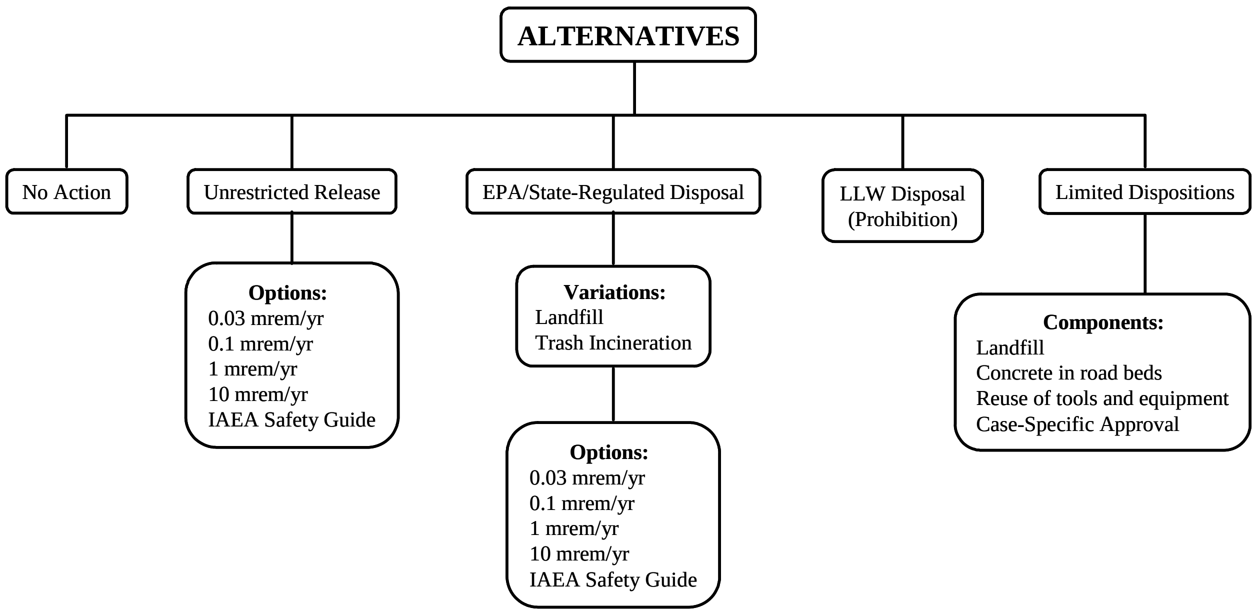
- No Action
- Unrestricted Release
- EPA/State-Regulated Disposal
- LLW Disposal (Prohibition) (hereinafter referred to as LLW Disposal)
- Limited Dispositions

Two dose-based standards were considered and then eliminated from detailed study. These standards, which are described in Section 2.5, are the American National Standards Institute (ANSI)/Health Physics Society (HPS) Standard ANSI/HPS N13.12-1999 and the European Commission (EC) Radiation Protection Reports Nos. 89 and 122 (European Commission 2000a; European Commission 2000b).

2.4 ALTERNATIVES STUDIED IN DETAIL

Regulatory alternatives for controlling the disposition of solid material analyzed in this Draft GEIS are shown in Figure 2-1 and described in detail in this section. The Unrestricted Release and EPA/State-Regulated Disposal Alternatives have dose options, which are sensitivity studies for those alternatives. The order of the description of the alternatives in this section follows the order in which the alternatives were analyzed. The Limited Dispositions Alternative evolved from the study of the other alternatives.

Figure 2-1 Alternatives



2.4.1 No Action

National Environmental Policy Act (NEPA) regulations (40 CFR 1502.14) require the analysis of a No Action Alternative to provide the decisionmaker with a basis for comparison to reasonable alternatives. In this case, under the No Action Alternative, NRC would continue to apply its current approach to determining the eligibility of solid material for unrestricted release in general commerce or disposal. The NRC's current approach is one that employs measurement-based guidelines to determine if solid materials can be released for any use or disposal. License conditions and facility-specific procedures require that solid materials that have been used in controlled or restricted areas are surveyed for the presence of radioactivity before being taken out of radiologically controlled areas. Solid materials can currently be released for any unrestricted use or disposal if the survey indicates that existing guidelines are met. Although NRC does not track release quantities if the materials meet the criteria, NRC inspectors routinely inspect a licensee's radiation protection programs and implementing procedures, which includes the survey records for compliance with Part 20 and license conditions.

However, 10 CFR Part 20 does not currently specify a numerical level (e.g., dose or concentration limits) below which the material can be released. Decisions on disposition of solid materials are currently made using levels contained in a set of existing guidelines that are based primarily on the ability of survey techniques to measure the radioactivity level on, or in, the solid material. Solid material releases have been evaluated at many sites during decommissioning.

Under the current case-by-case approach, NRC considers the volumes of material, exposure pathways, doses to individuals, environmental impacts, stakeholder concerns, and ALARA issues in evaluating licensee requests. Additional details on NRC's current approach to determining the eligibility of solid material for unrestricted release in general commerce can be found in Appendix B.

Under the No Action Alternative, solid material released (at or below guideline levels) for unrestricted release may be recycled and reused in a variety of end products, or it may be sent for disposal. Disposal may take place in an EPA/State-regulated landfill or LLW disposal facility. The potential exposures and the groups of individuals subject to exposures from released materials are dependent on their final dispositions.

Disadvantages of the current case-by-case approach are (1) the lack of a consistent criterion for controlling solid materials can result in inconsistent release levels, (2) there is no guidance for volumetrically contaminated materials, (3) there have been some inconsistencies when other types of detectors with different sensitivities are used and still lower levels of radioactivity are detected in previously released materials, and (4) additional time and resources are required to evaluate and implement an approach that can vary with each case.

2.4.2 Unrestricted Release

The Unrestricted Release Alternative would allow solid materials to be released for any use in general commerce (recycling and/or reuse into consumer products and industrial and construction uses) or for disposal, if they are below a dose-based criterion. Under the Unrestricted Release Alternative, all materials to be released would undergo a radiation survey and the measured level of radiation would be compared against the criterion for release for unrestricted release.[1] Solid materials with measured radiation levels below the established criterion would be released from licensed control, while solid materials with radiation levels above the criterion would be sent to a LLW disposal site. The proposed rulemaking would include a table of radionuclide concentrations (or clearance levels) corresponding to the selected dose-based criterion. In implementation, survey results would be compared to the clearance level of each radionuclide or mixture of radionuclides in demonstrating compliance with the rule. Compliance would be demonstrated when the survey results are less than the applicable clearance levels.

Under the Unrestricted Release Alternative, solid material released for unrestricted use may follow any disposition path – it may be recycled and reused in a variety of end products, or it may be sent for disposal. Disposal may take place in an EPA/State-regulated landfill or LLW disposal facility. The potential radionuclide exposures and the groups of individuals subject to exposures from released materials are dependent on their final dispositions.

This Draft GEIS considers a range of dose level options for the release of solid materials. The dose level that NRC selects would directly impact the amount of solid material released for use

[1] The term "clearance" is also used by various organizations and in various documents to mean removal from licensed control of material that meets certain release criteria.

in general commerce, with the amount of material released decreasing as the allowable dose criterion decreases. These dose options are:

- 0.03 mrem/yr[2]
- 0.1 mrem/yr
- 1 mrem/yr
- 10 mrem/yr
- International Atomic Energy Agency (IAEA) Safety Guide No. RS-G-1.7 (1 mrem/yr) (IAEA 2004)

For the first four dose options, NRC has independently assessed potential doses to individuals that could result from release of solid materials (NUREG-1640 (NRC 2003c)). This independent analysis is discussed in Chapter 3 of this Draft GEIS.

For the fifth dose option, IAEA Safety Guide No. RS-G-1.7 (IAEA 2004) was assessed. Appendix E compares RS-G-1.7, which is based on 1 mrem/yr, with a 1 mrem/yr dose criterion based on NUREG-1640 (NRC 2003c). The IAEA safety guide was considered because its use would provide more consistency with international numeric standards. Although both dose options (RS-G-1.7 and NUREG-1640) are based on a dose limit of 1 mrem/yr, their associated radionuclide concentration levels differ due to differences in dose modeling assumptions.

Under each of the dose options, solid materials to be released would have their level of radioactivity measured on-site by licensed facility workers (survey workers) prior to release. Those materials whose level of activity are found to be below the applicable clearance levels would be cleared for unrestricted release, including disposal in a landfill. Materials that do not meet clearance levels would be disposed of in a licensed LLW facility.

2.4.3 EPA/State-Regulated Disposal

Under this alternative, all potentially clearable solid material below a dose-based criterion would be released to EPA/State-regulated landfills and would be prohibited from general commerce (recycling into consumer products and industrial and construction uses). A base case and one variation of this alternative are being considered, specifically:

- EPA/State-Regulated Landfill (base case) – All released solid materials (including tools and equipment) would be disposed of in EPA/State-regulated Resource Conservation and Recovery Act (RCRA) Subtitle D landfills. Solid materials above the dose-based criterion would be sent to a LLW disposal facility.

- EPA/State-Regulated Trash Incineration (variation) – Trash would be incinerated at EPA/State-regulated incinerators and the ash disposed of in EPA/State-Regulated landfills. All non-trash solid materials (concrete, ferrous metal, etc.) would not be incinerated, but

[2] A realistic lower-bound dose limit of 0.03 mrem/yr was chosen because it is a small value at, or marginally above, detectable levels.

would be disposed of in EPA/State-regulated landfills. Solid materials above the dose-based criterion would be sent to a LLW disposal facility.

Under both the base case and the incinerator variations of this alternative, the following four dose options are being considered.

- 0.03 mrem/yr
- 0.1 mrem/yr
- 1 mrem/yr
- 10 mrem/yr

The four dose options are based on NRC's independent analysis in NUREG-1640 (NRC 2003c). Because allowing only landfill disposal would limit the public's exposure to potentially clearable material, this alternative results in higher radionuclide concentration limits. Thus a greater amount of activity could be released to landfills than the amount that could be released to general commerce under the Unrestricted Release Alternative because persons are exposed in a more limited manner.

EPA regulates municipal and industrial solid waste under RCRA. Under RCRA Subtitle D, the solid waste program encourages States to develop comprehensive plans for managing non-hazardous industrial solid waste and municipal solid waste and also sets criteria for municipal solid waste landfills and other solid waste disposal facilities. Further discussion of RCRA facilities is contained in Appendix J.

Under RCRA Subtitle C, the hazardous waste program establishes a system for controlling hazardous waste from the time it is generated until its disposal. Because hazardous materials are typically disposed of in Subtitle C facilities, this alternative considers only RCRA D facilities. However, it is useful to discuss the status of EPA efforts on RCRA Subtitle C facilities. EPA is considering a rulemaking that could permit disposal of certain NRC-regulated material in a RCRA Subtitle C facility subject to, if necessary, an appropriate NRC approval process (e.g., a site-specific or general license, or exemption). EPA published an Advanced Notice of Proposed Rulemaking (ANPR) in the Federal Register (68 FR 65119, November 18, 2003) (EPA 2003a) to solicit stakeholder input on a potential regulatory framework to permit disposal of low-activity radioactive waste, including mixed waste and other low-level waste, in RCRA Subtitle C disposal facilities. EPA is considering a wide range of allowable dose limits for materials being disposed, most of which are higher than the 1 mrem/yr dose limit. EPA is coordinating with NRC on the ANPR. If EPA decides to move foreward with a rulemaking for RCRA Subtitle C facilities, NRC would need to take conforming regulatory action in a separate rulemaking. That effort would be different from the proposed action discussed in this GEIS and would take place at a later time once EPA decides if it is moving forward with a rulemaking.

2.4.4 LLW Disposal (Prohibition)

Under the other alternatives, solid materials in excess of the release criteria would be sent to licensed LLW disposal facilities. However, under this alternative, also known as Prohibition, all potentially clearable solid material would be prohibited from general commerce and EPA/State-regulated landfill disposal. All solid material in restricted or impacted areas (including tools and equipment) would be classified as LLW and required to be disposed of under NRC's existing regulations. The requirements of 10 CFR Part 61 address the siting, operation, and closure of LLW disposal facilities. Requirements in Appendix G to 10 CFR Part 20 focus on licensees (as waste generators) and provide procedures to ship LLW to such disposal sites.

There are currently three LLW disposal sites operating in the country that could accept solid material under this alternative. These facilities are:

- Envirocare - Clive, UT
- Barnwell Disposal Facility - Barnwell, SC
- Hanford Off-Site LLW Disposal Facility - Hanford, WA

The Barnwell Disposal Facility will only accept non-regional waste until 2008, at which time it will accept waste only from the Atlantic Compact States of South Carolina, New Jersey, and Connecticut, which is a relatively small subset of the total population of licensed facilities. The Hanford Off-Site LLW Disposal Facility accepts waste only from the Northwest and Rocky Mountain Compact States, which are: Washington, Oregon, Idaho, Montana, Utah, Wyoming, Nevada, Colorado, New Mexico, Alaska, and Hawaii. Because it is assumed that very little of the solid material would be eligible for disposal at the Barnwell and Hanford facilities, this alternative assumes that in the future all solid material would be sent to the Envirocare site for disposal. Information on the remaining available capacity of the existing LLW disposal facilities is presented in Section 3.7.

2.4.5 Limited Dispositions

In this alternative, solid material would be released, but NRC would allow only certain authorized dispositions to limit the potential for public exposure. All materials to be released would undergo a radiation survey and the measured level of radiation would be compared against the criterion for release for limited dispositions. Solid materials with measured radiation levels below the established criterion would be released for pre-approved limited dispositions, while solid materials with radiation levels above those radionuclide concentrations would be sent to a LLW disposal facility. Any requests to release material other than to these limited end uses or at higher radionuclide concentrations would require case-specific approval from NRC. NRC regulations in 10 CFR Part 20 would be amended to add a dose-based regulation for limited dispositions.

For the pre-approved dispositions, the radionuclide concentrations were chosen based on a dose limit of 1 mrem/yr using the IAEA Safety Guide No. RS-G-1.7 (IAEA 2004). A dose limit of 1 mrem/yr was chosen because it is a small fraction of the public dose limit and it is based on the NCRP and the National Academies recommendations. The table of radionuclide concentrations accompanying the IAEA Safety Guide is based on unrestricted release. This is a reasonably conservative approach because, for the same 1 mrem/yr dose criterion, an unrestricted release is generally associated with lower (more restrictive) nuclide concentrations than a limited path release, for which persons are exposed in a more limited manner. Thus, it can be assured that even in the unlikely event that all materials released in a year from a licensee were inadvertently diverted for unrestricted release (despite the requirements of the proposed rule directing it to a limited use or disposal), a 1 mrem/yr dose would not be exceeded, and it could also be assured that an isolated unrestricted release would result in doses well below 1 mrem/yr. The materials that could be released under the Limited Dispositions Alternative are concrete, metals, and trash. The disposition of soils is excluded from this Alternative based on the analyses considering potential uses of released soil under varying scenarios. The results indicate that under some conditions, soils initially intended for burial in landfills could be diverted, at a point beyond the licensee's control, and used in other purposes given that there is a demand for “clean fill” that can be used as backfill. The staff analysis revealed that there is not enough information to characterize how soils might be used locally. Thus, the disposition of soils would be considered under the case-specific component of the rule, as is done under current practices. This aspect is discussed in more detail in the section addressing “case-specific approvals.”

The radionuclide tables in RS-G-1.7 are expressed in terms of the quantity of the nuclides contained within the volume of the solid material. However, in many situations, surface concentrations will need to be measured or be more readily measurable. In fact, NRC’s current approach in Regulatory Guide 1.86 includes a table of acceptable surface concentration levels. Since IAEA has not developed such information on surface concentrations at this time, NRC developed a table of surface concentrations by converting the volume concentrations of RS-G-1.7 to surface concentrations using information in NUREG-1640 (NRC 2003c) and by considering the values in the Department of Transportation transport requirements in 49 CFR Part 173. These surface concentrations are described in the NRC guidance document (NRC 2005a) that is being issued with this rule.

NRC considered whether solid material could be released if its further use would be restricted to only certain uses with limited potential for public exposure, such as use in a controlled environment. Examples include industrial uses such as metals in bridges or sewer lines, concrete use in road fill, and reuse of tools and equipment for their original purposes. Based on public comments during the scoping period, some of the possible recycling uses were not considered as pre-approved dispositions. Also, the marketplace is likely to limit the range of end-uses for the disposition of solid materials. For example, the recycling industry indicated it would be difficult to find scrap metal brokers and steels mills willing to accept and process the released materials. Although recycling of scrap metal was not considered as a pre-approved disposition, metal recycling could be considered as a case-specific application.

Based on public comments during the scoping period and on the analyses for the Unrestricted Release and EPA/State-Regulated Disposal Alternatives in Chapter 3, the only limited dispositions considered under this alternative are disposal in a RCRA Subtitle D landfill, concrete use in roadbeds, and reuse of tools and equipment for their original purpose. Licensees would need to demonstrate that material proposed for release is less than the radionuclide concentrations in the proposed rule. Any requests to release material other than these limited end uses would require case-specific approval (including the disposition of soils).

To ensure that the material releases are occurring to the pre-approved dispositions, there will be licensee recordkeeping and these activities would be evaluated periodically during routine staff inspections at licensed facilities. Also, enforcement action would be taken if necessary, according to NRC regulations in 10 CFR Part 2.

The following are the components of this alternative.

Landfills. For landfill disposal under this alternative, the released solid materials (concrete, metal or trash) at or below the 1 mrem/yr criterion using the RS-G-1.7 standard could be disposed of in RCRA Subtitle D landfills. At this risk level, the controls associated with disposal of solid materials at RCRA Subtitle D landfills are sufficient to provide reasonable assurance that doses are maintained well below levels established to ensure adequate protection of public health and safety and the environment. Solid materials above the 1 mrem/yr criterion would be sent to a LLW disposal facility. As explained in Section 2.4.3 (EPA/State-Regulated Disposal Alternative), this proposed rulemaking considers only RCRA Subtitle D facilities because EPA is currently evaluating the possibility of higher dose limits at RCRA Subtitle C facilities. At this time, because NRC does not want to prejudge eventual EPA decisions regarding RCRA Subtitle C landfills, a licensee request to dispose of solid material in a RCRA Subtitle C landfill could be addressed under existing provisions in 10 CFR 20.2002.

Although NRC would authorize, by rule, disposal in a RCRA Subtitle D facility, the municipal solid waste operators and the regulator of each RCRA facility (EPA and the States) have the discretion of allowing or refusing disposals in Subtitle D facilities. Even if allowed, EPA and the State agencies might impose additional constraints on such disposal. Accordingly, the implementation of the rule would have to consider EPA and State agency requirements. It is envisioned that some landfill operators and EPA and State agencies might not want to receive such materials, but others would, considering economic factors. At this time, however, it is not possible to determine readily which landfill operators and State agencies might find the NRC rule an effective option.

Concrete in Roadbeds. Released concrete at or below the 1 mrem/yr criterion using the RS-G-1.7 standard could be recycled into roadbed material. Licensees who could demonstrate that concrete would be recycled into roadbed material could proceed with that release of material without NRC approval, but subject to NRC inspections in demonstrating compliance with the provisions of the rule.

Reuse of Tools and Equipment for their Original Purpose. A separate provision of the rule would address the reuse of equipment, such as tools and vehicles, for their original purposes. Tools and equipment that meet the 1 mrem/yr dose criterion could be reused. Equipment at a licensed facility includes scaffolds, cranes, trucks and office furniture. Smaller pieces of equipment and tools are used by workers and may be transported in and out of restricted/impacted areas as part of the routine conduct of work in those areas.

Case-specific approvals. Any request to release solid material other than to these limited dispositions or releases at higher radionuclide concentration levels would require case-specific approval from NRC. For these requests, NRC would codify the process and the criteria for licensees to seek case-specific approvals under a license amendment request. The licensee would also be required to submit an environmental report on the proposed action. The proposed rule would identify the requirements that licensees need to observe in preparing and submitting such requests. It is expected that such applications would address end-uses for limited types and amounts of materials. For example, some types of structural steel could be reused for the construction of a framework for warehouses. For soils, materials may be used as backfill or as bedding in pipe trenches. For soil-like materials with cementitious properties, materials may be used as an additive to concrete in industrial settings, such as building footings and foundations or equipment pedestals. A licensee seeking a limited release for some restricted end use of material would be required to request an exemption based on pathways, worker protection, future uses, etc. A licensee could have to provide reasonable assurance that such materials are kept out of disposition paths that are not allowed and could have to submit a dose assessment to NRC for a case-specific disposition application.

The decision to include the disposal of soil under the case-specific component of the Alternative reflects the results of analyses considering potential uses of released soil under varying scenarios. The results indicate that under some conditions, soils initially intended for burial in a RCRA D landfill could be diverted, at a point beyond the licensee's control, and used in other purposes given that there is a demand for “clean fill” for use as backfill. The staff analysis revealed that, at this time, there is not enough information to characterize how soils might be used locally. For example, the analysis presented in NUREG-1725 (Human Interaction with Reused Soil: An Information Search) and evaluation conducted in support of this GEIS, indicates that there is much uncertainty in the potential volumes and types of soils that might be released and how soils might be used once released. For instance, is the amount of soil a decisive factor in dictating whether it would be used or disposed of locally? do USDA and State regulations and restrictions impose limitations on the movement and use of soils? are there shipping cost constraints that would favor disposal over use? are there factors that would lead licensees to leave soil onsite instead of shipping it for disposal? Moreover, the engineering properties of soils are expected to dictate where and under what conditions soils might be reused. For example, the relative proportions of soil, gravel, sand, and other materials (e.g., concrete and asphalt rubble) might restrict the use to very limited applications or dictate disposal. These considerations could not be fully addressed in the staff analysis because of the lack of supporting information. Given these uncertainties, the staff deemed it prudent to address the disposition of soils on a case-specific basis, as is done under current practices.

Recordkeeping. As part of its proposed rule, the NRC would include a requirement for records maintenance. These records would aid in allowing verification that the criterion has been met and provide reasonable assurance that the material was delivered to one of the allowed destinations. This recordkeeping could also provide the means to assess the effectiveness of this rule by confirming material released and estimated doses that have occurred as a result. Licensees would be required to maintain records indicating the nature of the material released (i.e., type and quantity of solid material, and nuclides present and their concentrations) and its destination (i.e., the landfill or specific end use shipped to, etc.).

Monitoring. All radioactive materials used, possessed, or stored onsite are required to be periodically monitored and inventoried. The monitoring includes the conduct of external radiation and surface contamination surveys. The inventory addresses quantities of radioactive materials as to their physical and chemical forms, uses, and dispositions, including radioactive decay. These requirements are stated in 10 CFR Part 20 and as license conditions stipulated in each license. Accordingly, the radiological status and locations of materials, before being designated for release, fall under the full control of the radiation safety program of each licensee. As a result no additional mitigation measures are anticipated as a result of implementing any of the alternatives. The implementation of the rule will be monitored through inspections, similar to those for releases to sewers.

In summary, the limited dispositions for each material are as follows:

- Concrete could be disposed in a RCRA Subtitle D landfill or recycled into roadbed material.
- Metals could be disposed in a RCRA Subtitle D landfill.
- Tools and equipment could be reused or disposed in a RCRA Subtitle D landfill.
- Trash could be disposed in a RCRA Subtitle D landfill.
- Disposition of soils, soil-like materials, or process materials would be case-specific.
- Any other disposition of these materials or disposition at higher radionuclide concentrations would require case-specific approval by NRC.

2.5 ALTERNATIVES AND OPTIONS CONSIDERED BUT ELIMINATED FROM DETAILED STUDY

One alternative (conditional use) and two dose options (both clearance standards) were considered by NRC and eliminated from detailed study. These options are therefore not analyzed in detail in this Draft GEIS. The following sections describe the reasons why they have been eliminated from consideration.

2.5.1 Conditional Use

In this alternative, solid material would be released, but its further use would be restricted to only certain authorized uses with limited potential for public exposure, such as use in controlled environments. Examples might include industrial uses such as metals in bridges, sewer lines, or industrial components, or concrete use in road fill. NRC regulations in 10 CFR Part 20 would be amended to add a dose-based regulation for conditional use. The Conditional Use Alternative would allow a greater amount of activity to be released than the amount that would be released under the Limited Dispositions Alternative because the latter uses unrestricted release radionuclide concentrations to establish the 1 mrem/yr dose limit and these are more conservative.

Material from these authorized uses may ultimately be reused or recycled into products not authorized under the Conditional Use Alternative. For this reason, the Conditional Use Alternative was replaced with the more restrictive Limited Dispositions Alternative, which uses radionuclide concentrations based on unrestricted release.

2.5.2 American National Standards Institute/Health Physics Society Standard N13.12-1999

In addition to the dose options being analyzed under the Unrestricted Release Alternative, the 1999 American National Standards Institute (ANSI)/Health Physics Society (HPS) Standard N13.12 was also considered. The National Technology Transfer and Advancement Act of 1995 (NTTAA), Public Law 104-113, requires all Federal agencies and departments to use technical standards developed or adopted by voluntary consensus standards bodies as a means to carry out policy objectives or activities determined by the agencies and departments, except when utilization of such standards "is inconsistent with applicable law or otherwise impractical."

The ANSI standard presents screening clearance criteria for unrestricted release (clearance) of solid materials based on an annual dose limit of 1 mrem. When justified on a case-by-case basis, clearance could be permitted at higher dose levels when it can be assured that exposures to multiple sources (including those that are beyond the scope of this standard) will be maintained ALARA (as low as reasonably achievable) and will provide an adequate margin of safety below the public dose limit of 1 mSv/yr (100 mrem/yr) TEDE. The standard excludes the release of land and soils intended for agricultural purposes.

As identified by the National Academies, one problem with the standard is that the bases for the screening clearance levels have not been fully documented. Moreover, the National Academies note that the approach used in deriving the volumetric screening levels is based on a room modeling scenario involving exposures only to external radiation, inhalation, and incidental ingestion of dust containing radioactivity. The total duration of the exposures is assumed to be only 500 hours, occurring over a brief time period. In evaluating case-specific applications, the NRC would consider exposure scenarios and pathways that were not addressed by the standard. Such differences make the use of the ANSI standard difficult to justify. Finally, the standard is due for its first 5-year review cycle in 2004 and ANSI may decide to revise it in accommodating comments from the National Academies and others. For these reasons, NRC believes that use of the ANSI standard is impractical, and the ANSI standard was not included in the detailed analysis.

2.5.3 European Commission Standard - Reports Nos. 89 and 122

An additional international standard considered by NRC as an option under the Unrestricted Release Alternative was the European Commission's (EC's) clearance levels as described in Radiation Protection Reports Nos. 89 and 122 (EC 2000a and 2000b). In these documents, there are a range of assumptions used for converting the actual measured concentrations at the release point to the dose received by various receptors. Appendix E provides a comparison between NRC's independent dose analysis (NUREG-1640), IAEA Safety Guide RS-G-1.7, and the EC clearance levels. Using the more recently adopted IAEA safety guide instead of the EC clearance levels would provide more consistency in international standards.

2.6 SUMMARY COMPARISON OF PREDICTED ENVIRONMENTAL IMPACTS

NEPA regulations require a comparison of the environmental impacts of all of the alternatives, in order to define the issues and provide a clear basis for choice among the various options. This section presents a brief comparison of the environmental impacts of the alternatives, which are compared in greater detail in Section 3.12. Table 2-1 provides a summary of the impacts.

Nuclear power plants would be disposing of material over the next 50 years. However, the time period over which impacts are considered includes (1) the operational phase of reactors during which some materials are expected to be released, (2) the post-shutdown and decommissioning phase of reactors during which materials will be released as well, (3) and the post-decommissioning time period after which materials that have been released are presumed to have some long-term impacts on the public. The operational phase of reactors takes into account the currently operating and shutdown reactors over the next 50 years. The post-decommissioning phase considers impacts over the next 200 years, while the analysis notes that doses beyond 200 years and out to 1,000 years become vanishingly small and contribute very little to the total of collective doses.

As discussed in Section 1.3, some environmental issues are not analyzed in detail in this Draft GEIS because NRC does not anticipate impacts to these environmental resources. These environmental resources and issues include soils, noise, ecological resources, socioeconomics, historic and cultural resources, environmental justice, visual and scenic resources, and land use (Table 2-1).

The impacts shown in Table 2-1 are defined in 10 CFR Part 51, Appendix B.

- "Small Impact" is defined as: "For the issue, environmental effects are not detectable or are so minor that they will neither destabilize nor noticeably alter any important attribute of the resource. For the purposes of assessing radiological impacts, the Commission has concluded that those impacts that do not exceed permissible levels in the Commission's regulations are considered small as the term is used in this table." In addition, those environmental resources or issues where there is no potential to cause impact are included under the term "small impact."

- "Moderate Impact" is defined as: "For the issue, environmental effects are sufficient to alter noticeably, but not to destabilize, important attributes of the resource."

- "Large Impact" is defined as: "For the issue, environmental effects are clearly noticeable and are sufficient to destabilize important attributes of the resource."

As described in Chapter 3, the following impacts were studied in detail: water quality, transportation, air quality, waste management, and public and worker health and safety. The impacts on water quality, air quality and public and worker health and safety would be small for all alternatives. The transportation effects (which are based on statistical information on non-radiological fatal traffic accidents) are highest for the LLW Disposal Alternative, because transport distances associated with this alternative are significantly higher for truck transport, resulting in higher estimated fatal traffic accidents. The effects on waste management associated with the LLW Disposal Alternative are considered large (more than four times the existing LLW capacity at the Envirocare site under its current State licenses and permits). Under the other alternatives, the amount of solid material that would be sent to a LLW facility is less than the existing LLW disposal capacity.

Table 2-1 Comparison of Alternatives and Associated Impacts[3]

	Alternatives				
	No Action	**Unrestricted Release**	**EPA/State-Regulated Disposal**	**LLW Disposal (Prohibition)**	**Limited Dispositions**
Soils	❍	❍	❍	❍	❍
Noise	❍	❍	❍	❍	❍
Ecological Resources	❍	❍	❍	❍	❍
Socioeconomics	❍	❍	❍	❍	❍
Historic and Cultural Resources	❍	❍	❍	❍	❍
Environmental Justice	❍	❍	❍	❍	❍
Visual and Scenic Resources	❍	❍	❍	❍	❍
Land Use	❍	❍	❍	❍	❍
Water Quality	❍	❍	❍	❍	❍
Transportation	❍	❍	❍	❍ to ◗	❍
Air Quality	❍	❍	❍	❍	❍
Waste Management	◗	❍	❍	●	❍
Public and Worker Health and Safety	❍	❍	❍	❍	❍
Benefit or (Cost)	0	247	181	(1,404)	257

❍ Small Impact ◗ Moderate Impact ● Large Impact

In analyzing the monetary costs and benefits associated with the alternatives, the No Action Alternative is the baseline against which the other alternatives are compared. There are no incremental costs or benefits for the No Action Alternative. For the Unrestricted Release and EPA/State-Regulated Disposal Alternatives, the incremental costs and benefits are dependent on the dose option selected. For both alternatives, benefits are associated with the 1 mrem/yr and 10 mrem/yr dose options, but costs are associated with the 0.03 mrem/yr and 0.1 mrem/yr dose options. These costs are due to the fact that under these lower dose options, smaller amounts of solid material are released, and larger amounts must be transported and disposed of in LLW disposal sites. In Table 2-1, the benefit shown for these alternatives is for a dose limit of 1 mrem/yr. The highest incremental costs are associated with the LLW Disposal Alternative and

[3] The terms "small," "moderate" and "large" impacts are discussed in Section 2.6.

are estimated to exceed $1.4 billion, primarily from transportation and disposal operations. For Limited Dispositions, with a dose criterion of 1 mrem/yr based on the IAEA standard, the benefit would be $257 million.

2.7 PRELIMINARY RECOMMENDATIONS REGARDING THE PROPOSED ACTION

The comparison of the alternatives is presented briefly in Section 2.6 and in detail in Section 3.12. After weighing the costs and benefits and comparing the impacts of the alternatives, the NRC staff, in accordance with 10 CFR 51.71(e), sets forth their preliminary National Environmental Policy Act (NEPA) recommendation regarding the proposed action. The NRC staff recommends that the staff promulgate a regulation for limited dispositions. As discussed in Section 2.4.5, solid material would be released, but NRC would allow only certain authorized dispositions to limit the potential for public exposure. The only pre-authorized limited dispositions considered under this alternative would be disposal of concrete, metal or trash in a RCRA Subtitle D landfill, concrete use in road fill, and reuse of tools and equipment for its original purpose. Licensees would need to demonstrate that releases would be below Part 20 radionuclide concentrations derived for a dose limit of 1 mrem/yr using the IAEA Safety Guide RS-G-1.7 for unrestricted release. Any requests to release material other than to these limited end uses or disposition at higher radionuclide concentrations would require case-specific approval from NRC.

The NRC staff preliminarily concluded the overall benefits of the proposed rulemaking outweigh the disadvantages based on consideration of the following:

- provide a risk-informed consistent criterion for controlling the disposition of solid materials,
- allow for a predictable regulatory process that is efficient and effective,
- set a dose criterion well below levels established to ensure adequate protection of public and safety and the environment,
- be consistent with international numeric guidelines,
- provide limited potential for public exposure,
- address public concerns with unrestricted release of solid materials into general commerce,
- address concerns from the steel and concrete industries that consumers could choose not to purchase items made from materials recycled from licensed facilities,
- provide guidance on materials with surficial and volumetric residual radioactivity, and
- ensure less time and resources would be expended on case-specific applications.

CHAPTER 3
AFFECTED ENVIRONMENT AND ENVIRONMENTAL CONSEQUENCES

3.1 INTRODUCTION

Chapter 3 describes the affected environment that could be impacted by the implementation of the Alternatives. The chapter also addresses the potential environmental consequences of the Alternatives. Costs and benefits of the Alternatives are discussed in Chapter 4, Cost-Benefit Analysis.

The affected environment of the Alternatives covers the entire United States and is not site specific in nature. For that reason, several environmental resource topics are not analyzed in detail in this Draft GEIS. These environmental topics include: soils, land use, socioeconomics, environmental justice, historic and cultural resources, visual and scenic resources, and noise.

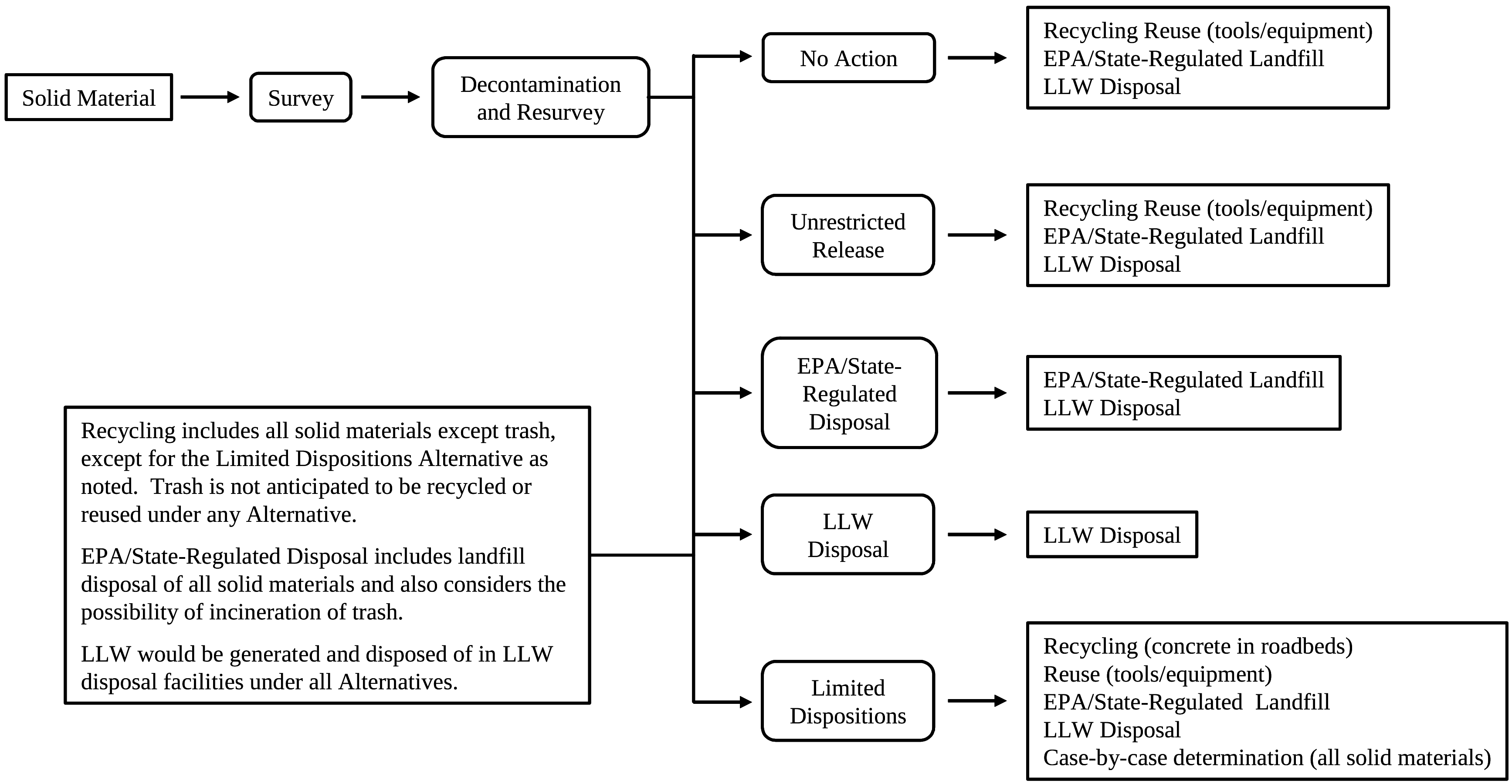
NRC does not anticipate construction activities that could have the potential to cause impacts to these environmental resources. In the event that there are construction activities associated with the disposition of solid material, any such construction activities would be subject to site-specific NEPA analysis conducted on a case-by-case basis. The affected environment of the Alternatives is limited to impacts associated with the transportation, recycling and disposal of solid materials and reuse of equipment and tools in their originally intended form and function.

The affected environment of the Alternatives does not include any solid materials left on site at licensee facilities after license termination. Solid materials remaining on site at facilities after license termination are subject to existing NRC regulations that would not be affected by the Proposed Action. When an NRC/Agreement State-licensed facility is decommissioned, the licensee must decontaminate the facility site to at least the minimum prescribed criterion prior to the NRC terminating the license (10 CFR Part 20 Subpart E). This limit pertains to both the facilities' remaining intrinsic structures (e.g., buildings) and site (e.g., soil). The potential impacts to the General Public, Non Licensed-Facility Workers, and Licensed-Facility Workers during decommissioning have already been analyzed through the NRC rulemaking for license termination.

The analysis of environmental consequences presented in this chapter evaluates the potential direct, indirect, and cumulative impacts that could occur with implementation of the Alternatives, including the No Action Alternative. As required by the Council on Environmental Quality (CEQ) regulations, this chapter also includes analysis of the potential adverse impacts on the environment associated with its short-term use and the potential adverse impacts on long-term productivity. In addition, this chapter includes a discussion of the irreversible and irretrievable commitment of resources associated with the Alternatives.

Figure 3-1 is a flowchart showing the disposition pathways for solid material under the Alternatives. Appendix F includes a description of licensees and the amounts of material and activity that could be released under each of the Alternatives.

Figure 3-1 Disposition Pathways



3.2 HUMAN HEALTH AND SAFETY

The Affected Environment is defined for the purposes of the Human Health and Safety Impact assessment as workers and the public potentially exposed to radiation dose from activities associated with generation, handling, processing, disposition, transportation, and disposal of the materials generated from licensed facilities under the Alternatives. Appendix G describes the affected General Public groups and the affected Non-Licensed Facility Worker groups and the radiological impact assessment methodology used for the collective dose assessment for the No Action, Unrestricted Use, EPA/State-Regulated Disposal, and Limited Disposition Alternatives for each solid material. This includes a description of the characteristics of each affected group and the assumed dispositions of each solid material under each Alternative upon which the collective dose assessment for each Alternative and solid material is based.

Occupational workers are defined in 10 CFR 20.1003 as only radiation workers, i.e., workers that work at LLW disposal facilities. Non-radiation workers are defined in 10 CFR 20.1003 as part of the public. For the purposes of the Draft GEIS, NRC has categorized potentially exposed individuals as (1) “Workers at Licensed Facilities,” (2) “Workers at Non-licensed Facilities,” and (3) “General Public,” as defined below. Affects on radiation workers (Workers at Licensed Facilities), non-radiation workers (Workers at Non-licensed Facilities), and the General Public are discussed in Section 3.2.3, 3.2.4, and 3.2.5 of the Draft GEIS.

<u>Workers at Licensed Facilities</u> - These workers are employed at NRC- or Agreement State-licensed sites, including licensee facilities and LLW disposal facilities. Their duties may involve exposure to radiation or to radioactive material which is potentially clearable. Doses to these workers could occur from surveying and decontaminating potentially clearable materials at licensed facilities or disposing of solid materials at licensed facilities.

<u>Workers at Non-Licensed Facilities</u> - These workers are members of the public who may experience work-related exposure while handling or otherwise encountering released material at their place of employment. Examples of these individuals include workers in scrap yards, iron and steel mills, EPA/State-regulated landfills, and EPA/State-regulated incinerators; truck drivers transporting released material; and building and road construction workers utilizing released material or byproducts of processing released material. Truck drivers transporting LLW to LLW disposal facilities are not workers situated at licensed facilities and are therefore categorized for the purposes of the Draft GEIS as Non-Licensed Facility Workers.

<u>General Public</u> - These individuals are members of the public who may experience non-work related exposures, i.e., exposures that occur outside their place of employment. For example, the General Public could be exposed to released materials utilized in automobiles, roadbeds, and buildings. Note that Workers are also members of the General Public when they are not working at their place of employment.

This section assesses the potential radiation exposures of workers at licensed facilities and non-licensed facilities, and the general public for each alternative. Detailed dose analyses were performed for concrete, ferrous metal, and trash generated from licensee facilities. Non-radiation impacts are discussed in Sections 3.3 (Transportation), 3.4 (Water Resources), 3.5 (Air Quality), and 3.6 (Ecological Impacts).

3.2.1 Background Radiation

Radiation is all around us, and it is naturally present in our environment. Consequently, life has evolved in an environment which has significant levels of ionizing radiation. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes. Certain foods such as bananas and brazil nuts contain higher levels of naturally-occurring radiation than other foods. Brick and stone homes have higher natural radiation levels than homes made of other building materials such as wood. Furthermore, a lot of our natural exposure is due to radon, a gas from the Earth's crust, that is present in the air we breathe.

Background radiation is defined as radiation that comes from cosmic sources, naturally occurring radioactive materials, including radon (except as a decay product of source or special nuclear material) and global fallout as it exists in the environment from the testing of nuclear explosive devices. Background radiation does not include radiation from source, byproduct, or special nuclear materials regulated by the NRC. The typically quoted average individual exposure from background (natural and artificial) radiation is 360 millirem (3.6 mSv) per year (Table 3-1) (NCRP 1987a). Appendix E provides additional discussion of background radiation data.

Levels of natural or background radiation can vary greatly from one location to the next. For example, people residing in Colorado are exposed to more natural radiation than residents of the east or west coasts because Colorado has more cosmic radiation at a higher altitude and more terrestrial radiation from soils enriched in naturally occurring uranium. The average annual radiation exposure from natural sources that every individual in the United States receives is about 300 millirem (3 mSv) (Table 3-1). Radon gas accounts for two-thirds of this exposure, while cosmic, terrestrial, and internal radiation account for the remainder. No adverse health effects have been discerned from doses arising from these levels of natural radiation exposure (NCRP 1987a).

Man-made sources of radiation from medical, commercial, and industrial activities contribute another 60 mrem (0.6 mSv) to our annual radiation exposure. One of the largest of these sources of exposure is medical x-rays. Diagnostic medical procedures account for about 40 mrem (0.4 mSv) each year. In addition, some consumer products such as tobacco, fertilizer, welding rods, gas mantles, luminous watch dials, and smoke detectors contribute another 10 mrem (0.1 mSv) to our annual radiation exposure (NCRP 1987b).

A typical breakdown between natural background radiation and artificial sources of radiation is shown in Table 3-1. Natural radiation contributes about 82 percent of the annual dose to the population while medical procedures contribute most of the remaining 18 percent. Both natural radiation and artificial radiation affect people in the same way.

Table 3-1 Average Annual Effective Dose Equivalent of Ionizing Radiations to a Member of the U.S. Population

	Effective dose equivalent	
Source of Radiation	**mSv (mrem)**	**Percent**
Natural		
Radon[a]	2 (200)	55
Cosmic	0.27 (27)	8
Terrestrial	0.28 (28)	8
Internal	0.39 (39)	11
Total natural[b]	***3 (300)***	***82***
Artificial		
Medical		
X-Ray Diagnosis	0.39 (39)	11
Nuclear Medicine	0.14 (14)	4
Consumer Products	0.1 (10)	3
Other		
Occupational	less than 0.01 (less than 1)	less than 0.03
Nuclear Fuel Cycle	less than 0.01 (less than 1)	less than 0.03
Fallout	less than 0.01 (less than 1)	less than 0.03
Miscellaneous[c]	less than 0.01 (less than 1)	less than 0.03
Total artificial[b]	***0.63 (63)***	***18***
Total natural and artificial[b]	***3.6 (360)***	***100***

[a] Dose equivalent to bronchi from radon daughter products.
[b] Totals have been rounded and may not be numerically identical to the sum of the dose values shown.
[c] From Department of Energy facilities, smelters, transportation, etc.

Source: NCRP, 1987a.

3.2.2 Dose Assessment

The dose-based standards considered in this Draft GEIS express doses to an individual on a yearly basis, such as 1 mrem (0.01 mSv) per year. The dose modeling developed under NUREG-1640 is discussed in Appendix E. The IAEA RS-G-1.7 (IAEA 2004) radionuclide concentration levels are based on a dose of 1 mrem (0.01 mSv) per year. The differences between the radionuclide concentration levels in RS-G-1.7 and the levels derived for a dose of 1 mrem/yr from the modeling studies in NUREG-1640 are generally considered to be minor by modelers because of the uncertainties in making such estimates and taking into account, to the extent practicable, variations in modeling complex industrial processes. In part, the uncertainty and variability are attributed to differences in code models; scenarios and exposure pathways describing industrial practices; model assumptions and parameters; differences in dose coefficients between ICRP 26 and 60 (ICRP 1991) recommendations given their respective use by the NRC and IAEA; methods in incorporating radon and its decay products; adjustments of

IAEA clearance values with that of other exemptions to ensure compatibility; and the process used in rounding off IAEA values to the nearest power of ten. For each given disposition of released materials, this means that a dose of one mrem would be incurred annually by an individual, ignoring radioactive decay, if the material continued to be released year after year.

The sum of all individual doses for a group of individuals or a population is called the collective dose, which is expressed in person-rem or person-Sv. As a measure, collective dose provides a way of comparing the impacts to population groups against various activities. The annual background collective dose to the U.S. population due to natural sources of radiation and radioactivity is estimated to be about 84 million person-rem (840,000 person-Sv), assuming an annual average effective dose equivalent of 300 mrem (3 mSv). Appendix E presents a more detailed discussion of the concept and its application, including the limitations in the application of collective dose (Section E-III). For example, at low individual doses, the uncertainty in potential health risk includes the possibility of zero risk. Thus for populations where all members receive low doses, collective dose provides a very uncertain measure of risk, and there may be no significant impacts or risks to the population. However, NRC's regulatory analysis uses collective dose to a population because it enables a more direct comparison of the relative impacts of the different alternatives.

The collective dose results are inclusive of all exposure pathways. (See the analytical methods using the Monte Carlo technique and pathways described in Appendix D.) The collective dose results are inclusive of the sum of all doses over all exposure pathways and times specified for the analysis. Exposure pathways, dose receptors, and dose contributions are dynamic in that the dominance of each varies as a function of time. At first, facility workers and truck drivers are the first group to incur doses and later the dose contribution shifts to members of the general public. The pathways include doses associated with external radiation, ingestion, and inhalation exposures. The pathways can be further defined as whether they are workers or members of the public. For workers and truck drivers, doses are associated, in decreasing order of contribution, with the following exposure pathways: external radiation, inhalation, and incidental ingestion of dust containing residual levels of radioactivity. The exposures and doses occurring early in the front end of the process involve the release of materials (i.e., while materials are being generated by licensed facilities, during transportation, and during end-use or disposal in landfills). During transportation, members of the public are exposed to external radiation while vehicles are traveling on roads. Once materials are no longer generated, there are no additional doses to workers and dose contributions shift to the members of the public over a more protracted time. At this point, doses to the public are associated with the movement of radioactive materials through ground and surface water. The predominant exposure pathways, in decreasing order, are the consumption of water and food crops irrigated with surface or ground water. In terms of radionuclides contributing to doses, the following, in decreasing order of relative presence in the mix, contribute to external radiation: Co-60, Cs-137, Co-58, and Cs-134. For worker exposures associated with inhalation and incidental ingestion, the following radionuclides, in decreasing order of the mix, contribute to internal doses: Co-60, Fe-55, Cs-137, Ni-63, Co-58, and Cs-134. For members of the public where doses are associated with slow environmental transport, radionuclides with long half-lives dominate - in decreasing order of the mix, they include Cs-137, Ni-63, Sr-90, C-14, Pu-238, Pu-239, and I-129.

Although collective doses are used to compare the alternatives, the rule will be based on individual risk. The individual would not receive a dose of more than a specified dose limit (e.g. 1 mrem/yr (0.01 mSv/yr)). If the individual dose limit is low, then the population is protected as well since it is virtually impossible for everyone in any population group to receive the maximum dose. In fact, the great majority of individuals in the population group considered in the analysis are expected to receive doses that are a small fraction of the dose limit considered in this Draft GEIS (1 mrem/yr). The collective dose analysis is summarized in Appendix D.

The majority of the mass, activity and collective dose associated with licensed facilities is associated with solid materials released from commercial nuclear reactor licenses. For nuclear power plants, the radionuclide profile and relative fraction of each are based on site characterization results and selected low-level waste data. A single inventory was derived for all reactors, both operating and shutdown. The radioactivity profile assumed the presence of 17 radionuclides, as beta and gamma emitters, and transuranics. The most predominant radionuclides, comprising about 96% of expected residual radioactivity levels, are Mn-54, Co-58, Co-60, Ni-63, Fe-55, Cs-134, and Cs-137. For these radionuclides, the radioactive half-lives range from about 71 days to 100 years. The collective doses are based on the time period up to the point when the currently operating reactors will be decommissioned. The collective dose analysis considers the time period (50 years) during which solid materials will be generated and 200 years beyond in assessing long-term impacts. The analysis assumes that the decontamination and decommissioning and remediation work of all commercial nuclear power reactors effectively will be completed by 2050. The time period of this analysis is 250 years, which is the time when potentially clearable materials from existing licensees would result in significant contribution to collective dose. It should be noted that because most of the radioactivity is due to radionuclides with half-lives measured in years (a fraction of a year to about 30 years) rather than in thousands of years, the collective doses and impacts beyond 250 years become vanishingly small.

However, for the impacts associated with landfill disposals, the analysis was carried out to 1,000 years. In both cases, no specific distinction is made between the results associated with the 250 or 1,000-year analysis given that beyond 250 years, collective doses become negligible.

The collective dose analysis (SC&A 2003) considered Licensed Facility Workers involved in surveying and decontamination at licensed facilities generating solid material and at LLW disposal facility sites. The analysis considered the following scenarios for exposures to Non-Licensed Facility Workers and the General Public (Figure 3-1):

- The collective dose from recycled concrete analyzed in this Draft GEIS results only from its use for road bed construction. The selection of road bed construction as the single end use is based on the fact that approximately 85 percent of road construction is recycled concrete (Appendix G).

- The collective dose from ferrous metals is dominated by five scenarios depicting population exposures to finished ferrous metal products. These five end use products are office buildings, beds, automobiles, office furniture and home appliances.

- The end use for trash was disposal at EPA/State-regulated disposal facilities. Most of the trash from licensed facilities consists of items not likely to be reused (e.g., rubber gloves). Even if there were some recycling of this trash, its amount, compared to the much larger volumes of other materials intended for recycle would be insignificant in terms of collective dose. Also, current practice for trash from restricted/impacted areas at licensed facilities is that various trash items are mixed together and sent for disposal, not reuse or recycle.

- Inventory information on other metals, besides ferrous metal, indicated these were primarily copper or aluminum, and there is a small amount of these materials generated as compared to ferrous metal. The results of a screening analysis indicated that collective doses for copper and aluminum are about one to two orders of magnitude lower than that of ferrous metals.

- The disposition for all materials could be LLW disposal.

- Collective doses were calculated for reuse of small and large pieces of equipment.

3.2.3 Licensed Facility Workers

This section describes the affected environment and environmental consequences associated with the Alternatives for Licensed Facility Workers.

3.2.3.1 Affected Environment

The affected environment with respect to Licensed Facility Worker collective dose includes survey workers and decontamination workers at licensed facilities generating solid material, and LLW disposal facility workers. Licensed Facility Worker activities contributing to collective dose include activities associated with surveying and decontaminating solid materials at licensed facilities and disposing of LLW at LLW disposal facility sites. Other solid material handling activities conducted at licensee facility sites, including management of solid material storage piles and loading of solid materials for transport to recycling or disposal facilities are assumed to be conducted by Licensed Facility Workers. Truck drivers within the impacted area during handling and loading operations would be considered Non-Licensed Facility Workers.

Activities conducted by Licensed Facility Workers in surveying and decontaminating the solid materials generated at licensed facilities are anticipated to be similar for all Alternatives. Licensed Facility Workers at LLW disposal facilities disposing of solid material as LLW are anticipated to be similar for all Alternatives. Therefore the affected environment for Licensed Facility Workers is similar for all Alternatives. These activities are described in this section and discussed in more detail in Appendix D.

<u>Survey Workers</u>

Survey workers are workers at licensed facilities who conduct radiation surveys of solid materials to assess their radiological characteristics. It is assumed for the purposes of the Draft GEIS that survey workers would conduct surveys specifically to characterize the solid materials in support of implementation of the proposed rule for the release of solid materials. Surveys of material expected to result in doses to members of the public ranging from 10 mrem/yr (0.1 mSv/yr) to 25 mrem/yr (0.25 mSv/yr) would be addressed as part of decommissioning activities under an NRC-approved license termination plan. Surveys conducted by survey workers in support of the decommissioning activities of licensed facilities for LLW disposal and to demonstrate compliance with the License Termination Rule, and that are not directly related to the release of solid materials, are not within the scope of the Proposed Action.

Decontamination Workers

Decontamination workers are workers at licensed facilities who decontaminate solid materials, mostly ferrous metal, to reduce the level of radioactivity of the solid materials. It is assumed for the purposes of the Draft GEIS that decontamination workers would conduct such activities specifically to decontaminate the solid materials in support of implementation of the proposed rule for release of solid materials. Decontamination activities conducted by workers in support of the decommissioning of licensed facilities and that are not related to the release of solid materials are not within the scope of the Proposed Action.

It is assumed that the Proposed Action would only apply to materials considered to be relatively free of both internal and external surface or volumetric contamination and with residual radioactivity levels close to or below the release criteria. In other words, the provisions of a proposed rule are not expected to change licensee practices in identifying and segregating materials with contamination levels that may warrant decontamination or disposal as LLW. Moreover, it is assumed that if decontamination were considered as a precursor to compliance with a proposed rule, the initial contamination levels would need to be such that release criteria could be readily achieved given the selection of an appropriate decontamination method. This recognizes that if contamination levels were too high and the decontamination factor were too low, it would be a futile exercise to spend time and resources on decontamination. In such a situation, disposal as LLW would be the most cost-effective course of action. The proposed action is not expected to impact this decision process, nor affect the related economic factors.

LLW Disposal Facility Workers

Under each alternative, different amounts of solid material would be disposed of as LLW at a LLW disposal facility. The quantity of solid material that would be disposed as LLW depends upon the Alternative and dose option selected and affects the collective dose to workers at these facilities.

The decision to dispose of useful material and equipment as LLW is driven by operational and economic considerations, taking into account replacement costs versus cost of repairs, lead time in procuring new equipment, amortization, and cost of money. These factors are expected to be different among facilities. The proposed action is not expected to impact this decision process, nor affect such economic factors.

3.2.3.2 Environmental Consequences

This section describes the environmental consequences associated with the Alternatives for Licensed Facility Workers. Environmental consequences are presented in terms of collective dose, in units of person-rem, for each alternative.

The collective doses to survey workers and decontamination workers at licensed facilities are assumed not to vary among the Alternatives and their associated dose options since all solid materials would be surveyed under each Alternative. However, it may be the case that for the 0.03 mrem/yr dose option for some of the Alternatives that the number of labor hours required to survey the material would be higher because the survey would be more difficult for the workers to conduct. Note that surveying materials at an actual “zero above background” dose option would not be feasible, because radiation survey equipment would be incapable of distinguishing the radiation content of the materials generated from ambient “background” radiation. Only sample collection followed by laboratory analysis are feasible, but at a much greater cost.

This analysis assumes that decontamination workers would decontaminate some of the ferrous metal generated from commercial nuclear reactor facilities in order to reduce the radionuclide concentration of the ferrous metal to below the dose option for the No Action, Unrestricted Release, EPA/State-Regulated Disposal and Limited Dispositions Alternatives. The analysis also assumed that some metals generated by commercial nuclear reactors would be decontaminated under all of the alternatives and over all dose options. The analysis assumed a representative decontamination factor of 15, with a range of 10 to 100 based on industry data. The resulting amount of steel is estimated to be about 40 tons per year per reactor and a total of 4,200 tons as additional material available for release. NRC has assumed that trash and concrete would not be decontaminated because it is not economical to do so.

Because the estimate of collective dose to decontamination workers is based on the decontamination of a fixed percentage of the ferrous metal generated, the collective dose to decontamination workers is assumed not to vary by Alternative. However, it may be the case for the 0.03 mrem/yr and 0.1 mrem/yr dose options for the Unrestricted Release Alternative and EPA/State-Regulated Disposal Alternative that decontamination of ferrous metals may not be feasible, based on economic considerations alone.

The collective doses are estimated to be about 290 person-rem (2.99 person-sievert) for survey workers and 308 person-rem (3.08 person-sievert) for decontamination workers for all dose options (Appendix D).

Under all the alternatives, solid material generated from licensed facilities that is within the scope of the alternatives but that does not meet the radiological criteria for release would be transported to a LLW disposal facility. Truck drivers transporting the solid material to the LLW disposal facility are classified as Non-Licensed Facility Workers. LLW disposal facility workers are classified as Licensed Facility Workers. The collective dose to workers at LLW disposal facilities does not vary significantly among the Alternatives and their associated dose options. The collective dose to LLW disposal facility workers for the Unrestricted Release Alternative and EPA/State-Regulated Disposal Alternative is 28 person-rem (0.28 person-sievert) for the 10 mrem/yr dose option and 35 person-rem (0.35 person-sievert) for the 0.03 mrem/yr dose option. The collective dose to LLW disposal facility workers is 34 person-rem (0.34 person-sievert) for the No Action Alternative and LLW Disposal Alternative (SC&A 2003).

3.2.3.2.1 No Action Alternative

Survey Workers

The estimate of collective dose to survey workers for the No Action Alternative is based on surveying all of the potentially clearable solid material. The collective dose to Licensed Facility Workers for surveying the entire inventory of ferrous metal, trash, and concrete generated from commercial nuclear reactor facilities would be about 290 person-rem (2.9 person-sievert), as shown in Table 3-2. The collective dose is dominated by the surveying of trash. This is because of the relatively low mass to surface area ratio of trash as compared to concrete and ferrous metal, which results in relatively large surface areas of trash to be surveyed compared to concrete and ferrous metal, and this increases the number of labor hours needed to conduct the surveys.

Table 3-2 No Action Alternative - Licensed Facility Worker Collective Dose from Surveying Materials Generated from Commercial Nuclear Reactor Facilities

Material	Exposure Rate (rem/hr)	Total Labor Hours	Collective Dose (person-rem)[1]
Trash	1.0E-04	27,400,000	274
Concrete and Ferrous Metal	5.0E-06	3,000,000	15
Total		31,400,000	289

[1] Source: SC&A 2003, Table 7.3.

Decontamination Workers

The collective dose to decontamination workers is estimated to be approximately 308 person-rem (3.08 person-sievert), as shown in Table 3-3.

Table 3-3 No Action Alternative - Licensed Facility Worker Collective Dose from Decontaminating Materials Generated from Commercial Nuclear Reactor Facilities (person-rem)

	Operating Ferrous metal	D&D Ferrous metal	Concrete	Trash	Total
Collective Dose	77	231	not applicable	not applicable	308

Source: SC&A 2003, Table 7.4.

LLW Disposal Facility Workers

Table 3-4 summarizes the collective dose to LLW disposal facility workers that would result from disposal of solid materials in LLW disposal facilities under the No Action Alternative.

Table 3-4 No Action Alternative - Licensed Facility Worker Collective Dose at LLW Disposal Facilities from Materials Generated from Commercial Nuclear Reactor Facilities

Total Radioactivity Generated (Ci)	Radioactivity in LLW (Ci)	Radioactivity Released (Ci)	Collective Dose (person-rem)
2,951	2,947	4	34

Source: SC&A 2003, Tables 8.6 and 8.7.

3.2.3.2.2 Unrestricted Release Alternative

The collective dose to survey workers and decontamination workers, for the Unrestricted Release Alternative is estimated to be 289 person-rem (2.89 person-sievert) for survey workers and 308 person-rem (3.08 person-sievert) for decontamination workers.

The collective dose to workers at LLW disposal facilities does not vary significantly among the dose options for the Unrestricted Release Alternative, as shown in Table 3-5. The total radioactivity generated is 2,951 Ci, as shown in Table 3-4. The collective dose to LLW disposal facility workers for the Unrestricted Release Alternative ranges from 28 person-rem (0.28 person-sievert) for the 10 mrem/yr dose option to 34 person-rem (0.34 person-sievert) for the other dose options.

Table 3-5 Unrestricted Release Alternative - Licensed Facility Worker Collective Dose at LLW Disposal Facilities from Materials Generated from Commercial Nuclear Reactor Facilities

Dose Option	Radioactivity in LLW (Ci)	Radioactivity Released (Ci)	Collective Dose (person-rem)
10 mrem/yr	2,413	538	28
1 mrem/yr	2,910	41	34
0.1 mrem/yr	2,948	3	34
0.03 mrem/yr	2,950	1	34

Source: SC&A 2003, Table 8.7.

3.2.3.2.3 EPA/State-Regulated Disposal Alternative

The collective dose to survey workers and decontamination workers for the EPA/State-Regulated Disposal alternative is estimated to be 289 person-rem (2.89 person-sievert) for survey workers and 308 person-rem (3.08 person-sievert) for decontamination workers.

The collective dose to workers at LLW disposal facilities does not vary significantly among the dose options for the EPA/State-Regulated Disposal Alternative, as shown in Table 3-6. The collective dose to LLW disposal facility workers for the EPA/State-Regulated Disposal Alternative ranges from 28 person-rem (0.28 person-sievert) for the 10 mrem/yr dose option to 34 person-rem (0.34 person-sievert) for the other dose options.

Table 3-6 EPA/State-Regulated Disposal Alternative - Licensed Facility Worker Collective Dose at LLW Disposal Facilities from Materials Generated from Commercial Nuclear Reactor Facilities

Dose Option	Radioactivity in LLW (Ci)	Radioactivity Released (Ci) to Landfills	Collective Dose (person-rem)
10 mrem/yr	2,402	549	28
1 mrem/yr	2,906	45	34
0.1 mrem/yr	2,946	5	34
0.03 mrem/yr	2,950	1	34

Source: SC&A 2003, Table 8.7.

3.2.3.2.4 Low-Level Waste Disposal Alternative

Under this Alternative, all the potentially clearable solid material would be disposed in LLW facilities. The collective dose to survey workers is estimated to be 289 person-rem (2.89 person-sievert). No decontamination is assumed for this Alternative. The collective dose to LLW disposal facility workers, as shown in Table 3-7, is 34 person-rem (0.34 person-sievert).

Table 3-7 Low-Level Waste Disposal Alternative - Licensed Facility Worker Collective Dose at LLW Disposal Facilities from Materials Generated from Commercial Nuclear Power Reactors

Total Radioactivity Generated (Ci)	Radioactivity in LLW (Ci)	Radioactivity Released (Ci)	Collective Dose (person-rem)
2,951	2,951	None	34

Source: SC&A 2003, Table 8.7.

3.2.3.2.5 Limited Dispositions Alternative

The environmental consequences for Workers at Licensed Facilities would be the same for the Limited Dispositions Alternative as for the No Action, Unrestricted Release and EPA/State-Regulated Disposal Alternatives described above. Solid material generated from licensed facilities under the Limited Dispositions Alternative would be subject to similar activities conducted by survey workers and decontamination workers as under the other Alternatives, resulting in similar collective doses to survey workers and decontamination workers. Solid materials not meeting the requirements under the Limited Dispositions Alternative would be disposed of in LLW disposal facilities, resulting in collective dose to LLW disposal facility workers. As shown above, the collective dose to LLW disposal facility workers does not vary significantly by Alternative, ranging from approximately 28 person-rem (0.28 person-sievert) to 34 person-rem (0.34 person-sievert). The collective dose to LLW disposal facility workers associated with the Limited Dispositions Alternative would be within the range of that for the other Alternatives.

3.2.3.2.6 Summary

Table 3-8 summarizes the collective dose for Licensed Facility workers for each of the alternatives. This table is derived from Tables 3-2 to 3-7 of this report. The total collective dose ranges from 323 person-rem (3.23 person-sievert) to 665 person-rem (6.65 person-sievert).

Table 3-8 Summary of Licensed Facility Worker Collective Dose Results (person-rem)

Alternative	Collective Dose			
	Survey Workers	Decontamination Workers	Workers at LLW Disposal Facilities	TOTAL
No Action	289	308	34	631
Unrestricted Release	289	308	28 - 34	625 - 631
EPA/State-Regulated Disposal	289	308	28 - 34	625 - 631
LLW Disposal	289	0	34	323
Limited Dispositions	289	308	34	631

3.2.4 Non-Licensed Facility Workers and the General Public

This section describes the affected environment and environmental consequences associated with the Alternatives for Non-Licensed Facility Workers and the General Public.

3.2.4.1 Affected Environment

This section describes the affected environment associated with the Alternatives for Non-Licensed Facility Workers and the General Public.

<u>Non-Licensed Facility Workers</u>

The affected environment for Non-Licensed Facility Workers for the No Action and Unrestricted Release Alternatives includes truck drivers transporting solid materials to recycling facilities and transporting products and byproducts from recycling facilities, and also includes workers at the recycling facilities. The categories of activities for affected Non-Licensed Facility Workers are:

- Material processing, including processes for recycling of materials into finished commodities and end use products;

- Materials disposition, including the installation of finished commodities (e.g., recycled concrete road building material) and end use products (e.g., metal products made from recycled ferrous metal);

- Byproducts disposition, including the application of products (e.g., furnace slag concrete) produced from byproducts of materials recycling processes;

- Waste disposal, including disposal of wastes (e.g., foundry dust) produced by materials recycling processes;

- Transportation, including transportation of generated materials, finished commodities and end use products made from recycled materials, and byproducts and wastes generated from materials processing activities.

The affected environment for all the Alternatives except the LLW Disposal Alternative includes truck drivers transporting solid material from licensed facilities to EPA/State-Regulated disposal facilities and workers at the EPA/State-Regulated disposal facilities, including EPA/State-Regulated landfills and incinerators.

The only Non Licensed-Facility Workers involved in the LLW Disposal Alternative are truck drivers or railroad workers transporting the LLW to the licensed disposal facility. The workers involved in surveying the LLW at the licensee facilities are categorized as Licensed-Facility Workers, and the workers involved in disposing of the LLW at licensed disposal facilities are also categorized as Licensed-Facility Workers.

Under the Limited Dispositions Alternative, the affected environment for concrete would be similar to that for the Unrestricted Release Alternative, which assumes recycling of concrete into road bed material. The affected environment for solid materials that would be disposed of in EPA/State-Regulated disposal facilities would be similar to that for the EPA/State-Regulated Disposal Alternative. The affected environment for reuse of equipment would be similar to that for the No Action and Unrestricted Release Alternatives for the reuse of furniture in office buildings and reuse of tools and other equipment in other workplace settings. The affected environment for equipment reuse would also include truck drivers driving trucks formerly used at licensed facilities.

General Public

The affected environment for the General Public for the No Action and Unrestricted Release Alternatives includes those individuals located in the vicinity of recycling facilities and along material transportation routes, and in locations where products produced from recycled materials are used. Products produced from recycled materials could be transported and utilized anywhere in the United States, and therefore the affected environment for the General Public for the No Action and Unrestricted Release Alternatives may encompass locations throughout the country.

Activities potentially contributing to General Public collective dose for the No Action Alternative and Unrestricted Release Alternatives are:

- Materials disposition, including direct radiation exposure from use of finished commodities (e.g., recycled concrete as road building material) and end use products (e.g., metal products made from recycled ferrous metal);

- Residuals disposition, including direct radiation exposure from the disposition of products (e.g., furnace slag concrete) produced from byproducts of materials recycling processes;

- Waste disposal, including ground-water discharges from disposal of wastes (e.g., concrete dust) produced by materials recycling processes; and

- Transportation of solid materials to recycling facilities and transportation of commodities from recycling facilities, including direct radiation exposure to finished commodities and end use products made of recycled solid materials, and byproducts and wastes generated from materials processing activities.

Under the No Action and Unrestricted Release Alternatives some material generated from licensed facilities would be disposed of as LLW, and byproducts from recycling activities would be disposed of in EPA/State-Regulated disposal facilities. Therefore the affected environment for the No Action and Unrestricted Release Alternatives also includes the General Public located in the vicinity of LLW disposal facilities and EPA/State-Regulated disposal facilities.

Under the EPA/State-Regulated Disposal Alternative some material generated from licensed facilities and covered under the Proposed Action would be disposed of as LLW. Therefore the affected environment for the EPA/State-Regulated Disposal Alternative also includes individuals located in the vicinity of LLW disposal facilities and along transportation routes.

Activities potentially contributing to radiation exposure to the General Public for the EPA/State-Regulated Disposal Alternative are:

- Transportation of solid materials for EPA/State-regulated disposal;
- Material disposal in EPA/State-regulated Subtitle D landfills;
- Trash disposal in EPA/State-regulated incinerators; and
- Landfill disposal of ash generated from trash incineration.

The affected environment for the General Public under the Limited Dispositions Alternative would be similar to that for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and LLW Disposal alternatives.

3.2.4.2 Environmental Consequences

This section describes the environmental consequences for Non-Licensed Facility Workers and the General Public associated with each Alternative. Environmental consequences are presented in terms of collective dose, in units of person-rem, for each Alternative.

3.2.4.2.1 No Action Alternative

This section summarizes the collective dose to Non-Licensed Facility Workers and the General Public for the No Action Alternative. A screening analysis conducted for the No Action Alternative and Unrestricted Release Alternatives indicates that the collective dose to Non-Licensed Facility Workers is negligible as compared to the collective dose to the General Public for the No Action Alternative. Therefore, quantitative collective dose results presented in this section for the No Action Alternative are primarily collective dose to the General Public.

Non-Licensed Facility Workers Collective Dose

A screening analysis was conducted (SC&A 2003) to illustrate the relative collective dose associated with the various activities conducted by Non-Licensed Facility Workers and the General Public for recycling of ferrous metal and concrete. The screening analysis is based on an evaluation of the collective dose experienced in the first year the solid material is released. The analysis indicates that the collective dose from recycling ferrous metal is dominated by five end use products manufactured from recycled ferrous metal: office buildings (i.e., structural ferrous metal); beds; automobiles; office furniture; and home appliances, all of which contribute to collective dose to the General Public. These five end use products manufactured from recycled ferrous metal and their associated collective dose to the General Public represent 99.8 percent of the total combined collective dose to the General Public and Non-Licensed Facility Workers. The collective dose to Non-Licensed Facility Workers involved in activities for recycling ferrous metal under the No Action and Unrestricted Release Alternatives represents less than 0.2 percent of the total collective dose. Thus the collective dose for ferrous metal for the No Action and Unrestricted Release Alternatives is dominated by the collective dose to the General Public.

The only end use of recycled concrete analyzed in the Draft GEIS is its use for roadbed construction (Appendix G). The amount of concrete dust that can become airborne depends mainly on its moisture content, physical properties, and engineered measures used to minimize such releases. The analysis assumed that the amounts of materials released via fugitive emissions are small, such releases are short-lived in duration, and long-term exposures associated with end uses are dominant in terms of collective doses. The collective dose from recycling of concrete is dominated by the collective dose to the General Public associated with this single disposition of recycled concrete: driving on roads built using recycled concrete. The collective dose to Non-Licensed Facility Workers involved in recycling concrete under the No Action Alternative represents less than 10 percent of the total first year collective dose. These Non-Licensed Facility Worker activities include transporting the concrete rubble, processing concrete rubble into road bed material, and building the road. More than 90 percent of the collective dose for concrete for the No Action and Unrestricted Release Alternatives is represented by collective dose to the General Public.

The use of concrete rubble is limited because reclaimed concrete is not pure Portland concrete, but rather a mixture of concrete, soil, some amounts of bituminous concrete, and other small size debris generated during demolition. The use of concrete with more than 15 percent reclaimed concrete has lead to problems in meeting material quality specifications, resulting in its difficult use and workability. Besides road construction, reclaimed concrete is being used in bulk fill applications on land and water, as riprap for shoreline protection, as trench backfill, as a mix in asphaltic concrete, and in revetments for fieldwork and mining. It is expected that such uses would result in much lower exposures and collective doses as compared to the construction and use of road bed made with reclaimed concrete.

General Public Collective Dose

Table 3-9 shows the collective dose to the General Public for the No Action Alternative. The total collective dose for the No Action Alternative is 3,996 person-rem (39.9 person-sievert). The collective dose is dominated by exposure of the General Public to products made from recycled ferrous metal. The primary exposure pathway for ferrous metal is external exposure (direct radiation) to products made from recycled ferrous metal, such as automobiles and appliances. Because Co-60 (with a 5-year half-life) is the primary radionuclide from the ferrous metal that partitions to the recycled metal (as opposed to partitioning to the furnace dust), the radiation exposure to the General Public rapidly decreases after the end of the period when there would be no additional nuclear reactors being decommissioned and when there would be no additional ferrous metal being generated from reactor decommissioning to be made into products. The other primary radionuclide considered in the collective dose assessment for the No Action Alternative, Cs-137, partitions primarily to the furnace dust at the mill. For the purposes of the collective dose assessment, the furnace dust is assumed to be disposed of in an EPA/State-Regulated landfill. Exposure pathways associated with landfill disposal of furnace dust include ground water and surface water discharges from the landfill and subsequent exposure of the General Public through drinking water and food ingestion, and direct radiation exposure of Non-Licensed Facility Workers (e.g., landfill workers, truck drivers) encountering the furnace dust. However, as discussed above, the collective dose to Non-Licensed Facility Workers from ferrous metal recycling is negligible as compared to the collective dose to the General Public.

Table 3-9 No Action Alternative - General Public Collective Dose for Materials Released from Commercial Nuclear Reactor Facilities (person-rem)[1]

Ferrous Metal	Concrete	Trash	Equipment Reuse	All Materials
3,920	3.91	0.006	72	3,996

[1] Source: SC&A 2003, Table 10.8.

Equipment Reuse

Table 3-10 describes the mean collective dose values to the General Public associated with the reuse of both large and small pieces of equipment for the Alternatives. The collective dose associated with equipment reuse for the No Action Alternative is 72 person-rem (0.72 person-sievert). The analysis of collective dose for equipment reuse is described in Section 12 of Appendix D.

Table 3-10 General Public Collective Doses Associated with Reuse of Large and Small Equipment from Commercial Nuclear Power Reactors

Dose Option	Collective Dose (person-rem) Small Equipment	Collective Dose (person-rem) Large Equipment	Total Collective Dose (person-rem) for Equipment Reuse
Unrestricted Release Alternative			
RS-G-1.7	5	56	61
10 mrem/yr	160	150	310
1 mrem/yr	16	15	31
0.1 mrem/yr	2	2	4
0.03 mrem/yr	<1	<1	<1
No Action Alternative	6	66	72

Note: Mean profile taken from Appendix D, Section 12 of this GEIS.
The IAEA volumetric criteria were converted to surficial limits using a mass-to-surface ratio of 5 g/cm^2, assuming that equipment consist of ferrous metals.

Collective doses to the General Public associated with the reuse of equipment were evaluated for two categories of equipment, large and small. The approach used in estimating collective doses relies on a scoping analysis because practices associated with the reuse of equipment are known to be highly variable. For example, it is known that different types of equipment and tools are used in radiologically controlled areas and later taken out of those areas. The type of equipment that could be potentially cleared from licensed facilities for reuse in an environment free of radiological controls ranges from small items, such as hand tools, to very large ones, such as mechanized equipment and industrial vehicles. The following are examples of potentially reusable equipment, tools, and miscellaneous items:

- small hand tools (wrenches, screw drivers, etc.) and power tools (drills, saws, etc.)
- electrical equipment, such as control panels, motors, pumps, and generators
- office furniture (desks, chairs, filing cabinets, etc.) and office equipment (copiers, computers, printers, fax machines, etc.)
- construction equipment, such as scaffolding, noise or dust-control barriers, wheelbarrows, etc.
- mechanized equipment, such as trucks, backhoes, bulldozers, and other vehicles
- materials and supplies for use in their original forms, but taken out as excess, such as piping, tubing, electrical wiring, floor covering, ductwork, sheet metal, pipe hangers, light fixtures, wall board, and sheet glass.

Table 3-10 describes the mean collective dose values to the General Public associated with the reuse of both large and small pieces of equipment.

3.2.4.2.2 Unrestricted Release Alternative

Non-Licensed Facility Workers and General Public

The screening analysis conducted for the collective dose to Non-Licensed Facility Workers for the No Action Alternative also applies to the Unrestricted Release Alternative as the same disposition of solid materials is assumed for both Alternatives in the screening analysis. The analysis indicates that the collective dose to Non-Licensed Facility Workers is negligible as compared to the collective dose to the General Public. Therefore, quantitative collective dose results are not presented separately for Non-Licensed Facility Workers for the Unrestricted Release Alternative.

Material-Specific and Material-Independent Collective Doses

Material-specific dose factors are developed for each radionuclide and each type of material. For example, the analysis for Co-60 in ferrous metal uses the dose factor for the scrap yard worker since it is the most limiting of all ferrous metal related scenarios that were evaluated (these scenarios include handling and processing, transportation, and product use). On the other hand, the material-independent dose factors consider the most conservative dose factor for each radionuclide, regardless of the type of material. For example, the presence of Co-60 in concrete (used in road building) results in the most limiting dose factor as compared to the presence of Co-60 in ferrous metal. More details can be found in Appendix D of the Draft GEIS for both cases - material-specific results (Case A) and material-independent results (Case B) (see Tables D-1 to D-3).

General Public Collective Dose

Table 3-11 shows the collective dose for the Unrestricted Release Alternative for concrete, ferrous metal, and trash for material specific and material independent dose factors. The collective dose is dominated by the exposure of the General Public to end-use products made from recycled ferrous metal. The primary exposure pathway for ferrous metal is external exposure (direct radiation) to products made from recycled ferrous metal. The total collective dose for concrete, ferrous metal, and trash ranges from 208 person-rem (2.08 person-sievert) for the 0.03 mrem/year dose option to 28,430 person-rem (284 person-sievert) for the 10 mrem/year dose option. Note that Table 3-11 presents collective dose results for material independent and material-specific cases, whereas Table 3-10 does not.

The collective dose for the RS-G-1.7 dose option is twice that of the 1 mrem/year dose option because the amount of activity anticipated to be released for this dose option is approximately twice that of the 1 mrem/year dose option, as shown in Table 3-11 (see Appendix D, Section 11).

Table 3-11 Unrestricted Release Alternative - General Public Mean Collective Dose Results (person-rem)[1]

Solid Material	Dose Option				
	0.03 mrem/yr	0.1 mrem/yr	1 mrem/yr	10 mrem/yr	RS-G-1.7
Unrestricted Release/ Material Specific					
Ferrous Metal	205	881	6,380	28,400	NA
Concrete	3	7	24	28	NA
Trash	<1	<1	<1	2	NA
TOTAL	208	887	6,404	28,430	NA
Unrestricted Release/Material Independent[2]					
Ferrous Metal	19	107	1,660	9,650	3,320
Concrete	3	7	24	28	48
Trash	<1	<1	<1	<1	<1
TOTAL	22	114	1,684	9,680	3,370

[1] Source: SC&A 2003, Table 10.8.
[2] For RS-G-1.7 results, see Appendix D, Section 11 of this report.

Inventory information on other metals, besides ferrous metal, indicated these were primarily copper or aluminum, and present in insignificant amounts as compared to ferrous metals. NUREG-1640 considers dose factors for both copper and aluminum for individual dose estimating purposes. However, regarding collective dose, the results were developed for ferrous metal and the small amounts of copper and aluminum inventory were evaluated using a screening analysis for the collective dose associated with the unrestricted release (recycling) of aluminum and copper generated from licensed facilities. A detailed collective dose assessment was not performed for aluminum and copper because of the small amount of these materials generated as compared to ferrous metal. The results indicate that collective doses for copper and aluminum are about one to two orders of magnitude lower than that of ferrous metal for all alternatives.

Table 3-10 describes the mean collective dose values to the General Public associated with the reuse of both large and small pieces of equipment for the Alternatives. The collective dose associated with equipment reuse for the Unrestricted Use Alternative is 61 person-rem.

3.2.4.2.3 EPA/State-Regulated Disposal Alternative

The collective dose to the Non-Licensed Facility Workers and the General Public for the EPA/State-Regulated Disposal Alternative is estimated for two scenarios, one assuming that the trash generated from licensed facilities is disposed of in EPA/State-Regulated landfills and one assuming that the trash generated from licensed facilities is disposed of in an EPA/State-Regulated incinerator, with subsequent disposal of the incinerator ash in an EPA/State-Regulated landfill. Concrete and metal solid materials are assumed not to be incinerated. Table 3-12 provides a summary of collective dose to Non-Licensed Facility Workers and the General Public for the EPA/State-Regulated Disposal Alternative for the trash landfill disposal and trash incineration disposal scenarios. The total collective dose for the EPA/State-Regulated Disposal Alternative without trash incineration ranges from 0.11 person-rem (0.0011 person-sievert) for

Table 3-12 EPA/State Regulated Disposal Alternative - General Public Mean Collective Dose Results (person-rem)

Solid Material	Dose Option				
	0.03 mrem/yr	0.1 mrem/yr	1 mrem/yr	10 mrem/yr	RS-G-1.7
EPA/State-Regulated Landfill					
Ferrous Metal	<1	<1	1	5	NA
Concrete	<1	<1	<1	<1	NA
Trash	0	<1	<1	2	NA
TOTAL	<1	<1	2	6	NA
EPA/State-Regulated Landfill with Trash Incineration					
Ferrous Metal	<1	<1	1	5	3
Concrete	<1	<1	<1	<1	<1
Trash	16	70	1,010	14,400	2,020
TOTAL	16	70	1,011	14,405	2,023

Source: SC&A 2003, Table 10.8.

the 0.03 mrem/year dose option to 6 person-rem (0.06 person-sievert) for the 10 mrem/year dose option. For the EPA/State-Regulated Disposal Alternative with trash incineration the total collective dose ranges from 16 person-rem (0.16 person-sievert) for the 0.03 mrem/year dose option to 14,400 person-rem (144 person-sievert) for the 10 mrem/year dose option. The collective dose assessment for trash for Non-Licensed Facility Workers and the General Public accounts for work activities involving truck drivers hauling trash, trash disposal in a landfill, trash incineration and ash disposal in a landfill, and a crane operator loading trash into an incinerator. Doses to offsite receptors consider the impacts associated with effluent discharges from landfill and incinerator operations. The collective dose associated with trash incineration is dominated by exposure of the General Public to airborne effluents.

The collective dose results in Table 3-12 are material specific. SC&A 2003 does not provide dose results for landfills evaluated for the material-independent case. It should be noted that such doses will be lower still than that shown for the material-specific case. This is because the material-independent case is based on the most limiting dose factors and corresponding lower release levels. Lower release levels yield lower collective doses.

The use of incineration at solid waste landfills has declined over the past decade (EPA, personal communication). In 2001, about 15 percent of all solid waste was incinerated, about 30 percent was recycled or composted, and the rest is sent to landfills. In the past, there was more emphasis on incineration when it was thought that landfill capacity would become scarce and expensive, but those concerns have not been borne out. In the near term, it seems likely that the percentage of waste incinerated will decline further. (See www.epa.gov/epaoswer/non-hw/muncpl/facts.htm for some basic information on solid waste.) However, even if all the trash is assumed to be incinerated, at the 1 mrem/yr dose option the collective dose is still less than for the No Action Alternative.

It is common practice for landfills to monitor incoming waste shipments for the presence of radioactivity. The radiation monitoring systems typically are installed at the scales where trucks are weighed before being sent to specific waste processing areas. The alarm set-points are set at varying levels, typically set at a multiple of ambient background levels. If a waste shipment were to set off an alarm, the shipment is set aside and the originator of the shipment is informed of the situation. Depending on operational procedures, landfill operators call the State agency responsible for radiation protection for guidance on how to proceed. In both cases, the originator of the shipment, at a minimum, is called upon to identify the type and quantities of radioactive materials present in the waste shipment, and demonstrate that the shipment complies with existing NRC or Agreement State regulations. In other instances, landfill operators do not accept any type of radioactive materials and the shipments are refused and returned to the originator.

Appendix J contains a discussion of RCRA facilities, including regulatory requirements, siting criteria, engineering design features, monitoring requirements, and exposure pathways. The evaluation of different RCRA Subtitle D landfills and their ability to affect environmental impacts supports the collective dose analysis. For municipal solid waste landfills the most important landfill parameters that affect the amount of radioactivity released are infiltration, waste thickness, and distribution coefficients (K_d).

3.2.4.2.4 Low-Level Waste Disposal Alternative

The only Non-Licensed Facility Workers that are associated with the LLW Disposal Alternative are truck drivers transporting the material to LLW disposal facilities. For the purposes of this analysis NRC has assumed that all of the potentially clearable material released from licensed facilities and transported to LLW disposal facilities under the LLW Disposal Alternative would be transported to the Envirocare facility in Utah. This is a reasonable assumption because little of the solid material would be eligible for disposal at the Barnwell and Hanford sites (Section 2.4.4). Also, this assumption would bound the analysis. Exposure time to truck drivers transporting the materials to the Envirocare facility under the LLW Disposal Alternative would be approximately a factor of eight higher than the exposure time for transport under the No Action and Unrestricted Release Alternatives, as calculated based on the vehicle miles traveled shown in Table 3-15. However, exposure time to truck drivers transporting the materials to the Envirocare facility would also depend on the curies transported to LLW disposal facilities. Under the No Action Alternative, 2,947 of a possible 2,951 curies of activity would be transported to LLW disposal facilities (Table 3-4). As shown in Tables 3-4 and 3-5, the collective dose to workers at LLW disposal facilities does not vary significantly among the alternatives and dose options.

Potential exposures for the General Public (which includes Non-Licensed Facility Workers) from the operation of LLW disposal facilities has been analyzed in the Final Environmental Impact Statement for 10 CFR Part 61 and in environmental reviews for licensing of existing LLW disposal facilities. The potential types of exposure mechanisms associated with the disposal of solid materials in LLW disposal facilities are similar to those for disposal in EPA/State-regulated landfills. Since materials that have been released have properties that are more like those found in the lower-most range of Class A wastes, it follows that potentially clearable materials can be safely disposed of in LLW sites without any further impacts to the public and environment. This aspect was addressed by comparing typical radioactive inventories of waste accepted by LLW disposal sites against that associated with releases (SC&A 2003, Section 8.1). A review of the data indicates that total receipts of radioactivity sent for disposal from 1986 to 2002 are about 9,300 curies, and 2 and 6.2 million curies at the Envirocare, Richland, and Barnwell disposal sites, respectively. These activity levels represent total curies without the contribution from H-3 and C-14, since these radionuclides contribute only minimally to exposures and doses. A review of the results presented earlier indicates that such inventories of radioactivity are lower by orders of magnitude. This comparison indicates that if LLW sites are authorized to receive several hundred thousands curies and be in compliance with Part 61 regulations, the small incremental amounts of radioactivity associated with potentially clearable materials will not adversely impact the site, nor compromise the health and safety of the public and workers. Therefore, no assessment of General Public or Non-Licensed Facility Worker collective dose is included in this Draft GEIS for the LLW Disposal Alternative.

3.2.4.2.5 Limited Dispositions Alternative

The Limited Dispositions Alternative involves different disposition pathways for different solid materials generated from licensed facilities. Tools and equipment released from licensed facilities could be reused in other locations. Recycling of concrete released from licensed facilities would be limited to recycling as road bed. Ferrous metals and trash released from licensed facilities would be limited to EPA/State-regulated disposal. Other dispositions could be approved on a case-by-case determination by NRC. The collective dose to Non-Licensed Facility Workers and the General Public resulting from the Limited Dispositions Alternative is anticipated to be similar to that for the Unrestricted Release Alternative for concrete and similar to that for the EPA/State-Regulated Disposal Alternative for other materials for ferrous metals and trash.

The collective dose for concrete under the Limited Dispositions Alternative would be similar to the Unrestricted Release Alternative, for which the collective dose assessment is based on concrete reuse as road bed (see Table 3-11). The collective dose for ferrous metals and trash would be similar to the EPA/State-Regulated Disposal Alternative (Table 3-12). The collective dose for reuse of tools and equipment would be similar to the Unrestricted Release Alternative.

The collective dose to the General Public associated with the Limited Dispositions Alternative is the sum of the following collective doses using the IAEA Safety Guide:

- concrete use in roadbeds (48 person-rem (0.48 person-sievert)) (Table 3-11);
- disposal of ferrous metal and trash in EPA/State-regulated disposal facilities (3 person-rem (0.03 person-sievert)) (Table 3-12); and
- reuse of tools and equipment (61 person-rem (0.61 person-sievert)) (Table 3-10).

3.2.4.2.6 Summary of Collective Doses for Non-Licensed Facility Workers and the General Public

Table 3-13 presents a summary of the collective doses to the General Public and Non-Licensed Facility Workers for the No Action, Unrestricted Use, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives. This table is based on Tables 3-9 to 3-12 of this report. Results for the LLW Disposal Alternative are expected to be small (Section 3.2.4.2.4). For comparison purposes, the collective doses for the Unrestricted Release Alternative are material-independent and presented for the 1 mrem/yr dose option using the IAEA Safety Guide to be comparable to the Limited Dispositions Alternative. These collective dose results are for potentially clearable solid materials released from commercial nuclear reactor facilities.

Table 3-13 Summary of Non-Licensed Facility Workers and General Public Collective Dose Results (person-rem)

Alternative	Collective Dose				
	Concrete	Ferrous metal	Trash	Equipment Reuse	Total
No Action	4	3,920	<1	72	3,996
Unrestricted Use	48	3,320	<1	61	3,429
EPA/State-Regulated Disposal without Trash Incineration	<1	1	<1	0	2
EPA/State-Regulated Disposal with Trash Incineration	<1	1	1,010	0	1,011
Limited Dispositions	48	3	<1	61	112

3.2.5 Collective Dose from Materials Generated from Licensed Facilities Other Than Reactors

The collective dose values reported above include only solid materials generated from commercial nuclear reactor licensees. These materials constitute the majority of the mass, activity, and collective dose associated with material generated from licensed facilities. The other licensed facilities (which are described in Appendix F) include:

- Large medical centers: includes regional and university medical centers administering nuclear medicine.

- Fuel fabrication facilities: includes wastes generated from decontamination and decommissioning of licensed facilities that fabricate nuclear reactor fuel and daily operations (e.g., trash).

- Conversion plant: includes wastes generated from decontamination and decommissioning of licensed facilities that manufacture uranium hexafluoride.

- Non-power reactor: includes wastes generated from decontamination and decommissioning of research reactors and reactors other than commercial power reactors.

- Independent Spent Fuel Storage Installations (ISFSI): includes wastes generated from decontamination and decommissioning of ISFSI and daily operations (e.g., trash).

Other licensed facilities also generate trash from within radiation control areas during operations.

A screening analysis was conducted for materials generated from NRC-licensed facilities other than commercial reactors for the No Action and Unrestricted Release Alternatives. A screening analysis was used because the mass and activity of the reactor-generated solid materials is much greater than that of other licensed facilities. A screening analysis was not necessary for the other alternatives because the No Action and Unrestricted Release Alternatives would result in the greatest quantities of materials released. Table 3-14 summarizes the collective doses associated with solid materials released from NRC licensees other than commercial nuclear reactor facilities for the No Action and Unrestricted Release Alternatives.

Table 3-14 Summary of Collective Dose Scoping Calculations for Solid Materials Generated from Licensees other than Commercial Nuclear Reactors (person-rem)

Alternative	Large Medical Centers (person-rem)	Fuel Fab.	Conv. Plant	Non-power Reactor	ISFSI	Total Non- Reactor	Trash Generated from Other Licensees
No Action	6	<1	<1	<1	<1	6	<1
Unrestricted Release							
10 mrem/yr	1,020	4	1	2	38	1,066	<1
1 mrem/yr	71	<1	<1	<1	4	76	<1
0.1 mrem/yr	4	<1	<1	<1	<1	5	<1
0.03 mrem/yr	1	<1	<1	<1	<1	1	<1

Source: SC&A 2003, Table 5.31, and Tables 3-9 and 3-11 of this report.

The collective dose associated with release of materials from large medical centers was estimated for the No Action Alternative and for all the dose options under the Unrestricted Release Alternative. The dose is attributed to tritium and carbon-14, which are the major long-lived radionuclides contributing to the collective dose. Short-lived radionuclides used in routine nuclear diagnostic tests (Tc-99m) and therapy (I-131) are not considered since current practices manage these radionuclides using radioactive decay. The material associated with routine releases are assumed to consist of miscellaneous glass and plastic wares, absorbent pads, protective clothing, trays and racks, disposable equipment, and some parts of experimental apparatus, such as sampling and dispensing devices, fluid path tubing, pumps, filters, etc. It should be noted that waste volumes could be higher in a few instances, such as when gutting a room during facility refurbishment or after spills. However, in such instances, all materials would be disposed as LLW. Collective doses vary from about 1 to 1,000 person-rem (0.011 to 10 person-sievert) over all dose options and for the duration of the Proposed Action (46 years).

For the No Action Alternative, the collective dose is estimated to be nearly 6 person-rem (0.06 person-sievert). At 1 mrem/yr the collective dose for materials generated from licensees other than commercial reactor facilities is less than 5 percent of the collective dose associated with materials generated from commercial reactors for the Unrestricted Release Alternative.

The collective dose associated with materials generated from commercial reactor facilities, including concrete, ferrous metal, and trash for the Unrestricted Release Alternative is approximately 3,400 person-rem (34 person-sievert) for the 1 mrem/year dose option using the IAEA standard (IAEA 2004) (Table 3-11).

Unlike the detailed inventory information available for power reactors, and their very detailed analysis, the other licensed facilities inventory information was much more limited. Because the preponderance of contribution to the collective dose comes from the power reactor industry, and only a small percentage comes from the rest of the licensees, a screening analysis for bounding the collective dose contribution associated with these other facilities was considered appropriate. Consequently, the level of detail presented for collective dose breakouts in terms of contributions from concrete, ferrous metal, trash, etc. was not developed to the same degree as for the more detailed analysis of commercial nuclear power reactors. However, more details about inventory (type of material, amount, and curie content) for these licensed facilities is available from Appendix F. The trash volume is based on a total from all different categories of facilities, and its method of estimation is presented in Chapter 4 of the collective dose report (SC&A 2003), which is summarized in Appendix D.

3.2.6 Summary of Collective Doses

The human health and safety impacts are measured in this Draft GEIS in terms of collective dose. Table 3-8 summarizes the predicted collective doses for Licensed Facility Workers and Table 3-13 for Non-Licensed Facility Workers and the General Public. All of these doses are small when compared to the background collective dose to the U.S. population due to natural sources of radiation and radioactivity (Appendix E).

3.3 TRANSPORTATION

The affected environment and environmental consequences related to transportation of solid materials released from licensed facilities are related to:

- Radiation doses to Workers at Non-Licensed Facilities and to the General Public, as associated with the routine transportation of solid materials by truck; and

- Potential non-radiological consequences to Workers at Non-Licensed Facilities and to the General Public, as related to truck and rail transportation accidents as obtained from statistical highway and rail data.

Truck drivers transporting materials generated from licensed facilities are categorized as Workers at Non-licensed Facilities for the purposes of the Draft GEIS. Radiation dose to truck drivers is included in the collective dose assessment for Non Licensed-Facility Workers and the General

Public, as discussed in Section 3.2, and is not further discussed in this section. In addition, the radiological impacts from the transport of all licensed radioactive material has been generically evaluated in NUREG-0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (NRC 1977). This analysis considered radiation exposure of transport workers and members of the General Public along transportation routes from both normal transportation and accidents. Based on this analysis, radiological transportation impacts are expected to be small for all alternatives. As a result, only non-radiological impacts from transportation accidents are discussed below.

3.3.1 Affected Environment

The affected environment associated with non routine occurrences (transportation accidents) involving truck and rail transportation of solid materials are Workers at Non-Licensed Facilities (truck drivers and railroad workers) and the General Public (persons along a route) potentially affected by injuries or fatalities resulting from transportation accidents involving trucks or railcars. Such injuries or fatalities would be the result of accidents during transport (e.g., truck collisions, railcar derailments). The affected environment with respect to the General Public includes transportation routes throughout the United States. The locations of the licensed facilities that would generate solid materials affected by the Proposed Action are known; however, the specific transportation routes that would be used in transporting solid materials from licensed facilities to recycling facilities and disposal facilities cannot be fully determined. The affected environment therefore cannot be associated with specific transportation routes.

The affected environment for transportation is generally similar for all Alternatives except workers at Non-Licensed Facilities for the LLW Disposal Alternative would include both truck drivers and railroad workers. Transportation routes in the vicinity of recycling facilities would be primarily affected under the No Action and Unrestricted Release Alternatives. Transportation routes in the vicinity of EPA/State-regulated disposal facilities would be primarily affected under the EPA/State-Regulated Disposal Alternative. Transportation routes in the vicinity of LLW disposal facilities would be affected under the LLW Disposal Alternative. The Limited Dispositions Alternative would involve both recycling concrete and EPA/State-regulated disposal of solid material and would therefore affect transportation routes in the vicinity of both recycling and EPA/State-regulated disposal facilities.

3.3.2 Transportation Requirements

Transportation safety addresses the performance of rail or motor carriers, trucks or rail cars, and drivers or crews, and is often measured through accident rates. The Federal Motor Carrier Safety Administration and Federal Railroad Administration each enforce comprehensive safety standards and monitor carrier operations. Rail shipments involve compliance with regulations for track quality and condition, signal and control systems, freight car standards, operating practices, inspections, crew qualifications, etc.

Intrastate, interstate, and international shipments of hazardous materials (including hazardous wastes) by any mode of transport are covered by federal and international laws. These laws cover:

Proper identification and classification of hazardous materials;

- Required hazard communications, such as shipping papers, markings, labels, and placards; and
- Material-specific packaging requirements.

Transport of LLW is subject to all of the hazardous materials requirements above, and the U.S. Department of Transportation (DOT) (in consultation with NRC) establishes the applicable packaging standards. The disposal of LLW is conducted in accordance with the specific waste acceptance criteria of the recipient disposal site and Federal regulations. These requirements are addressed in NRC regulations in 10 CFR Part 61. The requirements of 10 CFR Part 61 are complemented with Subpart K (waste disposal) and Appendix G (shipping) to 10 CFR Part 20 and DOT regulations for radioactive materials in Subpart I to 49 CFR Part 173. Among others, the criteria address radiological and non-radiological profiles of waste, containerization and package labeling, shipping requirements, and use of shipping manifests. There are also RCRA exclusions that are applicable to the transportation of recycled scrap metal, which can relieve some of the requirements for packaging, shipping papers, marking, labeling, placarding, etc. for such materials. However, since the proposed release levels for the Limited Dispositions Alternative are less than or equal to the DOT activity concentrations for exempt material under 49 CFR Part 173.436, the solid materials are not regulated as radioactive material while in transport.

3.3.3 Environmental Consequences

This section describes the potential non-radiological environmental consequences to Workers at Non-Licensed Facilities and the General Public from potential transportation accidents associated with solid materials released from licensed facilities. In the transportation accident analysis in this section, for transportation by truck, the analysis is based on the total vehicle miles traveled for each Alternative. For transportation by rail, in the main analysis, railcar miles are assumed only for the LLW Disposal Alternative; however, a sensitivity study assumed that for all the alternatives the material would be shipped to LLW facilities by rail (Section 4.6). National accident rates for truck and rail transportation are applied to the total miles traveled. The national accident rates are independent of the material being transported. That is, the railcar accident rate, in units of the number of accidents per billion railcar miles traveled, applies equally to railcars containing solid materials released from licensed facilities and railcars containing salt, grain, or other materials.

The environmental consequences associated with non-routine occurrences (i.e., transportation accidents) do not include collective dose to Non-Licensed Facility Workers and the General Public. As discussed in Section 3.2, the collective dose to truck drivers for routine transportation of solid materials is included as part of the collective dose assessment. It is anticipated that any individual truck driver would experience no more than a single transportation accident and would therefore be exposed to no more than one incident of exposure. In addition, it should be pointed out that the occurrence of an accident does not necessarily result in an additional exposure. Any additional incremental exposure that did occur would not significantly increase the collective dose to Non Licensed Facility Workers and the General Public. Therefore, no collective dose assessment for potential radiation exposures related to transportation accidents is included in the Draft GEIS.

Table 3-15 summarizes the transportation characteristics for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and LLW Disposal Alternatives under the bounding dose options. The table shows the total amount of material that would be transported under each Alternative (SC&A 2003, Tables 10.3 and 10.7) as well as the total truck or rail car miles traveled. These distances are based on the distances between current nuclear power plants and recycling and disposal facilities (SC&A 2003, Table 9-62 and page K-25 of this report). The distances for non-reactors are assumed to be the same. Based on the assumed capacity of the trucks (25 tons), the number of miles trucks would needed to transport material to recycling or disposal facilities was calculated (Appendix K).

Table 3-15 Solid Materials Transported Under Alternatives

Solid Material	No Action		Unrestricted Release 10 mrem/yr dose option		Unrestricted Release 0.03 mrem/yr dose option	
	Tons	Vehicle Miles Traveled	Tons	Vehicle Miles Traveled	Tons	Vehicle Miles Traveled
Ferrous metal	2,059,800	22,163,448	2,450,961	26,372, 340	970,286	10,440,278
Concrete	16,213,364	128,409,843	19,772,249	156,596,212	15,038,234	119,102,813
Trash	20,408	326,528	66,102	1,057,632	13,643	218,288
Aluminum	173	1,861	211	2,270	192	2,066
Copper	5,362	57,695	6,539	70,360	4,255	45,784
Total Released	18,299,107	150,959,375	22,296,062	184,098,814	16,026,610	129,809,228
Total to LLW Disposal	4,406,964	272,174,097	410,009	25,322,156	6,679,461	412,523,511
TOTAL	**22,706,071**	**423,133,472**	**22,706,071**	**209,420,970**	**22,706,071**	**542,332,740**

Solid Material	EPA/State-Regulated Disposal 10 mrem/yr dose option		EPA/State-Regulated Disposal 0.03 mrem/yr dose option		LLW Disposal	
	Tons	Vehicle Miles Traveled	Tons	Vehicle Miles Traveled	Tons	Miles Traveled
Ferrous metal	2,480,000	5,753,600	1,570,000	3,642,400	2,498,911	19,791,375
Concrete	19,800,000	45,936,000	15,600,000	36,192,000	19,877,341	157,428,541
Trash	66,000	1,056,000	14,000	224,000	323,023	2,558,342
Aluminum	211	490	192	445	212	1,679
Copper	6,369	14,776	4,255	9,872	6,584	52,145
Total Released	22,352,580	52,760,866	17,188,447	40,068,717	22,706,071	-
Total to LLW Disposal	353,491	21,831,604	5,517,624	340,768,458	22,706,071	**318,710,669 by rail 1,402,326,945 by truck**
TOTAL	**22,706,071**	**74,592,470**	**22,706,071**	**380,837,175**	**22,706,071**	

Source: Materials tonnage based on SC&A 2003, Tables 4.7, 10.2 and 10.3.

The amount of potentially clearable solid material varies among the Alternatives, depending on (1) dose limits and (2) whether the material is transported to recycling facilities, EPA/State-regulated disposal facilities, or LLW disposal facilities. Separate quantitative analyses are provided for the 10 mrem/year dose option and the 0.03 mrem/year dose option for the Unrestricted Release and the EPA/State-Regulated Disposal Alternatives as lower and upper bounds for all the dose options. Note that some solid material is transported to LLW disposal facilities under each of the Alternatives. Only a single analysis is provided for the No Action Alternative and the LLW Disposal Alternative because there are no dose options for these Alternatives.

The fatal accident rate for large truck transportation is 3.2E-09 fatalities per vehicle mile traveled for truck occupants (Non-Licensed Facility Workers), and 2.0E-08 fatalities per vehicle mile for the occupants of other vehicles involved in an accident or for pedestrians (the General Public) as obtained from statistical highway data (FMCSA 2004). The accident rate for rail transportation is generally presented as an accident rate per train mile, or a combination of accident rates based on both train miles and rail car miles depending on the accident cause. In this instance an overall rate per rail car mile is desired as it is not known how many rail cars might be shipped per train.

Based on Federal Railroad Administration (FRA 2004) statistics, the accident rate for the crew (Non-Licensed Facility Workers) is 7.6E-10 fatalities per rail car mile traveled, and the rate for occupants of other vehicles and pedestrians (the General Public) is 2.0E-08 fatalities per rail car mile traveled.

Table 3-16 provides a summary of predicted transportation fatalities for each of the Alternatives over the period of the impacts (about 50 years). As shown, the fewest number of transportation accident fatalities, roughly 2 total fatalities for Non-Licensed Facility Workers and the General Public, is associated with the 1 mrem/year dose option under the EPA/State-Regulated Disposal Alternative. This result is because the largest amount of solid materials are transported the shortest distance under this Alternative and dose option. The highest number of transportation accident fatalities, approximately 32 fatalities, is associated with the LLW Disposal Alternative assuming truck transportation. This Alternative involves the highest vehicle miles traveled. For the LLW Disposal Alternative assuming rail transportation the number of transportation accidents is approximately 7. By comparison, there are approximately 10 fatalities from transportation accidents estimated for the No Action Alternative. For the Limited Dispositions Alternative, there are approximately 9 transportation fatalities.

3.3.3.1 No Action Alternative

The No Action Alternative is predicted to result in 1.4 fatalities for truck drivers (Non-Licensed Facility Workers) and 8.5 fatalities for the General Public over the time period of the Proposed Action.

Table 3-16 Summary of Transportation Impacts (Accident Fatalities) for Alternatives (Vehicle Miles are for Trucks, unless indicated)

Alternative	Dose Option (mrem/year)	Vehicle Miles Traveled	Fatalities NLFW[a]	Fatalities GP[b]	Total
No Action	not applicable	423,133,472	1.4	8.5	9.9
Unrestricted Release	10	209,420,970	0.7	4.2	4.9
	1	230,120,298	0.8	4.6	5.3
	0.03	542,332,740	1.7	10.9	12.6
EPA/State-Regulated Disposal	10	74,592,470	0.2	1.5	1.7
	1	87,624,470	0.3	1.8	2.1
	0.03	380,837,175	1.2	7.6	8.8
LLW Disposal	not applicable	1,402,326,945 (truck)	4.5	28	32.5
		318,710,669 (rail)	0.2	6.4	6.6
Limited Dispositions	RS-G-1.7	405,493,883	1.3	8.1	9.4

a - NLFW = Non-Licensed Facility Workers b - General Public

3.3.3.2 Unrestricted Release Alternative

The 10 mrem/yr and the 0.03 mrem/yr dose options provide a lower bound and upper bound for the vehicle miles traveled and number of transportation fatalities for the 1 mrem/year, 0.1 mrem/year, and RS-G-1.7 dose options. The fatalities to Non-Licensed Facility Workers are predicted to fall between 1 and 2 over the period of the Proposed Action, while for the General Public the range is 4 to 11 over the same period.

3.3.3.3 EPA/State-Regulated Disposal Alternative

The 10 mrem/year and the 0.03 mrem/yr dose options provide a lower bound and upper bound for the vehicle miles traveled and number of transportation fatalities for the 1 mrem/year, 0.1 mrem/year, and RS-G-1.7 dose options. The fatalities to Non-Licensed Facility Workers are predicted to fall between 0 and 1 over the period of the Proposed Action, while for the General Public the range is 2 to 8 over the same period.

3.3.3.4 Low-Level Waste Disposal Alternative

Transportation of solid material under the LLW Disposal Alternative could be conducted by truck, rail, or a combination of the two. The analyses in Table 3-16 are based on all of the solid material being transported either by rail or all of the solid material being transported by truck. Depending on the actual mix of rail and truck, the fatalities predicted would be expected to fall between 0 and 5 for Non-Licensed Facility Workers and between 6 and 28 for the General Public over the period of the Proposed Action.

3.3.3.5 Limited Dispositions Alternative

It is assumed that transportation impacts associated with reuse of tools and equipment are negligible. The fatalities are predicted to be 1 for Non-Licensed Facility Workers and 8 for the General Public over the period of the Proposed Action (about 50 years). NRC could allow solid material (e.g., metal) generated by a particular licensed facility to be recycled as a case-specific approval. Trash is not anticipated to be recycled. For these specific cases, the total amount of material that would be transported to recycling facilities and transported to disposal facilities under the Limited Dispositions Alternative and the associated vehicle miles traveled cannot be estimated. However, the case-by-case approval of a licensee's application would include an environmental review.

3.3.4 Summary of Transportation Impacts

Transportation impacts are measured in this Draft GEIS in terms of fatal vehicle accidents and railcar incidents (e.g., derailments). Table 3-16 summarizes the predicted transportation fatalities for each of the alternatives. The Unrestricted Release, EPA/State-Regulated Disposal and Limited Dispositions alternatives have similar impacts compared to the No Action Alternative, and the transportation impacts associated with these Alternatives are small. However, the LLW Disposal Alternative assuming truck transportation has a higher number of transportation accident fatalities because this alternative involves the highest vehicle miles traveled. Thus, the transportation impacts associated with the LLW Disposal Alternative are small to moderate, depending on whether transportation is by rail or truck.

3.4 WATER RESOURCES

This section discusses the potential incremental exposures associated with non-radionuclide releases to surface water, ground water, and drinking water. Supplemental detailed information is in Appendix H. The potential radiological impacts in terms of collective dose associated with discharges to surface water, ground water, and drinking water are addressed in Section 3.2.

The significance of any exposure consequences depends on the presence, identity, and level of contaminants in the materials released from licensed facilities, and the ability of those contaminants to migrate to the waters which contact those materials. This section limits the discussion of the affected environment to populations potentially exposed to waterborne constituents, and does not address secondary paths involving waterborne constituents which transfer to other media, such as by adsorption onto soil particles, dispersion as airborne particulate matter, or conversion to a gaseous state. These secondary pathways are considered to have negligible exposure consequences. Inhalation pathways are specifically excluded from this section and covered in Section 3.5. Impacts from stormwater runoff along transportation routes are considered to be insignificant for all the Alternatives, and therefore are excluded from this discussion. The analysis begins at the point following release of the material, and does not address wastewater from decontamination activities. Potential exposure of decontamination workers to nonradiological constituents of wastewater is considered to be a negligible exposure pathway.

The incremental quantities of secondary aluminum and secondary copper under all the Alternatives will have negligible non-radiological impacts on water resources, and are excluded from further discussion in this section. The quantity of aluminum generated from commercial nuclear reactor facilities under the Proposed Action is less than 212 tons. The incremental impacts of this amount of aluminum, compared to the 1.1 million metric tons (USGS 2004) of secondary aluminum produced from old scrap in 2003, are negligible. The quantity of copper generated from commercial nuclear reactor facilities under the Proposed Action is less than 6,600 tons over the period of the Proposed Action. The annual release would be less than 700 tons per year. The incremental impacts of this amount of copper, compared to the 210,000 metric tons (USGS, 2004b) of secondary copper produced from old scrap in 2003, are negligible.

3.4.1 Regulatory Framework

The NRC recognizes, in 10 CFR 51.10(c), " ... that responsibility for Federal regulation of nonradiological pollutant discharges into receiving waters [from Licensed Facilities] rests by statute with the Environmental Protection Agency."

Surface Water

The National Pollutant Discharge Elimination System (NPDES) (40 CFR Part 122) requires permits for the discharge of pollutants from any point source into waters of the United States under authority of the Clean Water Act. The requirements for discharge permits cover, among other activities, process wastewater discharges and industrial stormwater discharges (including construction activities). Ground water generally does not meet the definition of a water of the United States and is not subject to NPDES requirements.

NPDES sets two types of discharge criteria: technology-based limits (based on the ability of dischargers in the same industrial category to treat wastewater) and water quality-based limits (if technology-based limits are not sufficient to provide protection of the water body). The effluent limits and conditions in an individual NPDES permit are unique to the permittee.

NPDES regulations apply to the discharge of industrial process water, wastewater and stormwater. The stormwater regulations define 11 industrial categories. For all the Alternatives, applicable industrial categories and the relevant covered industries or activities appear in Table 3-17.

Subtitle D of the Resource Conservation and Recovery Act (RCRA) of 1976 (42 USC 82, Subchapter IV) authorized regulation of State or regional solid waste plans. RCRA Subtitle D covers solid wastes, including hazardous wastes specifically excluded from RCRA Subtitle C. The promulgated solid waste regulations appear in 40 CFR Part 239 to 282, with Part 257 (Criteria For Classification Of Solid Waste Disposal Facilities And Practices) and Part 258 (Criteria For Municipal Solid Waste Landfills) specifying the siting, design, operational,

Table 3-17 NPDES Storm Water Discharges Associated with Relevant Industrial Activities

NPDES Industrial Category	Relevant Covered Industries or Activities
Category (I), 40 CFR Subchapter N	40 CFR 411 Cement manufacturing 40 CFR 420 Iron and steel manufacturing 40 CFR 421 Nonferrous metal manufacturing 40 CFR 433 Metal finishing 40 CFR 443 Paving and roofing materials 40 CFR 464 Metal molding and casting 40 CFR 467 Aluminum forming 40 CFR 468 Copper forming
Category (ii)	SIC Code 33 Primary metal industry SIC Code 3441 Fabricated structural steel SIC Code 373 Ship and boat building and repair
Category (iv) Hazardous waste	Subtitle C Hazardous waste disposal facilities
Category (v) Landfills	Industrial waste landfills Subtitle D landfills receiving industrial waste
Category (vi) Recycling Facilities	Metal scrap yards Salvage yards
Category (ix) Treatment Works	Domestic or municipal sewage treatment works or wastewater treatment system
Category (x) Construction	Clearing, grading, and excavation
Category (xi) Light Industry	SIC Code 34 Fabricated metal products SIC Code 35 Industrial machinery and equipment SIC Code 36 Electronic and other electric equipment SIC Code 37 Transportation equipment (except 373) SIC Code 38 Instruments and related products SIC Code 39 Miscellaneous manufacturing

Source: 40 CFR Part 122.

monitoring, and closure requirements. Subtitle D landfills that receive or have received any industrial waste from facilities requiring an NPDES discharge permit are themselves required to have an NPDES discharge permit. Subtitle D landfills have additional restrictions on run-on and run-off control, discharges to surface water bodies, and contamination of ground water.

The EPA regulations pertaining to incineration, 40 CFR Part 60 (Standards of Performance for New Stationary Sources), deal primarily with air emissions. 40 CFR Part 240 (Guidelines for the Thermal Processing of Solid Wastes), Section 240.204-1 additionally requires that all waters discharged by a solid waste thermal processing facility "shall be sufficiently treated to meet the most stringent of applicable water quality standards, established in accordance with or effective under the provisions of the Federal Water Pollution Control Act, as amended."

Ground Water

Federal laws provide for ground-water protection primarily by regulating potential sources of ground-water contamination. EPA oversees ground-water protection activities authorized by the laws listed in Table 3-18, but actual implementation and enforcement normally resides with individual States. All 50 States have some form of ground-water protection program.

Table 3-18 Federal Ground-water Protection Laws

Federal Laws	Summary Description
Safe Drinking Water Act	authorizes maximum contaminant levels in drinking water, regulates deep well disposal of wastes, designates single aquifer water supply areas, and encourages development of State wellhead protection programs
Resource Conservation and Recovery Act	regulates the storage, transportation, treatment, and disposal of solid and hazardous wastes to prevent contaminants from leaching into ground water from municipal landfills, underground storage tanks, surface impoundments, and hazardous waste disposal facilities
Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)	authorizes government clean up of contamination caused by chemical spills or hazardous waste sites that do or could pose threats to the environment
Federal Insecticide, Fungicide, and Rodenticide Act	controls the availability of pesticides that can leach into ground water
Toxic Substances Control Act	controls the manufacture, use, storage, distribution, or disposal of toxic chemicals that can leach into ground water
Clean Water Act	helps States develop ground-water protection strategies

NRC regulations for disposal facility performance objectives (10 CFR 61.41) address only radiological discharge restrictions. However, 10 CFR 51.10(c) states "In accordance with section 511(c)(2) of the Federal Water Pollution Control Act (86 Stat. 893, 33 U.S.C 1371(c)(2)) the NRC recognizes that responsibility for Federal regulation of nonradiological pollutant discharges into receiving waters rests by statute with the Environmental Protection Agency."

Drinking Water

The Safe Drinking Water Act regulates all public water supplies, defined as water systems with at least 15 service connections or regularly serving at least 25 persons. Under the National Primary Drinking Water regulations, 40 CFR Part 141, the EPA has set Maximum Contaminant Levels (MCLs) applicable to public water systems for organic chemicals, inorganic chemicals, radioactivity, turbidity, microbiological contaminants, and disinfection byproducts. EPA has also developed non-enforceable National Secondary Drinking Water Standards to regulate contaminants that may cause cosmetic or aesthetic effects in drinking water.

3.4.2 Affected Environment

Many of the activities associated with the generation, handling, processing, end use, and disposal of solid materials are common to two or more of the Alternatives. Under every Alternative, material handling, stockpiling and loading is expected to occur at the Licensed Facility; transportation of the material will occur; and some fraction of the material streams may be sent for direct disposal in LLW Disposal Facilities. Other activities only occur under some Alternatives. Table 3-19 indicates which activities occur under each Alternative.

Table 3-19 Water Resources Affected Environment for Alternatives

Activity	Alternatives Under Which Activity Occurs				
	No Action	Unrestricted Release	EPA/State -Regulated Disposal	Low-Level Waste Disposal	Limited Dispositions
Material handling, stockpiling, and loading at Licensee Facility	X	X	X	X	X
Material unloading, handling, stockpiling, and loading at recycling facility	X	X			X
Transportation	X	X	X	X	X
Recycling processing	X	X			X
Disposition to End Use for recycled material	X	X			X
Disposal in EPA/State-Regulated Landfill	X	X	X		X
Disposal in EPA/State-Regulated Incinerator	X	X	X		X
Disposal in LLW Disposal Facility	X	X	X	X	X

The affected environment for surface water is the surface water in the U.S. Workers at Licensed Facilities and Workers at Non-Licensed Facilities may potentially be exposed to wastewater, runoff, or collected leachate either created by direct contact with the materials released from a licensed site during the generation, handling, processing, usage, or disposal of the released materials; or created by direct contact with any byproducts, end use products, or waste products derived from the released materials. The General Public and Ecological Receptors may also potentially be exposed to surface water bodies into which wastewater, runoff, or collected leachate flows or is discharged, either directly or through a ground-water pathway.

The affected environment for ground water is all ground waters in the U.S. Workers at Licensed Facilities, Workers at Non-Licensed Facilities, the General Public, and Ecological Receptors may potentially be exposed to ground water compromised by process wastewater, surface runoff, or leachate which is not retained by or escapes barrier systems and subsequently seeps into the soil. The General Public faces potential non-drinking water exposures to affected ground water through dermal contact only. Ground water has little to no ecological influence until it is extracted from a well. Ground water extracted from a well and used for agricultural or residential irrigation is not considered a significant pathway for ecological impacts.

Ground water or surface water bodies may be used as sources for drinking water. Standard monitoring and treatment of public drinking water supplies, including wells on industrial properties serving more than 25 persons, limit the risk of exposure of Workers at Licensed Facilities and Workers at Non-Licensed Facilities to elevated levels of contaminants from the Proposed Action. Ingestion of drinking water by the General Public from private ground-water wells or private surface water supplies may lead to potential exposures.

3.4.3 Environmental Consequences

Environmental consequences for Workers at Licensed Facilities and Workers at Non Licensed Facilities are limited to dermal exposure to surface water in the form of process wastewater, runoff, and collected leachate. There are not anticipated to be any significant ground-water or drinking water impacts to workers.

The General Public does not face any significant environmental consequences from any of the Alternatives related to surface water. The General Public may experience impacts from dermal exposure to ground water extracted from a private well, or ingestion of drinking water from a private ground-water well or private ground-water fed surface water body. However, such exposure is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required.

Ecological receptors only face potential environmental consequences from surface water in ground-water fed surface water bodies. Ground water extracted from a well and used for agricultural or residential irrigation is not considered a significant pathway for ecological impacts.

Water quality effects are primarily associated with point source and area source water discharges from the storage, handling, and processing of solid materials. For the No Action and Unrestricted Release Alternatives, the effects are generated mostly by runoff discharges from rubblization of concrete and runoff and process wastewater discharges from recycling of ferrous metal. The incremental quantity of these discharges would be small as compared to the overall amount of discharges generated from the total amount of concrete and ferrous metal being recycled annually in the U.S. The impact on water quality would be proportionally small. Similarly, the quantity of additional leachate and potential effects on ground water associated with disposal of solid materials under the EPA/State-Regulated Disposal Alternative and the LLW Disposal Alternative would be small compared with the overall amount of leachate being generated annually by these facilities. Therefore, the overall effects on water quality associated with all of the alternatives would be small when compared with other sources of discharges. The quantities of materials released and therefore the volumes of surface water potentially impacted will differ among the alternatives. The contaminant concentrations in impacted waters may also be higher in scenarios in which greater volumes of material are released. Table 3-20 presents a summary of the potential environmental consequences to water resources.

Table 3-20 Summary of Potential Water Resources Environmental Consequences

	Workers	General Public	Ecological Receptors
Surface Water	Dermal exposure to process water, runoff, and leachate. Mitigated by avoidance of contact and use of personal protective equipment.	Direct discharge precluded by NPDES requirements. Low probability of indirect impacts from ground-water fed surface water bodies.	Direct discharge precluded by NPDES requirements. Low probability of indirect impacts from ground-water fed surface water bodies.
Ground Water	Limited potential for contact. Mitigated by avoidance of contact and use of personal protective equipment.	Low probability of dermal impacts from private wells.	None
Drinking Water	Limited by testing of onsite drinking water wells.	Low probability of ingestion impacts from private wells or ground-water fed surface water bodies.	N/A

3.4.4 Summary of Water Resources Impacts

This section assesses non-radiological impacts to surface water, ground water and drinking water. Radiological impacts are included in the dose assessments in Section 3.2.

The impacts to surface water described in Sections 3.4.2 and 3.4.3 are expected to be small because compliance with EPA and State permits (discussed in Section 3.4.1) would preclude significant impacts from direct discharges, the low probability of the simultaneous occurrence of the combination of factors required to affect surface water chemistry through ground-water flow limits the potential for impacts from indirect discharges, and the mild acidity of the majority of lakes and ponds provides natural protection against the most likely impact, an increase in pH level.

Ground water impacts are anticipated to be small due to limited opportunities for worker exposure to ground water and the use of personal protective equipment, and due to the low probability of the simultaneous occurrence of conditions required to cause dermal impacts to the General Public from the use of water from private wells.

The General Public may experience impacts from ingestion of drinking water from a private ground-water well or private ground-water fed surface water body. However such exposure is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required.

Furthermore, the incremental quantity of predicted discharges would be small as compared to the overall amount of discharges generated from the total amount of concrete and ferrous metal being recycled annually in the U.S. Similarly, the quantity of additional leachate and potential effects on ground water associated with disposal of solid materials under the EPA/State-Regulated Disposal Alternative and the LLW Disposal Alternative would be small compared with the overall amount of leachate being generated annually by these facilities. Therefore, the overall effects on water quality associated with all of the alternatives would be small when compared with other sources of discharges.

3.5 AIR QUALITY

The affected environment and potential environmental consequences discussed in this section address non radiological air pollutants emitted from activities associated with the release, handling, processing, transportation, and disposal of potentially clearable solid materials. Supplemental detailed information is in Appendix I. The affected environment and potential impacts associated with radionuclide air emissions are included in the collective dose analysis discussed in Section 3.2.

Activities associated with the Alternatives would occur at licensed facilities, along transportation routes, and at recycling facilities, EPA/State-regulated disposal facilities and LLW disposal facilities. The specific locations of recycling facilities, EPA/State-regulated disposal facilities, and transportation routes where activities would occur cannot be identified. Therefore the discussion of the affected environment in Section 3.5.2 is not site specific.

Air quality impacts are assessed in Section 3.5.3 through comparison of the air emissions associated with each Alternative with national air emissions trends. The emissions estimates are compared to the national emissions estimates for the processes that are involved on an average annual basis. In the analysis it is assumed that materials generated at the licensed facilities are released at a uniform rate over a 47 year period. Site-specific air quality impacts are not addressed, because the locations of activities emitting air pollutants cannot be identified.

3.5.1 Regulatory Framework

There are four broad categories of air pollutants associated with the processes and activities under the Alternatives. These include:

- Pollutants regulated as National Ambient Air Quality Standards (NAAQS) under Title 1 of the Clean Air Act (CAA) (EPA 2003b);

- Pollutants regulated by National Emissions Standards for Hazardous Air Pollutants (NESHAP) under Title 3 of the CAA (EPA 2003c);

- Pollutants regulated for the purposes of public welfare (e.g., acid rain, visibility); and

- Pollutants considered to be greenhouse gases (e.g., carbon dioxide, methane, nitrous oxide).

NAAQS are pollutants that are emitted by or caused by emissions from a wide variety of air emissions sources and have been identified as contributing to human health effects. All States are required under the CAA to monitor these pollutants and develop State implementation plans (SIPs) to control the emissions of these pollutants to achieve and then maintain the concentration levels stipulated by the NAAQS. Table 3-21 lists the National Ambient Air Quality Standards.

Table 3-21 National Ambient Air Quality Standards

Parameter	Standard	National Standard	Average Period
Ozone*	Primary and Secondary	0.12 ppm (235 μg/m^3) 0.08 ppm (150 μg/m^3)	1-hour average 8-hour average
Particulate matter (PM_{10})	Primary	150 μg/m^3 50* μg/m^3	24-hour average Annual average
Fine particulate matter ($PM_{2.5}$)*	Primary	65 μg/m^3	24-hour average
	Primary and Secondary	15 μg/m^3	Annual average
Nitrogen dioxide	Primary and Secondary	0.053 ppm (100 μg/m^3)	Annual average
Sulfur dioxide	Secondary	0.50 ppm (1,300 μg/m^3)	3-hour average
	Primary	0.14 ppm (365 μg/m^3) 0.03 ppm (80 μg/m^3)	24-hour average Annual average
Carbon monoxide	Primary	35 ppm (40 mg/m^3) 9 ppm (10 mg/m^3)	1-hour average 8-hour average
Lead	Primary and Secondary	1.5 μg/m^3	3-month average

ppm Parts per million
μg/m^3 Micrograms per cubic meter.
* The revised ozone standard of 0.08 parts per million (ppm) for an 8-hour averaging period, and the standards for particulate matter of 2.5 microns in diameter (PM2.5) became effective in September 1997. However, due to legal challenges EPA has just recently completed designating attainment or nonattainment areas; and SIP plans to achieve these standards are currently in development.

Source: 40 CFR Part 50.

Hazardous air pollutants (HAPs), frequently referred to as air toxics, have been linked to human health effects. These pollutants are generally associated with specific types of air emissions sources and activities and, therefore, affect primarily specific local areas. Since these pollutants are emitted by specific types of air emissions sources, they are not regulated under the NAAQS provisions of the CAA, but are regulated under the source-specific National Emissions Standards for Hazardous Air Pollutants (NESHAP). Sources of these pollutants are required to apply Maximum Achievable Control Technology (MACT) to control releases of the HAP pollutants. A list of NESHAP regulations applicable to source categories related to the Alternatives is provided in Table 3-22.

Pollutants identified in the CAA associated with public welfare effects include precursors of acid rain and regional haze. Acid rain is produced by sulfur and nitrogen-containing air pollutants that react in the atmosphere to create acidic compounds that are then deposited through precipitation or dry deposition processes onto the surface of the Earth. The accumulation of these acid compounds over time can damage sensitive aquatic, agricultural, and forest ecosystems resulting in reduced productivity and reduced biodiversity. Regional haze results from the same precursors of acid rain, plus organic compounds, and soils that are suspended in the atmosphere by mechanical processes. The largest stationary sources of sulfur compounds and a major source of nitrogen compounds are coal-fired power plants. The precursor pollutants of acid rain and regional haze are also emitted by highway and off road mobile sources, ferrous metal mills, other secondary metals processes, incinerators, and the processes used to reduce concrete into smaller pieces that can be hauled away and used as road bed aggregate. These sources, however,

Table 3-22 Potential Relevant Source Categories Covered by NESHAP MACT Regulations

Source Category	Federal Register Citation	Pollutants Regulated	Date of Implementation
Hazardous Waste Combustion	64 FR 52827	dioxins, furans, mercury, cadmium, lead, antimony, arsenic, beryllium, chromium, acid gases and chlorine gas	9/20/01
Ferroalloys Production	64 FR 27450	particulate matter	5/20/01
Secondary Aluminum Production	65 FR 15689	metals, dioxins, furans, polycyclic organic matter, HCl, and chlorine gas	3/24/03
Integrated Iron and Steel Production	68 FR 27645	particulate matter	5/20/06
Iron and Steel Foundries	signed 8/29/03	HAP Metals and HAP Organics	
Subtitle D Landfills	68 FR 2227	Represented as total PM and Total Organics	11/16/03
Offsite Waste Recovery Operations[1]	61 FR 34140	Removal of HAP Materials Before Treatment	7/10/06

[1] Includes non RCRA exempt hazardous waste landfills and incinerators (EPA 2003c).

represent only a small fraction of the emissions resulting from power plants, existing mobile sources and existing activities of the type related to the Alternatives. Acid rain is regulated largely by the emissions trading program implemented under Title 4 of the CAA which restricts the collective emissions of sulfur dioxide and oxides of nitrogen from the largest coal-fired power plants. Regional haze precursor pollutants are regulated in conjunction with PM2.5 programs and most States are just beginning to implement plans to achieve the visibility objectives.

Sources associated with the Alternatives emit long lasting air contaminants that absorb heat energy and are thought to be capable of causing changes in the Earth's climate. These compounds act like the panes of glass in a greenhouse to trap heat and, therefore, have become known as greenhouse gases (GHGs). The primary GHGs are carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Carbon dioxide is the dominant gaseous byproduct of fossil and biomass fuel combustion, and any such combustion source (e.g., industrial furnaces, solid waste incinerators, gasoline engines, diesel engines) releases CO_2. Methane and N_2O are also released by fuel combustion sources, although at very small levels, and also by other industrial processes. EPA prepares an annual assessment of emissions of GHGs in the U.S[1] (EPA 2003d): Greenhouse gases are not currently regulated under the CAA, although there are many voluntary programs that are being implemented to reduce the amount of these gases that are released in the

[1] http://yosemite.epa.gov.oar/globalwarming.nsf/ResourceCenterPublicationsGHGEmissions.html.

U.S. The contribution of the activities associated with the Alternatives to total GHG loading is negligible in comparison to power generation and total mobile source activities.

3.5.2 Affected Environment

The affected environment, as defined for the purposes of the air quality impact assessment, includes the ambient air affected by non radiological air pollutants emitted from activities associated with the release, handling, processing, transportation, and disposal of solid materials generated from licensed facilities under the Alternatives, and the General Public potentially exposed to such non radiological air pollutants. The affected environment also includes environmental receptors potentially affected by air emissions from activities associated with the Alternatives.

3.5.3 Environmental Consequences

Total national air emissions (in units of tons per year) from processes and activities associated with the Alternatives are estimated using emission factors. For example, the total amount of particulate matter (PM) associated with the recycling of ferrous metal under the Unrestricted Release Alternative is estimated by multiplying the total amount of ferrous metal generated from licensed facilities that is recycled in ferrous metal mills (in units of tons per year) by a factor for the amount of particulate matter emitted per ton of ferrous metal recycled (in units of mass PM per ton ferrous metal processed). Emission factors (EPA 2004a) are applied to appropriate estimates of the material flow through each process to estimate the incremental effects on air quality associated with each Alternative. A summary of the total air emissions expected to result from each of the Alternatives is provided in Table 3-23.

Table 3-23 Summary Table – Total Air Emissions from Alternatives (metric tons)

No Action and Unrestricted Release Alternatives	**PM_{10}**	**SO_2**	**NO_x**	**VOC**	**CO**
Concrete	1,219	Neg.	4,654	1,132	910
Ferrous Metal	8,362	2,905	7,248	4,614	--
Trash (landfill disposal)	67	Neg.	186	94	94
TOTAL	9,648	2,905	12,124	5,839	1,004
EPA/State-Regulated Disposal Alternative	**PM_{10}**	**SO_2**	**NO_x**	**VOC**	**CO**
Concrete (landfill disposal)	1,210	Neg.	3	1,132	910
Ferrous metal (landfill disposal)	36	Neg.	772	60	326
Trash (landfill disposal)	10	Neg.	186	94	94
Trash (incineration)	171	117	337	94	157
TOTAL	1,417	117	5,696	1,285	1,393
LLW Disposal Alternative	**PM_{10}**	**SO_2**	**NO_x**	**VOC**	**CO**
All Materials total	93	7	889	94	94
Limited Dispositions Alternative	**PM_{10}**	**SO_2**	**NO_x**	**VOC**	**CO**
All Materials	205	62	258	123	21

Note: Neg. means negligible.

Approximately 19.8 million metric tons of concrete and 2.4 million tons of ferrous metal would be released from licensed commercial nuclear reactor facilities under any of the Alternatives (SC&A 2003, Table 10.3). This amount of ferrous metal is compared to approximately 82 million metric tons per year in the United States. Conversely, approximately 6,600 metric tons of copper and 200 metric tons of aluminum are anticipated to be released from commercial nuclear reactor facilities. Due to the relatively small quantities, air quality impacts associated with recycling and disposal of aluminum and copper are not discussed quantitatively in the Draft GEIS. Approximately 0.066 million metric tons of trash would be released from licensed nuclear reactor facilities, with an additional 0.886 million tons of trash released from licensed facilities other than commercial nuclear reactors. This compares with estimates of approximately 209 million metric tons per year of municipal solid waste. The air quality impact analysis for trash is based on the disposal of trash in either EPA/State-regulated landfills, EPA/State-regulated incinerators, or LLW disposal facilities. Trash is not assumed to be recycled or reused under any of the Alternatives.

Sources and activities associated with the Alternatives to which NESHAP standards apply are described in Appendix I. Process emissions of hazardous air pollutants (HAPs) would be generated from the recycling of ferrous metal under the No Action and Unrestricted Release Alternatives. The emission factors for HAPs for ferrous metal recycling are small compared to the emission factors for the criteria (NAAQS) air pollutants for ferrous metal recycling, in terms of emissions per ton of ferrous metal recycled. Therefore, the HAP emissions from ferrous metal recycling would be small as compared to the total inventory of HAPs emitted on a national basis. Similarly, the HAP emissions associated with disposal of licensee-generated material in Subtitle D landfills or EPA/State-regulated incinerators would also be small as compared to the total inventory of HAPs emitted from landfill disposal and incineration of solid waste. In addition, the facilities where these materials would be processed are already subject to HAP emissions limitation standards whether or not the materials from licensed facilities are processed. Therefore, HAP emissions from ferrous metal recycling and landfill disposal and incineration of solid waste are not discussed quantitatively in the Draft GEIS.

The preceding analysis has been completed based on material quantity estimates for commercial reactor licensees. There are a variety of other types of activities that release materials that could be included in the various alternatives. With the exception of trash, the total quantities of the other materials from these non reactor facilities are extremely low and will not add to the air quality impacts. The quantity of trash generated from these other licensed facilities is estimated to be 883,000 tons (SC&A 2003, Tale 5.6). The emissions totals for trash incineration assume incineration of only the 66,000 tons (SC&A 2003, Table 10.7) generated from commercial nuclear reactor facilities. These totals remain in the range of less than one percent of existing emissions represented in the annual national emissions inventory.

3.5.4 Summary of Air Quality Impacts

This section assesses non-radiological impacts to air quality. Radiological impacts are included in the dose assessments in Section 3.2.

Non-radiological air emissions associated with processes and activities associated with the Alternatives are summarized in Table 3-23. These emissions will take place over a large geographical area, and at various times depending on when individual sites are decommissioned and the materials are released. Some of these emissions will also occur over the operating life of the facility. The potential impacts on any individual community will be intermittent and short lived. Therefore, it is concluded that incremental impacts on ambient air quality and human exposure to non-radiological air pollutants in individual communities will be inconsequential for all of the alternatives.

Furthermore, the incremental quantity of predicted air emissions would be small as compared to the overall amount of air emissions generated from the total amount of concrete and ferrous metal, being recycled annually in the U.S. The overall effects on air quality associated with all of the alternatives would be small when compared with other sources of emissions.

3.6 ECOLOGICAL IMPACTS

Section 3.4 concludes the potential non-radiological impacts to surface water, ground water and drinking water are expected to be small because compliance with EPA and State permits would preclude significant impacts. Furthermore, ecological receptors only face potential environmental consequences from surface water in ground-water fed surface water bodies. Leachate or runoff that seeps into ground water and ultimately reaches a surface water body, especially a small pond, could alter the pH of or introduce organic and inorganic compounds into the surface water body. Since the non-radiological impacts to surface water, ground water and drinking water described in Section 3.4 are expected to be small, then non-radiological impacts to ecological receptors are also expected to be small.

Radiological impacts to environmental receptors are considered to be insignificant. The current position of the International Commission on Radiological Protection (ICRP 1991) is that "the standard of environmental control needed to protect man to the degree currently thought desirable will ensure that other species are not put at risk." Recently, ICRP has stated that the ICRP "system for protection of human beings has indirectly provided a fairly good level of protection of the human habitat." (ICRP 2003, page 201) However, the ICRP has decided to develop a framework for the assessment of radiation effects in non-human species. "The primary purpose of developing such a framework is to fill a conceptual gap in radiological protection; it does not reflect any particular concern over environmental radiation hazards." (ICRP 2003, page 207) Since a dose rate of 1 mrem/yr is a small fraction of background radiation, there would be no significant radiological impact to ecological resources associated with the Alternatives.

The DOE standard *A Graded Approach for Evaluating Radiation Doses to Aquatic and Terrestrial Biota* (DOE-STD-1153-2002, July 2002, p. xxi) (DOE 2002a) states:

> “The technical standard assumes a threshold of protection for plants and animals at the following doses: for aquatic animals, 1 rad/d (10 mGy/d); for terrestrial plants, 1 rad/d (10 mGy/d); and for terrestrial animals, 0.1 rad/d (1 mGy/d). Available data indicate that dose rates below these limits cause no measurable adverse effects to populations of plants and animals.”

These exposure thresholds are consistent with the values in the Report of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) to the General Assembly - "Effects of Radiation on the Environment" (UNSCEAR 1996). The units associated with exposure and dose to non-human species, and value of the relative biological effectiveness is currently the subject of international debate. It should be noted that the annual dose rate thresholds identified by these agencies are orders of magnitude above any of the dose limits being considered under the alternatives. As a result, it is impossible under the provisions of the proposed rule to attain such high dose rates. Consequently, the rule provides ample protection to biota.

3.7 WASTE MANAGEMENT

Under the five proposed Alternatives, materials generated from licensee facilities can be released to one or more of the following dispositions: use in general commerce (including recycling into consumer products or industrial and construction uses); reuse; disposal in EPA/State-regulated facilities[2]; or disposal at Low-Level Radioactive Waste (LLW) disposal facilities. The waste management discussion below describes the affected environment and analyzes potential environmental consequences of the Alternatives with respect to disposal of materials in EPA/State-regulated landfills and LLW disposal facilities. Section 3.7.1 provides a discussion of the affected environment with respect to waste management, and Section 3.7.2 provides a discussion of the potential environmental consequences with respect to waste management.

3.7.1 Affected Environment

The affected environment for the Proposed Action includes EPA/State-regulated disposal facilities (landfills and incinerators) and LLW disposal facilities where licensees would dispose released solid material. Under each of the Alternatives some amount of potentially clearable material would be disposed of at LLW disposal facilities; the amount of material disposed of as LLW varies by Alternative. For the LLW Disposal Alternative all of the potentially clearable material released would be disposed of as LLW. For the other Alternatives a smaller amount of the material which is below the release criteria would be disposed of as LLW. Under the EPA/State-Regulated Disposal Alternative almost all of the potentially clearable solid material would be disposed of in EPA/State-regulated disposal facilities, with the remainder disposed of in LLW disposal facilities.[3] Under the No Action and Unrestricted Release Alternatives licensees could dispose of solid materials in EPA/State-regulated disposal facilities or recycle the materials. Under the Limited Dispositions Alternative, ferrous metals and trash could be

[2] Disposal in EPA/State-regulated Subtitle C disposal facilities is not being considered as an Alternative in the Draft GEIS. Please see the discussion on Subtitle C disposal facilities in Chapter 2, Section 2.4.3.

[3] Note that under the No Action, Unrestricted Release, and Limited Dispositions Alternatives byproducts of solid material recycling processes (e.g., furnace slag) are anticipated to be disposed of in EPA/State-regulated landfills. Such disposal is not quantitatively evaluated in the waste management consequences analysis in Section 3.7.2., because these quantities are much lower quantities than the quantities of solid materials that would be disposed of under the Alternatives.

disposed of in EPA/State-regulated disposal facilities, while concrete could either be recycled into roadbed material or disposed of in EPA/State-regulated landfills.

The environment in the vicinity of the EPA/State-regulated disposal facilities and LLW disposal facilities may be affected by disposal in terms of consumption of the existing disposal capacity of these facilities and associated consumption of available land area. The environmental consequences analysis for disposal of solid materials in EPA/State-regulated disposal facilities or in LLW disposal facilities evaluates the effects of such disposal on the existing disposal capacities of these waste disposal facilities and the potential need for additional facility capacity and the associated utilization of land. There are three licensed LLW disposal facilities - Barnwell, South Carolina, Hanford, Washington, and Clive, Utah. These three facilities and their environs represent the affected environment with respect to LLW disposal conducted under any of the Alternatives. Under the EPA/State-Regulated Disposal Alternative, NRC would authorize the disposal of solid materials at any EPA/State-regulated landfill or incinerator (for trash only) in the United States. The affected environment with respect to EPA/State-regulated disposal potentially includes any RCRA Subtitle D landfill or incinerator facility in the United States and the environs of such facilities. However, no site-specific analyses are conducted for EPA/State-regulated disposal because the specific facilities that may accept solid materials for disposal cannot be identified, and therefore no site-specific discussion of the affected environment is provided in this section.

3.7.1.1 EPA/State-Regulated Disposal Facilities

As discussed in Section 2.4.3, the EPA/State-regulated facilities are RCRA Subtitle D landfills.

Capacity data for Subtitle D landfills was obtained from “The State of Garbage in America”, a report on municipal solid waste published annually in *BioCycle* (BioCycle 2002). The methodology and a full discussion of these data can be found in Attachment 2 of Appendix J. The remaining Subtitle D landfill capacity reported in 2001 is 6,584,885,975 tons. Although capacity expanded between 1998 and 2000 as a result of the addition of new landfills or expansion of existing landfills, NRC assumes that the amount of remaining capacity would remain equal to the 2001 value for the purposes of this environmental consequences analysis.

The actual cubic yards of disposal capacity remaining in the Subtitle D landfills depends on what assumption is made concerning how tightly the waste is compacted. Using low, middle, and high end conversion factors (see Table 3-24) gives the following range of the remaining volume of disposal capacity.

Regional disposal capacity, regional waste generation, and remaining years of capacity have been calculated as part of Appendix J. In general, the Mountain region of the U.S. has much more disposal capacity than it needs to dispose of the solid waste generated in that region, while the New England and the Mid Atlantic regions have the lowest amount of disposal capacity (out of seven regions) as compared to the amount of solid waste generated in those regions. However, exporting solid waste to different regions alleviates some of the disparity in capacity. For the assessment of environmental consequences with respect to Subtitle D landfills in Section 3.7.2, the national low and high capacity estimates from 2001 in Table 3-24 were used.

Table 3-24 Remaining Disposal Capacity for Subtitle D Landfills, 2001

Remaining Capacity in 2001 (million tons)	Cubic Yards per Ton	Cubic Yards of Remaining Capacity (million cubic yards)
6,584	1.66 (low)	10,970
6,584	4.33 (medium)	28,513
6,584	7 (high)	46,094

Source: Online searches and interviews with randomly chosen landfill operators were used to find standard "tons to cubic yards" conversions. Conversions ranged from 1.66 cubic yards per ton to 7 cubic yards per ton, depending on the compaction rate and density of waste.

Solid Waste Incinerator Capacity

The existing solid waste incinerator capacity was evaluated with respect to disposal of trash for the EPA/State-Regulated Disposal Alternative. Solid materials other than trash (concrete and metal) are assumed not to be incinerated. The incinerator capacity data were derived from *BioCycle's* (BioCycle 2002) annual report. The methodology is described in Appendix J. The existing solid waste incinerator capacity for the 2001 study year is 33,791,899 tons/year. For the purposes of the capacity analysis, the analysis assumed that the incineration capacity would remain equal to the capacity reported in 2001.

3.7.1.2 LLW Disposal Facilities

Three facilities in the country currently accept LLW for disposal. Their total remaining capacity is roughly 10.4 million cubic yards, as summarized in Table 3-25.

The Hanford LLW disposal facility accepts waste from the Northwest and Rocky Mountain compacts. Hanford is licensed by the State of Washington to receive wastes in Classes A-C. The "compact States" include Washington, Oregon, Idaho, Montana, Utah, Wyoming, Nevada, Colorado, New Mexico, Alaska, and Hawaii. The only power reactors in these compact States are the four "Energy Northwest" units at Hanford. The Barnwell LLW disposal facility currently accepts waste from all U.S. generators except those in Rocky Mountain and Northwest compacts. Beginning in 2008, Barnwell will only accept waste from the Atlantic Compact States (Connecticut, New Jersey, and South Carolina). The Barnwell facility is licensed by the State of South Carolina to receive wastes in Classes A-C. Therefore, the existing LLW disposal capacity is reported in the following section with and without consideration of the capacity at the Barnwell and Hanford facilities, as most commercial nuclear reactor facilities would be precluded from disposing of LLW at the Hanford and Barnwell facilities during the period of the Proposed Action.

Table 3-25 NRC-Licensed LLW Disposal Facility Capacity, 2002

Facility	Remaining Volume (million cubic yards)	Notes
Envirocare - Clive, UT	2.7	Remaining capacity as of 12/02
Barnwell Disposal Facility - Barnwell, SC	0.008	Reported as 230,000 cubic feet. This only accounts for non-regional* waste. Barnwell will stop accepting non-regional waste in 2008.
Hanford Off-Site LLW Disposal Facility - Hanford, WA	7.7	Excluding facilities for wastes generated at the Hanford Site.
Total	10.4	Not including Barnwell.

* Non-regional waste is anything generated outside the Atlantic Compact, which includes South Carolina, New Jersey, and Connecticut.

3.7.2 Environmental Consequences

Environmental consequences could affect EPA/State-regulated disposal facilities and LLW disposal facilities. Potential environmental consequences to RCRA Subtitle D facilities under each Alternative are discussed in Section 3.7.2.1. Potential environmental consequences to LLW disposal facilities under each Alternative are discussed in Section 3.7.2.2.

3.7.2.1 EPA/State-Regulated Disposal Facilities

Under four of the five Alternatives, some amount of solid material released from licensed facilities could be disposed of in EPA/State-regulated licensed landfills. For the Unrestricted Release Alternative and the EPA/State-Regulated Disposal Alternative, the amount of material that could be disposed of at EPA/State-regulated landfills would depend upon the specific dose option for the Alternative. For the No Action and the Limited Dispositions Alternatives the amount of material that could be disposed of in EPA/State-regulated landfills would be determined by case-by-case assessment by NRC, and therefore the amount of material that would be disposed of cannot be estimated. However, the No Action and Limited Dispositions Alternatives would be bounded by the Unrestricted Release and EPA/State-Regulated Disposal Alternatives.

The environmental consequences of disposal of solid materials in EPA/State-regulated landfills relates to the consumption of disposal capacity of the existing population of landfills, displacement of materials from other sources that would normally have been disposed of in EPA/State-regulated landfills, and potential exceedance of available disposal capacity. If only a small percentage of the overall existing landfill disposal capacity would be utilized under a particular Alternative, then neither exceedance of capacity nor displacement of materials would occur. The following evaluation of environmental consequences is based on the projected amount of material released for disposal and the remaining capacity of EPA/State-regulated landfills. The analysis demonstrates that the existing capacity of Subtitle D landfills is adequate for disposal of all potentially clearable solid materials that could be released under any of the alternatives.

3.7.2.1.1 No Action Alternative

Solid materials can currently be released for unrestricted use or disposal. Any future changes in the proportion of those dispositions would be covered by the impacts of the Unrestricted Release and EPA/State Regulated Disposal Alternatives. The EPA/State-regulated landfill capacity discussed in Section 3.7.1 would be adequate to accommodate the disposal of solid material in RCRA Subtitle D landfills under the No Action Alternative.

3.7.2.1.2 Unrestricted Release Alternative

Under the Unrestricted Release Alternative five dose options are considered for the release of solid materials. For purposes of this analysis, it is assumed that all of the ferrous metal, concrete, and trash[4] released for each dose option would be disposed of in EPA/State-regulated landfills. This assumption would represent the maximum amount of material that would be disposed of in Subtitle D landfills under any of the Alternatives and would include solid material that could otherwise be recycled under the Unrestricted Release Alternative. Under this assumption, the amount of material that would be disposed of in EPA/State-regulated landfills under the Unrestricted Release Alternative is approximately the same as the amount that would be disposed of in EPA/State-regulated landfills under the EPA/State-Regulated Disposal Alternative. This also bounds the amount from the Limited Dispositions Alternative.

Figure 3-2 shows the amount of total material released and the amounts of ferrous metal, concrete, and trash under each dose option. The amount of material released under each dose option is: 8.4 million cubic yards for the 0.03 mrem/yr dose option; 9.9 million cubic yards for the 0.1 mrem/yr dose option; 11.1 million cubic yards for the 1 mrem/yr dose option, and 11.3 million cubic yards for the 10 mrem/yr dose option. The amount of material that would be released under the Unrestricted Release Alternative RS-G-1.7 dose option would be approximately the same as the 1 mrem/yr dose option.

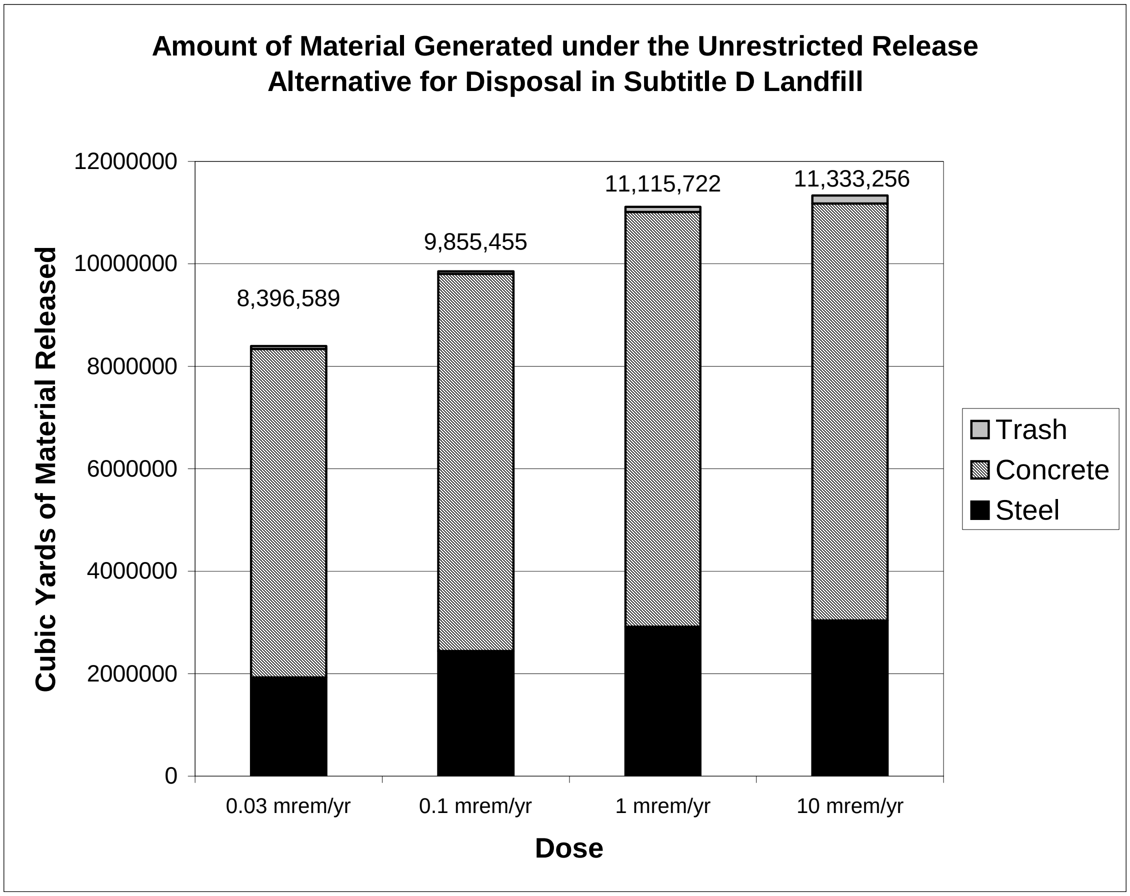
Table 3-26 provides a comparison of the estimated remaining Subtitle D landfill capacity and the maximum estimated amount of material anticipated to be released under the Unrestricted Release Alternative that could be disposed of in EPA/State-regulated landfills.

By 2049 an estimated 6.4 million cubic yards of concrete and 1.9 million cubic yards of ferrous metal is anticipated to be released under the 0.03 mrem/yr dose option for the Unrestricted Release Alternative. This 8.3 million cubic yards of material represents 0.08 percent of the

[4] These figures represent the total amount of concrete, ferrous metal, and trash. Note that aluminum, and copper are not included in this capacity analysis.

remaining capacity of Subtitle D landfills in the United States. For the 10 mrem/yr dose option an estimated 11.3 million cubic yards of concrete, ferrous metal, and trash would be released. This represents 0.10 percent of the remaining Subtitle D landfill capacity. Thus, the existing capacity of Subtitle D landfills would be adequate for the disposal of all of the potentially clearable materials that would be released under the Unrestricted Release Alternative under all dose options. There will therefore be no additional environmental consequences from the release of materials for disposal in Subtitle D landfills under the Unrestricted Release Alternative.

Figure 3-2



Note: Volumes of materials for the 1 mrem/yr and RS-G-1.7 dose options are the same.

Table 3-26 Estimated Remaining Subtitle D Disposal Capacity and Projected Materials Released under the Unrestricted Release Alternative

Subtitle D Landfill	Estimated Remaining Disposal Capacity (million cubic yards)	Projected Material Released (million cubic yards and percent of remaining capacity)*							
		.03 mrem/yr		.1 mrem/yr		1 mrem/yr		10 mrem/yr	
Low Capacity Estimate	10,970	8.4	0.08%	9.9	0.09%	11.1	0.10%	11.3	0.10%
High Capacity Estimate	46,094	8.4	0.02%	9.9	0.02%	11.1	0.02%	11.3	0.02%

* Figures for "projected material released" apply to the period of 2003 to 2049.

3.7.2.1.3 EPA/State-Regulated Disposal Alternative

The EPA/State-Regulated Disposal Alternative would require that all potentially clearable materials released from licensed facilities be disposed of in EPA/State-regulated landfills or incinerators (for trash only). The same five dose options evaluated under the Unrestricted Release Alternative apply to the release of materials for disposal in EPA/State-regulated landfills under this Alternative. Each dose option represents a different amount of material released, as shown in Figure 3-2. Under the EPA/State-Regulated Disposal Alternative, all solid material would be prohibited from general commerce (recycling into consumer products and industrial and construction uses). The maximum amounts of materials assumed to be disposed of in EPA/State-regulated landfills under the EPA/State-Regulated Disposal Alternative under each dose option are the same as for the Unrestricted Release Alternative in Section 3.7.2.1.2.

The estimated remaining Subtitle D landfill disposal capacity under the EPA/State-Regulated Disposal Alternative is the same as shown in Table 3-26. The maximum amount of remaining Subtitle D landfill capacity that would be utilized under the EPA/State-Regulated Disposal Alternative is approximately 0.10 percent. There will therefore be no additional environmental waste management impacts from the release of materials for disposal in Subtitle D landfills under the EPA/State-Regulated Disposal Alternative.

3.7.2.1.4 Low-Level Waste Disposal Alternative

No solid material would be disposed of in Subtitle D disposal facilities under the LLW Disposal Alternative.

3.7.2.1.5 Limited Dispositions Alternative

Under the Limited Dispositions Alternative concrete could be recycled only into roadbed material. Other materials would be required to be disposed of in EPA/State-regulated disposal facilities, except for those materials released in a case-by-case assessment by NRC. Tools and other equipment could be reused under this Alternative. Therefore the amount of solid material anticipated to be disposed of in EPA/State-regulated landfills under this Alternative would be less than that anticipated to be disposed under the EPA/State-Regulated Disposal Alternative described in Section 3.7.2.1.3 above.

3.7.2.2 LLW Disposal Facilities

Similar to the discussions above for environmental consequences to EPA/State-regulated disposal facilities, environmental consequences associated with waste management at LLW facilities can be categorized in two main groups: potential exceedance of capacity of the current population of LLW facilities or displacement of materials from other sources that would normally have been disposed of in a LLW facility. Exceedance of capacity or displacement of materials would most likely precipitate construction of new LLW facilities or expansion of existing facilities. The impacts associated with construction of new facilities or expansion of existing facilities are outside of the scope of the Proposed Action, but are discussed qualitatively in Section 3.7.3 below.

The total amount of potentially clearable solid material anticipated to be released from commercial nuclear reactor facilities is summarized in Table 3-27. Under the LLW Disposal Alternative all of this material would be disposed of in LLW disposal facilities. The amount of solid material that would be disposed of as LLW under the other four Alternatives will be less. Table 3-28 lists the estimated amount of material to be disposed of as LLW under each of the Alternatives.

Table 3-27 Mass of Potentially Clearable Materials from Commercial Nuclear Reactor Facilities

Material	Total Mass (tons)
Ferrous Metal	2,498,911
Concrete	19,877,341
Trash	323,023
Aluminum	212
Copper	6,584
Total	22,706,071
Total Cubic Yards	**11.5 Million Cubic Yards**

Source: SC&A 2003, Table 10.3.

Table 3-28 Projected Material Released to LLW Disposal* and Estimated Remaining Disposal Capacity Under Each Alternative

Alternative		Projected Material Released (million cubic yards)	Percent of Estimated Remaining LLW Disposal Capacity: Hanford, Barnwell and Envirocare (10.4 Mil cubic yards)	Percent of Estimated Remaining LLW Disposal Capacity: Envirocare Only (2.7 Mil cubic yards)
No Action		2.27	21.9	84.5
Unrestricted Release	0.03 mrem/yr	3.4	32.5	125
	1.0 mrem/yr	0.41	4	15.2
	10 mrem/yr	0.21	2.1	7.9
EPA/State-Regulated Disposal	0.03 mrem/yr	2.8	26.9	103
	1.0 mrem/yr	0.29	2.8	10.9
	10 mrem/yr	0.18	1.7	6.6
LLW Disposal		11.5	111.6	425.9
Limited Dispositions	RS-G-1.7	0.41	4	15.2

* Figures for "projected material released" apply to the period 2003 to 2049.

Source: Volume of materials based on Table 10.3 SC&A 2003 and Tables 3-15 and 3-27 of this report. Tonnage to cubic yard conversions assume a density of 0.51 cubic yard per ton.

The estimated remaining LLW disposal capacity for each alternative is shown in Table 3-28. It is anticipated that because of waste acceptance restrictions on the Hanford and Barnwell facilities the only licensed facility that would be available to accept LLW generated under the Proposed Action would be the Envirocare facility in Utah. As shown above, several of the "projected material released" scenarios exceed the current capacity of the Envirocare LLW facility. Under the No Action Alternative the amount of solid material anticipated to be disposed as LLW would utilize 84 percent of the available Envirocare facility disposal capacity or 22 percent of the available capacity of all three of the currently licensed LLW disposal facilities. The amount of solid material anticipated to be disposed of as LLW under the LLW Disposal Alternative is equivalent to 426 percent of the LLW disposal capacity of the Envirocare facility, or 112 percent of the disposal capacity of all three of the currently licensed LLW disposal facilities.

Note that these disposal capacity utilization estimates include only the solid materials that would be generated from commercial nuclear reactors under the Proposed Action. Given the anticipated rate of generation of LLW from all facilities under the Proposed Action, the existing LLW disposal capacity at the Envirocare disposal facility may be either completely utilized or come close to capacity for at least one dose option under each of the Alternatives. This is even without considering the fact that facilities that are not reactors would also continue to generate LLW during the time frame of the Proposed Action. The 1 mrem/yr dose option under the Unrestricted Release and EPA/State-Regulated Disposal Alternatives, however, would not exceed the current

LLW disposal capacity, but would utilize only 11 to 15 percent of Envirocare's total available disposal capacity.

If the existing LLW disposal capacity is completely utilized within the time frame of the Proposed Action, then either other material will need to be displaced from LLW disposal, waste acceptance restrictions on the Hanford and Barnwell facilities will need to be lifted, or LLW facilities will need to be constructed or expanded to accommodate the LLW disposal. Note however that under the LLW Disposal Alternative, even if all the waste acceptance restrictions were lifted from the Hanford and Barnwell facilities, the total capacity of the three licensed LLW disposal facilities would not be sufficient to accommodate all of the LLW that would be generated. Potential construction of new LLW disposal facilities or expansion of LLW disposal facilities is discussed in Section 3.7.3, however quantitative evaluation of construction impacts is not within the scope of the Draft GEIS.

3.7.3 Potential Impacts from Construction of Additional Facilities

There will be no need for construction of additional RCRA Subtitle D disposal facilities as a direct result of any of the Alternatives described in Section 3.7.1 above. The existing Subtitle D landfill capacity will not be adversely affected under any of the Alternatives and associated dose options and therefore no land-take for future construction would occur related to these Alternatives in the time period analyzed. Because there will be no new construction, there are no associated waste management consequences from disposal in current landfills. If in the future, a need for constructing new Subtitle D landfills arises in response to any site-specific conditions, then a site-specific environmental review would be conducted for that Proposed Action as it falls outside of the scope of this analysis.

The need for construction of additional LLW disposal facilities or expansion of existing facility capacity may result from any of the Alternatives described in Section 3.7.2. This would depend upon the specific dose option. The LLW Disposal Alternative would result in utilization of more than 100 percent of the available LLW disposal capacity. The availability of LLW disposal facility capacity could potentially be adversely affected by several of the proposed Alternatives, and therefore land-take for future construction of new facilities or expansion of existing facilities may be necessary. Potential environmental consequences related to new construction or expansion of LLW facilities are outside of the scope of this Draft GEIS, however. If, in the future, new LLW disposal facilities are proposed to be constructed or existing facilities expanded, then site-specific environmental reviews would be conducted that would evaluate all related environmental consequences.

3.8 CUMULATIVE IMPACTS

Cumulative impact is defined in 40 CFR 1508.7 as "the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time." CEQ guidelines (CEQ 1997) describe those attributes that should be considered when analyzing cumulative impacts of a proposed action (such as this rulemaking), including:

- Determining which resources are affected by the proposed action;

- Identifying other past, present, and reasonably foreseeable future actions that either have or might affect those resources;

- Identifying and evaluating potential impacts, but focusing on the most important cumulative impact issues; and

- Determining the magnitude and significance of the proposed action in the context of the cumulative impacts of other past, present and future actions.

The environmental consequences we considered were doses to the public and LLW disposal capacity. The cumulative impacts considered in this section are (1) exposure of individuals to multiple sources, (2) disposition of DOE scrap metals, (3) industrial activities involving naturally-occurring radioactive materials (NORM), and (4) the proposed NRC licensing of facilities with significant quantities of LLW.

Individuals could be exposed to very low levels of radioactivity from more than one source, for example from a vehicle's engine block and recycled concrete in a roadbed. Appendix E considers the possible frequency of multiple scenarios affecting the same individual. There could be multiple radionuclides involved, or multiple kinds of materials released, or multiple concurrent scenarios (such as multiple facilities releasing materials, or processing released materials while using consumer products made from released materials). Appendix E concludes the likelihood of such multiple concurrent exposures becomes vanishingly small as the number of potential concurrent scenarios increases. While it is difficult to estimate the actual probability of a particular scenario, with each additional scenario, the potential for all the scenarios occurring together becomes smaller. Even with only a few scenarios, this potential is very small.

Another source of potentially clearable solid materials is the decommissioning of DOE facilities. DOE is developing an environmental impact statement (EIS) related to the disposition of DOE scrap metals with small amounts of radioactivity. At this time, because DOE has not yet published its EIS, NRC has found insufficient information in the published literature to quantitatively characterize DOE facilities. Although the relative contribution of DOE materials to public doses cannot be estimated, the release of DOE scrap metal could contribute to cumulative impacts if the material leaves DOE sites.

Most Department of Defense facilities using potentially clearable materials are licensed by the NRC and are thus captured by the licensed facilities analyzed in this GEIS.

Other sources of potentially clearable solid materials are commercial industries not licensed by NRC that use or process materials that contain NORM, which because of their operations create higher concentrations of radioactivity than that associated with an undisturbed natural setting. This material is defined as technologically enhanced NORM (TENORM). The following industries generate TENORM - petroleum production, uranium mining, phosphate and phosphate fertilizer production, fossil fuel combustion, drinking water treatment, metal mining and processing, and geothermal energy production. Radioactive species associated with TENORM are typically uranium, thorium and their decay products. Contaminated equipment could be decontaminated and reused, disposed of, or sold as scrap. Limited information was uncovered in the published literature to quantitatively characterize potential cumulative impacts (DOE 1996).

Investigation of the recycle of scrap metal contaminated with NORM has found that the NORM goes into the slag rather than the metal products. Because the same NORM species present as contamination are present in the ore or raw materials that initially contain the metals, and these species go to the slag during processing, recycle of metals from these industries has been performed for decades and gives no cause for concern. Although NORM use is not federally regulated, many States have promulgated regulations to control exposure from TENORM. In 2004, the States published model State regulations and Implementation Guidance for TENORM (Part N of the Suggested State Regulations for Control of Radiation), which were developed working through the Conference of Radiation Control Program Directors, Inc. Adoption of State regulations equivalent to Part N provide basic radiation protection standards for TENORM that are the same as the basic standards for radiation protection in NRC's 10 CFR Part 20. Although the industries mentioned above are not licensed by NRC, some States may amend their TENORM regulations in response to an NRC rulemaking on controlling the disposition of solids.

When considering cumulative impacts related to LLW disposal capacity, the analysis considered proposed NRC-licensed facilities that would generate large quantities of solid materials that would be classified as LLW. There are two proposed new uranium enrichment plants, one proposed by the USEC, Inc. for construction in Portsmouth, Ohio and one proposed by Louisiana Energy Services (LES) for construction in Lea County, New Mexico, that would generate LLW. In the event that NRC does not license a new enrichment plant, the existing USEC enrichment plant in Paducah, Kentucky is anticipated to remain in operation. (The Paducah plant is anticipated to cease operations if a new USEC plant is licensed.) Each proposed enrichment plant and also the existing USEC Paducah plant, if it continues to operate, would generate depleted uranium hexafluoride (DUF_6) that under current DOE requirements would be converted to uranium oxide (DU_3O_8) in a DUF_6 conversion plant. DOE is proposing to construct and operate two conversion facilities for converting DUF_6 at Portsmouth, OH and Paducah, KY. These facilities would convert DOE's inventory of DUF_6 to a more stable chemical form suitable for beneficial use or disposal. For the proposed USEC enrichment plant, LLW would be generated from site preparation activities including D&D of existing USEC-controlled buildings and structures at the USEC Portsmouth and Paducah plants. For the proposed USEC and LES enrichment plants, additional LLW would be generated from D&D of the enrichment plants at the end of their operating life. The amount of such D&D waste that would be classified as LLW would depend upon what Alternative NRC selects for the Proposed Action.

The license application processes for the proposed USEC and LES enrichment facilities are in their early stages and quantitative estimates of the amount of LLW that would be generated from these proposed facilities are not available. In the event that no new commercial LLW disposal capacity is constructed in the U.S. during the time frame of the Proposed Action, the Proposed

Action itself would have a small to large (significant) impact on existing LLW disposal capacity. The combined amount of LLW generated from the Proposed Action and the two proposed uranium enrichment plants would have a greater impact on existing LLW disposal capacity than the Proposed Action alone.

When considering past, present, and foreseeable future actions and the impacts from the proposed rulemaking, cumulative impacts to doses to the public are expected to be small due to the low doses considered in the NRC rulemaking. In considering cumulative impacts on LLW disposal capacity, NRC will continue to follow DOE's environmental review of the recycling of DOE scrap metals and the licensing of the USEC and LES enrichment facilities. NRC considers the cumulative impacts on LLW disposal capacity to be potentially small to large (significant), depending on the Alternative considered under this Proposed Action.

3.9 UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS, SHORT-TERM USES OF THE ENVIRONMENT, AND LONG-TERM PRODUCTIVITY

The radiation doses that would occur as a result of the proposed action are well below NRC regulatory limits and represent a small fraction of the existing background levels of radiation. Unavoidable adverse environmental impacts, short-term uses of the environment, and long-term productivity were previously considered under the activities expected during operation and decommissioning of licensed facilities.

3.10 IRREVERSIBLE AND IRRETRIEVABLE COMMITMENT OF RESOURCES

For all but the LLW Disposal Alternative, no resources would be lost because the Proposed Action falls within the activities expected during operation and decommissioning of licensed facilities. For the LLW Disposal Alternative, no solid material would be released and all the potentially clearable material would be disposed of in LLW disposal facilities. This amount of LLW would be more than four times the available LLW disposal capacity at Envirocare and more than the disposal capacity at Hanford, Barnwell and Envirocare combined (Table 3-28). The LLW Disposal Alternative would result in the commitment of land for additional LLW facilities or the expansion of current LLW facilities.

The Proposed Action would also commit energy resources related to transportation of the solid material to either recycling or disposal facilities. For the No Action Alternative, approximately 475 million vehicle miles would be traveled transporting the solid materials to recycling facilities and licensed LLW disposal facilities (Table 3-15). By comparison, under the LLW Disposal Alternative, approximately 1.4 billion vehicle miles would be traveled transporting by truck all of the solid materials released to licensed LLW disposal facilities. The LLW Disposal Alternative represents approximately a 350 percent increase in energy expended for transportation as compared to the No Action Alternative.

The No Action and Unrestricted Release Alternatives would result in recycling of concrete, ferrous metal, aluminum and copper. The Limited Dispositions Alternative would result in recycling of concrete but not metals, except by case-by-case determination by NRC. For the No Action Alternative 18.3 million tons of solid material, including 16.2 million tons of concrete and 2.06 million tons of ferrous metal, would be recycled (Table 3-15). The recycled ferrous metal could displace the need for production of more than 2 million tons of new ferrous metal. Production of one ton of recycled ferrous metal requires less energy and materials than production of one ton of new ferrous metal using virgin materials. Therefore the No Action Alternative and Unrestricted Release Alternative, under which ferrous metal would be recycled, would commit fewer resources towards steelmaking than would the EPA/State-Regulated Disposal Alternative or LLW Disposal Alternative, under which no recycling would be conducted. The amount of ferrous metal that would be recycled under the Limited Dispositions Alternative cannot be estimated but would likely be much lower than the amount for the No Action or Unrestricted Release Alternatives.

3.11 MITIGATION MEASURES AND MONITORING

All radioactive materials used, possessed, or stored onsite are required to be periodically monitored and inventoried. The monitoring includes the conduct of external radiation and surface contamination surveys. The inventory addresses quantities of radioactive materials as to their physical and chemical forms, uses, and dispositions, including radioactive decay. These requirements are stated in 10 CFR Part 20 and as license conditions stipulated in each license. Accordingly, the radiological status and locations of materials, before being designated for release, fall under the full control of the radiation safety program of each licensee. As a result, no additional mitigation measures are anticipated as a result of implementing any of the alternatives. The implementation of the rule will be monitored through inspections, similar to those for releases to sewers.

3.12 COMPARISON OF PREDICTED ENVIRONMENTAL IMPACTS

NEPA regulations require a comparison of the environmental impacts of the alternatives, in order to define the issues and provide a clear basis for choice among the alternatives. This section presents a comparison of the environmental impacts of the alternatives described in Section 2.4 of this Draft GEIS, based on information and analysis presented in Chapter 3, Affected Environment and Environmental Consequences. Table 2-1 provides a summary of the impacts.

Some environmental issues are not analyzed in detail in this Draft GEIS because NRC does not anticipate activities that could have the potential to impact these environmental resources. These environmental resources and issues include soils, noise, ecological resources, socioeconomics, historic and cultural resources, environmental justice, visual and scenic resources, and land use. In the event that there are site-specific construction activities associated with the disposition of solid material, any such activities would be subject to site-specific NEPA analysis conducted on a case-by-case basis.

3.12.1 Human Health and Safety

The radiological effects to the General Public, Non-Licensed Facility Workers, and Licensed Facility Workers are assessed in this Draft GEIS in terms of collective dose, in units of person-rem. Even using the highest dose option (10 mrem/year), the effects of exposure on all three categories of exposed groups would be small when compared with background exposure coming from other sources (Appendix E). However, there is a variation between alternatives.

Table 3-29 presents a summary of the collective dose results discussed in Section 3.2. For the Unrestricted Release Alternative, the dose option chosen for the comparison is the IAEA Safety Guide RS-G-1.7, which is also part of the Limited Dispositions Alternative. For Licensed Facility Workers, the collective doses associated with all of the alternatives are similar, except that for the LLW Disposal Alternative the collective dose is lower because there is no decontamination of the solid materials.

Table 3-29 Summary of Collective Dose Results (person-rem)

	Collective Dose	
Alternative	**Licensed Workers**	**Non-Licensed Facility Workers and General Public**
No Action	631	3,996
Unrestricted Release	631	3,429
EPA/State-Regulated Disposal without Trash Incineration	631	2
EPA/State-Regulated Disposal with Trash Incineration	631	1,011
LLW Disposal	323	-
Limited Dispositions	631	112

For Non-Licensed Facility Workers and the General Public, the highest collective doses are for the No Action and Unrestricted Release Alternatives because for these alternatives the collective dose is dominated by exposure of the General Public to products made from recycled ferrous metal. The lowest collective dose to Non-Licensed Facility Workers and the General Public is for the EPA/State-Regulated Disposal Alternative without incineration. Collective dose was not calculated for the LLW Disposal Alternative for Non-Licensed Facility Workers and the General Public, but is assumed to be low, similar to the collective dose for the EPA/State-Regulated Disposal Alternative. The collective dose for the Limited Dispositions Alternative is smaller than for the No Action and Unrestricted Release Alternatives.

3.12.2 Transportation

Transportation effects are measured in this Draft GEIS in terms of fatal vehicle accidents and railcar incidents (e.g., derailments). These effects are based on statistical information on non-radiological accidents. The effects are highest for the LLW Disposal Alternative, with an estimated 32 fatal accidents over the 250 year period of the analysis if the material is transported by truck, or approximately 7 accidents if it is transported by rail (Table 3-16). This results from the fact that the analysis for the LLW Disposal Alternative assumes that all materials must be transported to a single LLW disposal site in Utah, which is an average trip of 1,544 miles. Transport distances associated with all the other alternatives are significantly shorter, resulting in significantly lower transportation effects. The number of fatal accidents under the No Action Alternative is estimated at 11, which is about double the effect associated with the Unrestricted Release Alternative at 1 mrem/yr. For the EPA/State-Regulated Disposal Alternative, the effect would be even lower due to the large number of Subtitle D landfills located throughout the country resulting in short transportation distances, typically less than 100 miles. For the Limited Dispositions Alternative, there are approximately 9 fatalities.

3.12.3 Water Quality

As discussed in Section 3.4, impacts to water quality are expected to be small because compliance with EPA and State permits would preclude significant impacts. Water quality effects are primarily associated with point source and area source water discharges from the storage, handling, and processing of solid materials. For the No Action and Unrestricted Release Alternatives, the effects are generated mostly by runoff discharges from rubblization of concrete and runoff and process wastewater discharges from recycling of ferrous metal. The incremental quantity of these discharges generated would be small as compared to the overall amount of discharges generated from the total amount of concrete and ferrous metal being recycled annually in the U.S., and the impact on water quality would be equally small. Similarly, the quantity of additional leachate and potential effects on ground water associated with disposal of solid materials under the EPA/State-Regulated Disposal Alternative and the LLW Disposal Alternative would be small compared with the overall amount of leachate being generated annually by these facilities. Therefore the overall effects on water quality associated with all of the alternatives would be small when compared with other sources of discharges.

3.12.4 Air Quality

Air quality effects are primarily associated with mobile source emissions from transportation of solid materials to recycling and disposal facilities, fugitive dust emissions from rubblization of concrete, process emissions from recycling of ferrous metal, and emissions from the incineration of trash (Section 3.5). The effects on air quality would be greatest for the EPA/State-Regulated Disposal Alternative trash incineration variation. The air quality effects associated with all other alternatives would be negligible. However, the overall effects on air quality associated with all of the alternatives are small when compared with other sources of emissions (Table 3-23).

3.12.5 Waste Management

The resource being evaluated for waste management is disposal capacity. The EPA/State-regulated disposal facilities considered were RCRA Subtitle D landfills. The analysis in Section 3.7 demonstrates that the existing capacity of Subtitle D landfills would be adequate for the disposal of all of the potentially clearable materials that could be released under any of the alternatives.

Section 3.7 also discusses the analysis of disposal capacity at LLW disposal sites for all the alternatives. A summary of the LLW disposal capacity analysis is shown in Table 3-30. For the Unrestricted Release and EPA/State Regulated Disposal Alternatives, the dose option chosen for the comparison is IAEA Safety Guide RS-G-1.7, which is also part of the Limited Dispositions

Alternative. For small impacts, there is currently sufficient LLW disposal capacity and the need to expand existing LLW storage is small. For moderate impacts, there is currently insufficient LLW disposal capacity and expansion of existing LLW storage capacity would be needed. For large impacts, the amount of additional LLW disposal capacity needed is of such a magnitude that this impact should be avoided.

Table 3-30 Summary of LLW Disposal Capacity Analysis

Alternative	Percent of Estimated Remaining LLW Disposal Capacity	
	Hanford, Barnwell and Envirocare	Envirocare Only
No Action	22	84
Unrestricted Release	4[1]	15
EPA/State-Regulated Disposal	3[1]	11
LLW Disposal	112	426
Limited Dispositions	4	15

[1] Percentage presented is based on the 1 mrem/yr dose option. See Table 3-28.

The effects associated with the LLW Disposal Alternative are considered large. Under this alternative, the amount of solid material projected to be disposed of in the Envirocare LLW facility totals more than four times the existing capacity of the facility under its current State licenses and permits. Under the No Action Alternative, the amount of solid material that would be sent to the Envirocare LLW disposal site is approximately 84 percent of the existing capacity of the site; this is considered a moderate impact. For the other Alternatives, the impacts are small. Under the Unrestricted Release and Limited Dispositions Alternatives the amount of potentially clearable solid material that would be disposed of at the Envirocare LLW disposal site, would total approximately 15 percent of the existing LLW disposal capacity of the Envirocare facility for the 1 mrem/year dose option. Similarly, for the EPA/State-Regulated Disposal Alternative, the amount of potentially clearable solid material that would not be disposed in an EPA/State-regulated landfill, but would be disposed at the Envirocare LLW disposal site, would correspond to approximately 11 percent of the existing LLW disposal capacity of the Envirocare facility.

3.12.6 Cost/Benefit

The cost/benefit analysis is discussed in Chapter 4 and summarized in Table 3-31 for the dose limit of 1 mrem/yr. The No Action Alternative is the baseline and by definition there are no incremental costs or benefits associated with this alternative. Incremental costs for the other alternatives are those costs above the No Action Alternative costs. In Table 3-31 only the most significant attributes are shown. Public and Occupational Health (Routine) includes collective doses to the public and licensed workers and represents less than 0.5 percent of the total incremental benefit or cost of each alternative. Public and Occupational Health (Accident) includes traffic accidents and represents about 1 percent of the total. Industry Operations includes the cost of surveys, disposal fees, and transportation costs and represents about 99 percent of the total. Environmental considerations include air emissions and reductions in the use of virgin materials due to recycling and represent less than 1 percent of the total. Transportation and disposal costs are the most significant sub-attributes when considering costs and benefits.

Table 3-31 Summary of Net Incremental Benefit (Cost) Associated with Major Attributes by Alternative

	Benefit (Cost) in Millions of Dollars				
Alternative	**Public and Occupational Health (Routine)**	**Public and Occupational Health (Accident)**	**Industry Operations**	**Environmental Considerations**	**Total**
No Action	-	-	-	-	-
Unrestricted Release	<1	0	246	1	247
EPA/State-Regulated Disposal	1	0	181	(1)	181
LLW Disposal	1	(13)	(1,378)	(13)	(1,404)
Limited Dispositions	1	0	258	(2)	257

The incremental costs and benefits associated with the various alternatives vary greatly. The highest incremental costs are associated with the LLW Disposal Alternative and are estimated to exceed $1.4 billion, primarily from transportation and disposal costs. For the Unrestricted Use and EPA/State-Regulated Disposal Alternatives, the incremental costs and benefits are highly dependent on the dose option selected. For both, benefits are associated with the 1 mrem/yr and 10 mrem/yr dose options, but costs are associated with the 0.03 mrem/yr and 0.1 mrem/yr dose options due to the fact that under these smaller dose options, smaller amounts of solid material are cleared, and larger amounts must be transported and disposed of in LLW disposal sites. For the comparison of the Unrestricted Release, EPA/State-Regulated Disposal and Limited Disposition Alternatives in Table 3-31, the 1 mrem/yr dose option was chosen. For these three alternatives, the total benefits are similar.

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CHAPTER 4
COST-BENEFIT ANALYSIS

4.1 INTRODUCTION

This chapter describes the costs and benefits of the alternatives described in Chapter 2. Although a cost-benefit analysis is not a specific NEPA or CEQ requirement, NRC regulations in 10 CFR 51.71(d) specify that "draft environmental impact statements should also include consideration of the economic, technical, and other benefits and costs of the proposed action and alternatives."

The cost-benefit analysis sets forth the various economic benefits and costs of the alternatives under consideration, including environmental benefits. Benefits and costs are assessed at the national level. The benefits and costs are with respect to the No Action Alternative, which is the baseline. Table 4-3 summarizes the net incremental benefits for each alternative by dose option. Table 4-4 presents a summary of the net incremental benefits for each "attribute" by alternative and dose-option. (Attributes are defined in Section 4.3) Some costs and benefits may be significant but not quantifiable in terms of dollars, as discussed in Section 4.5, and these are not reflected in Tables 4-3 and 4-4. Further details on the cost-benefit analysis are provided in Appendix K.

Based on the currently available data:

- The Limited Dispositions Alternative is expected to result in a net incremental benefit of about $257 million (present value, 2003$) (compared to the No Action Alternative).

- The Unrestricted Release Alternative is projected to result in a net incremental *benefit* under the 1 mrem/yr, 10 mrem/yr and IAEA RS-G-1.7 dose options, but to result in a net *cost* at the lower dose option levels.

- The Unrestricted Release Alternative results in a benefits of $247 million, which is approximately the same as, but slightly lower than the benefit of $257 million associated with the Limited Dispositions Alternative for the IAEA RS-G-1.7 dose option. This may appear counter intuitive because in the Limited Dispositions Alternative ferrous metals cannot be recycled, resulting in the loss of a revenue stream and the addition of a disposal fee. However, a larger quantity of material can be released in the Limited Dispositions Alternative than in the Unrestricted Release Alternative, resulting in a benefit that offsets those costs.

- The EPA/State-Regulated Disposal Alternative, while less beneficial than the Unrestricted Release Alternative, also would result in a substantial net incremental benefit at the 1 mrem/yr, 10 mrem/yr and IAEA RS-G-1.7 dose options, but would result in a net cost under the lower dose levels. This net benefit arises because under this Alternative a larger quantity of material can be released than in the No Action Alternative. Thus the avoided transport and disposal costs for LLW create a benefit relative to the No Action Alternative, which is offset slightly by the loss of recycling revenues and the cost of EPA/State-regulated disposal.

- The LLW Disposal Alternative would result in a substantial net cost of about $1.4 billion.

4.2 SCOPE OF COST-BENEFIT ANALYSIS

Ideally, the cost-benefit analysis should analyze each of the following five rule alternatives under consideration:

1. No Action
2. Unrestricted Release
   - Material-specific limits
   - Material-independent limits
3. EPA/State-Regulated Disposal
   - RCRA Subtitle D Landfill Disposal without Incineration
   - Disposal with Trash Incineration
4. LLW Disposal
5. Limited Dispositions

The five dose options (for the dose-specific alternatives):

- 0.03 mrem/yr;
- 0.1 mrem/yr;
- 1.0 mrem/yr;
- 10.0 mrem/yr; and
- IAEA Safety Guide No. RS-G-1.7.

All facility types:

- Light water reactors (LWRs);
- Independent spent fuel storage installations (ISFSIs);
- Research reactors;
- Facilities included in the site decommissioning management plan (SDMP);
- Fuel cycle facilities; and
- Other materials licensees including, but not limited to medical, academic, industrial, source, and special nuclear licensees.

All affected materials:

- Ferrous Metal;
- Concrete;
- Copper;
- Aluminum;
- Equipment, and
- Trash.

Due to the broad scope of this Draft GEIS and limited data availability, not all facility types and materials could be evaluated for all rule alternatives. Nevertheless, the analysis captures a substantial majority of material and activity (i.e., radioactivity) that could be released, as well as the resulting dose.

Alternatives/Dose Options Considered

The cost-benefit analysis addresses all of the alternatives under consideration. For the dose-specific alternatives (Unrestricted Release and EPA/State-Regulated Disposal), all five dose options are evaluated.

Materials/Facilities Covered

This analysis quantitatively addresses LWRs for ferrous metal, concrete, and trash. LWR copper, aluminum, and equipment suitable for reuse were analyzed qualitatively, because distributions of these materials were not available over time for the alternatives analyzed. The analysis focuses on LWRs because the collective dose for materials generated from licensees other than commercial reactor facilities is approximately 5 percent or less of the collective dose associated with materials generated from commercial reactors for both the No Action and Unrestricted Release Alternatives.

4.3 IDENTIFICATION OF AFFECTED ATTRIBUTES

This section identifies the factors within the public and private sectors that the alternatives are expected to affect. These factors are classified as "attributes" using the list of potential attributes provided in Chapter 5 of the *Regulatory Analysis Technical Evaluation Handbook* (NRC 1997b).

- ***Environmental Considerations***. For each alternative, air emissions could be affected by the number of vehicle miles traveled and/or the relative production of new versus recycled materials (i.e., ferrous metal, copper, aluminum).

- ***Industry Operation***. Industry may incur operational costs or savings related to surveys, transportation of either LLW or released material, disposal as either LLW or released material, and recycling fees or revenues for released material.

- ***Public Health (Routine)***. The dose to the public associated with release levels or released materials may increase or decrease as a result of the alternatives. The dose is monetized using a value of $2,000 per person rem.

- ***Occupational Health (Routine)***. The dose to workers associated with release levels or released materials may increase or decrease as a result of the alternatives. The dose is monetized using a value of $2,000 per person rem.

- ***Public Health (Accidental)***. The number of driver deaths associated with accidents may be affected by changes in the number of vehicle miles traveled. Deaths are monetized using a value of $3 million per death.

- ***Industry Implementation***. One-time costs or savings may result from incremental activities such as reading the regulations and guidance documents; training employees on new procedures; capital outlays for equipment; increased recordkeeping if required; and researching markets and vendors for released material.

- ***NRC Implementation***. The NRC may incur an incremental staff burden to conduct the following implementation tasks: develop guidance, procedures, and aids for use by NRC; develop enforcement procedures; and develop guidance, procedures, and aids for use by licensees.

- ***NRC Operation***. The NRC may incur an annual incremental staff burden to conduct inspections, evaluate licensee compliance, and conduct enforcement activities.

- ***Other Government***. Other government costs could include costs related to rulemakings in Agreement States. (This excludes facilities that are assumed to be covered under the industry operation and industry implementation attributes, such as DOE and DoD facilities.)

In addition to the above, two attributes are evaluated on an entirely qualitative basis:

- ***Regulatory Efficiency***. The alternatives will result in benefits associated with the streamlining of procedures compared with baseline (current) procedures.

- ***Other Considerations***. Public confidence in NRC may be affected by the outcome of this action.

The following attributes are not expected to be affected:

- Occupational Health (Accidental),
- Offsite Property,
- Onsite Property,
- Other Costs to General Public,
- Improvements in Knowledge,
- Antitrust Considerations, and
- Safeguards and Security Considerations.

4.4 ANALYTICAL METHODOLOGY

This section describes the process used to evaluate benefits and costs associated with the alternatives. The benefits include any desirable changes in affected attributes (e.g., improved safety, monetary savings) while the costs include any undesirable changes in affected attributes (e.g., increased radiological exposure, monetary costs).

With the two exceptions noted above, the analysis evaluates all attributes quantitatively.[1] Quantitative analysis requires a baseline characterization of factors such as the number of affected facilities, the quantities of materials generated, the rate and time over which the materials are generated, cost information, and a range of other factors. Additional details regarding the calculations used in the analysis are presented in Appendix K. The appendix also presents equations for the analysis and input data, including data on unit costs, hourly wage rates, number of affected facilities, and other information.

4.4.1 Baseline for Analysis

The analysis measures the incremental impacts of each alternative relative to a baseline, which is how things would be if the alternative were not imposed (i.e., the No Action Alternative). The baseline used in this analysis assumes full licensee compliance with existing NRC requirements, including current regulations. This is consistent with the *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission* which states that, "...in evaluating a new requirement for existing plants, the staff should assume that all existing NRC and Agreement State requirements have been implemented" (NRC 2000c). The incremental costs and savings relative to this baseline are presented in Section 4.5.

4.4.2 Data and Assumptions

As discussed in more detail in Appendix K, this analysis draws on data regarding material quantities, doses, and survey costs that were developed in the SC&A 2003 and NRC 2004a reports, prepared under technical basis contracts for NRC. Some additional information was collected as part of the Draft GEIS and regulatory analysis.

The collective dose is based on the time period when each reactor will be decommissioned. For metals, the modeling is a cumulative total of all source terms and pathways having significance. Since all of the expected amounts of materials are expected to be generated during the remediation of power reactors, the analysis considers the time period (47 years) during which such materials will be generated and 200 years beyond in assessing long-term impacts. The analysis assumes that the remediation work of all power reactors effectively will be completed by 2050. The time period of the analysis in SC&A 2003 is 250 years, which is the time during which potentially clearable materials from existing licensees would be released. It should be noted that because most of the radioactivity is due to radionuclides with half-lives measured in years (fraction of a year to about 30 years) rather than in thousands of year, the doses and impacts beyond 250 years become vanishingly small. For the impacts associated with landfill disposals, the analysis was carried out to 1,000 years. However, in both cases, no specific distinction is made between the results associated with the 250 or 1000-year analysis given that beyond 250 years collective doses become negligible.

[1] A third attribute, environmental considerations, is evaluated partly quantitatively and partly qualitatively. In addition, the analysis addresses certain subsets of material on a qualitative basis (copper and aluminum from LWRs and all materials from research reactors).

The analysis estimates costs based on the actual remaining operating lives of the LWRs. For the analysis as a whole, however, costs and savings are estimated for 47 years, with each year's costs and savings discounted back to the present at a 7 percent discount rate, in accordance with NUREG/BR-0184 (NRC 1997b). The 47 year period encompasses the planned shutdown dates and subsequent decommissioning of all LWRs. Dose is estimated for 100 years, because the dose will not cease at the end of 47 years (SC&A 2003). In fact, dose will continue after 100 years, however, after that point, dose becomes negligible in the cost-benefit analysis. As a sensitivity analysis, the analysis also presents results calculated using a 3 percent discount rate, as called for by NUREG/BR-0184 and the Office of Management and Budget (OMB) Circular A-4 (OMB 2003). Section 4.6 presents the results of this sensitivity analysis.

SC&A 2003 estimates differing quantities of materials that could be released under each dose option and each alternative. In many combinations of alternative and dose option, more material could be released than in the No Action Alternative. Consequently, this shift in the amount of material released has a great impact on the calculated costs, often eclipsing the impacts on costs associated with the shifts in management of the material. Tables K-10 and K-11 in Appendix K show the quantities of materials assumed to be released under each alternative and dose option. By far, the attribute that has the biggest effect on the overall benefits and costs of the rule is industry operation, which includes paperwork costs, survey costs, transportation costs and disposal costs. Section 2.2 of Appendix K describes the major assumptions and unit costs associated with this attribute.

The analysis assumes economic rationality (i.e., least cost behavior) on the part of all entities affected by the rule. For example, under the Unrestricted Release Alternative, in which ferrous metal could be recycled, this analysis assumes that ferrous metal will only be recycled if it is more profitable (or less costly) to recycle steel than to dispose of it. Similarly, the costs associated with a municipal solid waste (MSW) incinerator are greater than those associated with an MSW landfill due to transport and disposal costs. Therefore, this analysis assumes that facilities will not choose to send their trash to an MSW incinerator, even if allowed to do so, and instead will dispose of their trash in a MSW landfill. Consequently, the costs and benefits of EPA/State-regulated trash incineration are the same as the RCRA Subtitle D Landfill Alternative. Table 4-1 summarizes the assumptions made about how materials are managed in the baseline and in each alternative under consideration.

Table 4-1 Disposition of Released Material under Baseline and Alternatives

Alternative	Concrete[1]	Ferrous Metal	Trash
Baseline/No Action	Recycled	Recycled	MSW Landfill
Unrestricted Release	Recycled	Recycled	MSW Landfill
EPA/State-Regulated Landfill Disposal	MSW Landfill	MSW Landfill	MSW Landfill
LLW Disposal	LLW	LLW	LLW
Limited Dispositions	Recycled	MSW Landfill	MSW Landfill

[1] Concrete would be released at or below the 1 mrem/yr criterion and could be recycled into roadbed material.

MSW = municipal solid waste; LLW = low-level waste.

The analysis also assumes it will not be cost effective to decontaminate and resurvey any material that is not releasable based on the initial survey. Such material is assumed to be sent for disposal at a LLW facility. Additionally, recycling fees and/or revenues from recycling are calculated only for the first recipient of the material (e.g., a scrap yard) because after that point, the material has been released.[2]

Finally, the analysis assumes that future disposal costs will not change. It is possible that new disposal capacity will be required, or required earlier, as a result of some alternatives of this rule. Appendix J presents a capacity analysis addressing this subject. As available disposal capacity is used, or if new disposal facilities are constructed, it is possible that disposal costs will change as a result. To address the uncertainty of LLW disposal cost, which is a major cost driver, this analysis conducts a sensitivity analysis that considers the effect of a 15 percent increase in disposal costs effective in the year 2020 (see Section 4.6).

Inventory information on other metals, besides ferrous metal, indicated these were primarily copper or aluminum, and there is a small amount of these materials generated as compared to ferrous metal. The results of a screening analysis indicated that collective doses for copper and aluminum are about one to two orders of magnitude lower than that of ferrous metals (Section 3.2.4.2.2 and Appendix F, Table F-1). Consequently, these materials were not included in the cost-benefit analysis. Since data on the type and quantity of tools and equipment available for reuse and the frequency at which they are being released were not available, equipment reuse was not included in the cost-benefit analysis, but a scoping assessment of collective doses is presented in Appendix D, Section 12.

4.5 RESULTS

The quantifiable net benefits associated with each of the various alternatives are presented in Table 4-2. Negative benefits (shown in parentheses) reflect net costs, rather than benefits. These

Table 4-2 Net Incremental Benefit (Cost) Associated with Rule Alternatives by Dose Level ($2003)

Dose	No Action	Unrestricted Release Material Specific Limits	Unrestricted Release Material Independent Limits	EPA Landfill	LLW Disposal/ Prohibition	Limited Dispositions
0.03 mrem/yr		($1,402,791,183)	($1,404,275,647)	($1,402,724,765)		
0.1 mrem/yr		($226,445,926)	($293,721,822)	($282,786,154)		
1 mrem/yr		$294,339,854	$247,048,219	$180,994,024		
10 mrem/yr		$323,222,558	$306,761,633	$193,277,348		
IAEA RS-G-1.7			$246,520,945	$180,993,217		$257,201,896
No Action	-					
LLW Disposal					($1,404,070,173)	

Notes: Results are calculated as the present value of all quantitatively analyzed attributes calculated over 50 years and discounted at 7 percent. This excludes attributes described qualitatively in Section 4.5 (regulatory efficiency and other considerations).

[2] In contrast, dose is calculated through end users.

benefits are broken out by attribute in Table 4-3. Appendix K presents year-by-year undiscounted costs for each alternative, by dose option and attribute, in Tables K-15 through K-28. Qualitative results are discussed below.

- By definition, there are no benefits or costs associated with the No Action Alternative.

- The Unrestricted Release Alternative is expected to result in net incremental benefits under the 1 mrem/yr, 10 mrem/yr, and IAEA RS-G-1.7 dose options. As shown in Table 4-4, most of the benefits result from changes in industry operations (i.e., costs and benefits associated with survey, transportation, and recycling or disposal of material). Public health benefits arise as there are fewer vehicular accidents. Environmental benefits arise as there are fewer air emissions due to a decrease in vehicle miles traveled and as a result of favorable manufacturing tradeoffs as recycled steel replaces virgin steel. (The changes in ferrous metal scrap due to this rule would be approximately a tenth of a percent of the total U.S. market and therefore not expected to have any significant disruptions.) Sometimes these benefits are slightly offset by a cost resulting from a slight increase in dose to the public.

- Conversely, under the Unrestricted Release Alternative, at the 0.1 mrem/yr and 0.03 mrem/yr dose option levels, the analysis projects net costs, because more material fails to clear and, therefore, must be transported across the country for disposal as low-level waste.

- The EPA/State-Regulated Disposal Alternative, while less beneficial than the Unrestricted Release Alternative also is expected to result in substantial net incremental benefits at the 1 mrem/yr, 10 mrem/yr, and IAEA RS-G-1.7 dose options. In this alternative, benefits result from changes in industry operation. A small additional benefit results from changes in public health (routine) because the dose to the public is less than in the baseline. However, some benefit is offset by environmental costs related to a decrease in recycling.

- The LLW Disposal Alternative is projected to result in a net cost of approximately $1.4 billion. Most of this cost results from changes in industry operation, including transportation and disposal of materials as LLW. Other substantial costs result from change in public health - accidental, as a result of more deaths from the increased transportation distances. A lower collective dose to the public is the only benefit of this alternative. All of the other quantifiable attributes contribute to a net cost.

- The Limited Dispositions Alternative is expected to result in a net incremental benefit of about $260 million. Most of the benefits result from changes in industry operations (i.e., benefits associated with survey, transportation, and recycling or disposal of material). Public health benefits arise from both lower radiological doses and fewer vehicular accidents. There is a slight environmental cost associated with the loss of otherwise recyclable ferrous metals being disposed in landfills. Because this material is not recycled, recycled ferrous metal cannot replace virgin ferrous metal production.

Table 4-3 Net Incremental Benefit (Cost) Associated with Attributes by Alternative and Dose Level ($2003)

Alternative	Dose option	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations	Total
No Action	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0
Unrestricted Release Material Specific Limits	0.03	$1,174,216	($13,514,350)	($219,720)	($1,376,897,891)	($3,395)	$0	($451,377)	($12,878,667)	($1,402,791,183)
	0.1	$960,746	$0	($219,720)	($226,113,873)	($3,395)	$0	($451,377)	($618,308)	($226,445,926)
	1	($787,022)	$0	($219,720)	$293,675,372	($3,395)	$0	($451,377)	$2,125,995	$294,339,854
	10	($8,167,397)	$0	($219,720)	$329,263,365	($3,395)	$0	($451,377)	$2,801,081	$323,222,558
Unrestricted Release Material Independent Limits	0.03	$1,233,593	($13,514,350)	($219,720)	($1,378,418,237)	($3,395)	$0	($451,377)	($12,902,162)	($1,404,275,647)
	0.1	$1,205,052	$0	($219,720)	($291,974,108)	($3,395)	$0	($451,377)	($2,278,274)	($293,721,822)
	1	$713,415	$0	($219,720)	$246,021,542	($3,395)	$0	($451,377)	$987,754	$247,048,219
	10	($1,851,424)	$0	($219,720)	$306,935,439	($3,395)	$0	($451,377)	$2,352,109	$306,761,633
	RS-G-1.7	$186,142	$0	($219,720)	$246,021,542	($3,395)	$0	($451,377)	$987,754	$246,520,945
EPA/State-Regulated Disposal (Landfill)	0.03	$1,240,634	($13,514,350)	($219,720)	($1,376,897,891)	($3,395)	$0	($451,377)	($12,878,667)	($1,402,724,765)
	0.1	$1,240,530	$0	($219,720)	($281,093,000)	($3,395)	$0	($451,377)	($2,259,193)	($282,786,154)
	1	$1,239,881	$0	($219,720)	$181,462,308	($3,395)	$0	($451,377)	($1,033,674)	$180,994,024
	10	$1,237,267	$0	($219,720)	$193,637,557	($3,395)	$0	($451,377)	($922,985)	$193,277,348
	RS-G-1.7	$1,239,074	$0	($219,720)	$181,462,308	($3,395)	$0	($451,377)	($1,033,674)	$180,993,217
LLW Disposal/Prohibition	NA	$1,240,689	($13,514,350)	$0	($1,378,439,254)	($3,395)	$0	($451,377)	($12,902,486)	($1,404,070,173)
Limited Dispositions	RS-G-1.7	$1,227,219	$0	($219,720)	$258,149,485	($3,395)	$0	($451,377)	($1,500,316)	$257,201,896

Notes: Results are calculated as the present value of all quantitatively analyzed attributes calculated over 50 years and discounted at 7 percent. This excludes attributes described qualitatively in Section 4.5 (regulatory efficiency and other considerations).

Table 4-4 Sensitivity Analysis in Net Incremental Benefit Using a 3 Percent Discount Rate ($2003)

Dose	No Action	Unrestricted Release Material Specific Limits	Unrestricted Release Material Independent Limits	EPA Landfill	LLW Disposal/ Prohibition	Limited Dispositions
0.03 mrem/yr		($3,096,851,438)	($3,098,955,560)	($3,096,677,677)		
0.1 mrem/yr		($503,025,207)	($648,746,117)	($625,205,528)		
1 mrem/yr		$646,271,345	$546,801,706	$398,563,623		
10 mrem/yr		$704,293,966	$677,063,566	$422,314,544		
IAEA RS-G-1.7			$545,402,481	$398,561,911		$567,379,193
No Action	-					
LLW Disposal					($3,098,503,318)	

Notes: Results are calculated as the present value of all quantitatively analyzed attributes calculated over 50 years and discounted at 3 percent. This excludes attributes described qualitatively in Section 4.5 (regulatory efficiency and other considerations).

- For the 0.03 mrem/yr dose options (regardless of the Alternative) it is economically infeasible to survey concrete and ferrous metal. Consequently, these materials are sent to LLW disposal, resulting in costs similar to the LLW Disposal Alternative. Because trash can still be surveyed at this dose level, some trash is sent to EPA landfills, resulting in a slightly lower cost than the LLW disposal alternative.

- Note that OMB considers a rule “economically significant” under Executive Order 12866 if annual effects are greater than $100 million. The $1.4 billion cost associated with the LLW Disposal Alternative and the 0.03 dose options of the Unrestricted Release and EPA/State-Regulated Disposal Alternatives are discounted. When these costs are spread over the 47 year time frame of the analysis using a 7 percent discount rate, the annual cost exceeds the $100 million threshold and thus would qualify as “economically significant.”

Qualitative Results

- Regulatory Efficiency - By developing standardized procedures to clear material, there will be increased regulatory efficiency for both NRC and for facilities that are undergoing decommissioning (except under the No Action Alternative). By having clearly defined procedures for clearing materials, facilities will be more certain of the options open to them at decommissioning. At the same time, NRC will have guidance in place that address how material can be released.

- Other Considerations - Public confidence in NRC likely will be affected by this action, regardless of which one of the alternatives NRC adopts. Early public comment indicated that the public is concerned about the safety issues related to radioactive materials. NRC will need to consider public confidence as it proceeds in the decision making process.

4.6 DISCUSSION OF SENSITIVITY RESULTS

This analysis utilizes many assumptions to estimate the net costs and benefits of the alternatives. This section presents several sensitivity analyses to determine the impact of several key assumptions.

Table 4-4 presents a sensitivity analysis using a three percent discount rate. Compared to the seven percent discount rate used in the main analysis, all net benefits and costs are roughly twice as high using the three percent discount rate. This reflects the relatively long timeframe (i.e., almost 50 years) in which materials will be affected.

As described in Section 4.4.2, there is uncertainty about future LLW disposal costs. Table 4-5 presents the results of a sensitivity analysis in which LLW disposal costs increase by 15 percent in 2020 to address increases in cost associated with the need for additional LLW disposal capacity. These results are not significantly different from the results of the main analysis. For example, for the Limited Dispositions Alternative, the change in disposal costs results in about a five percent *increase* in the overall benefit. The benefits increase because more material is sent to LLW Disposal in the baseline than in the alternative. In the LLW Disposal alternative, the change results in about a four percent *decrease* in overall benefit. The benefits decrease because more material is sent to LLW disposal in this alternative than in the baseline, resulting in a higher cost.

Table 4-5 Sensitivity Analysis in Net Incremental Benefit Assuming a 15 Percent Increase in LLW Disposal Costs in 2020

Dose	No Action	Unrestricted Release Material Specific Limits	Unrestricted Release Material Independent Limits	EPA Landfill	LLW Disposal/ Prohibition	Limited Dispositions
0.03 mrem/yr		($1,467,655,460)	($1,469,165,029)	($1,467,589,042)		
0.1 mrem/yr		($223,501,643)	($293,222,556)	($276,935,787)		
1 mrem/yr		$307,248,543	$258,283,611	$194,858,206		
10 mrem/yr		$337,467,478	$320,393,318	$207,587,058		
IAEA RS-G-1.7			$257,756,338	$194,857,399		$270,719,576
No Action	-					
LLW Disposal					($1,468,959,903)	

Notes: Results are calculated as the present value of all quantitatively analyzed attributes calculated over 50 years and discounted at 3 percent. This excludes attributes described qualitatively in Section 4.5 (regulatory efficiency and other considerations).

A third sensitivity analysis was performed to assess the impact of transportation costs on the overall benefits and costs of the alternatives. In the main analysis all material was assumed to be shipped by truck. However, given the long distances that are involved in transporting material to LLW disposal facilities (1,544 miles on average), a sensitivity analysis was run in which all material being shipped to LLW facilities was shipped by rail. Table 4-6 presents the results of this analysis. Use of rail lowers the cost of this rule by about 40 percent for the LLW Disposal

Table 4-6 Sensitivity Analysis in Net Incremental Benefit (Cost) Assuming Transport of Material Destined for LLW Disposal by Rail ($2003)

Dose	No Action	Unrestricted Release Material Specific Limits	Unrestricted Release Material Independent Limits	EPA Landfill	LLW Disposal/ Prohibition	Limited Dispositions
0.03 mrem/yr		($883,613,800)	($884,334,260)	($883,547,382)		
0.1 mrem/yr		($242,967,381)	($284,430,964)	($325,705,793)		
1 mrem/yr		$195,798,319	$166,990,577	$73,595,507		
10 mrem/yr		$211,169,015	$203,341,050	$80,396,722		
IAEA RS-G-1.7			$166,463,304	$73,594,700		$152,405,179
No Action	-					
LLW Disposal					($884,118,225)	

Notes: Results are calculated as the present value of all quantitatively analyzed attributes calculated over 50 years and discounted at 3 percent. This excludes attributes described qualitatively in Section 4.5 (regulatory efficiency and other considerations).

Alternative as well as the 0.03 mrem/yr dose option in the Unrestricted Release and EPA/State-Regulated Disposal Alternatives. The benefit of this rule for the Limited Dispositions Alternative, and the 1 mrem/yr and and 10 mrem/yr dose options for the Unrestricted Release and EPA/State-Regulated Disposal Alternatives is reduced, because the more expensive truck transport of material to LLW disposal is avoided, reducing overall baseline costs.

CHAPTER 5
STAFF ASSESSMENT

Based on the analyses presented in this document, it can be concluded that for all the alternatives there are no significant impacts, except for the LLW Disposal Alternative. For this alternative, there are higher estimated transportation accidents, a large impact on LLW disposal capacity, and a large cost. A summary of the environmental impacts of the alternatives is presented in Section 2.6.

The No Action Alternative (NRC's current approach) is workable and familiar to licensees. However, there is a lack of an overall risk basis or consistent approach, the measurement bases are outdated, there is no regulation associated with the current approach, licensees have problems using the current approach when dealing with materials day-to-day, and there are expenditures of NRC staff resources on case-specific reviews.

The National Academies report indicates that NRC's current approach for controlling the disposition of solid materials (the No Action Alternative) is "sufficiently protective of public health that it does not need immediate revamping." However, the National Academies report also indicates that the current approach is incomplete and inconsistent and that NRC's approach should be risk-informed. As a result, the National Academies study states that NRC should conduct a process to evaluate alternatives to provide clear risk-informed direction on controlling the disposition of solid materials. This Draft GEIS is part of that process and considers several alternatives which are risk-based rulemakings.

One of the rulemakings considered is the Unrestricted Release Alternative. This alternative would allow solid materials to be released for use in general commerce if a radiation survey verifies that radionuclide concentrations in a dose-based regulation have been met. This alternative satisfies the NRC strategic goal of ensuring protection of public health and safety and the environment. A dose limit of 1 mrem/yr was analyzed for this alternative because it is a small fraction of the public dose limit, the National Academies recommended it in their study, and it is consistent with national and international clearance guidelines. Other dose limits (0.03, 0.1 and 10 mrem/yr) were also considered as options. The lower dose limits were rejected because there are difficulties in surveying at these dose limits (Appendix K) and disposal costs would be higher. Larger amounts of material were released for the 10 mrem/yr dose limit.

Some commenters viewed the Unrestricted Release Alternative as the least expensive option, while still providing adequate protection. They found disposal of all potentially clearable solid materials in a licensed LLW disposal facility is costly to licensees without an accompanying health and safety benefit and would cause a severe economic impact for small licensees (e.g., medical facilities, universities). However, most of the public commenters were concerned that risks associated with unrestricted use of these solid materials are avoidable and involuntary, the risks of radiation are underestimated, there is a potential for exposures to multiple products, and releases would not be accurately measured and tracked. Also commenters from the steel and concrete industries, who would receive the cleared material, indicated that their potential costs could be very large because consumers could choose not to purchase items made from material recycled from licensed facilities.

To answer some of the public's concerns with unrestricted use, we also examined the EPA/State-Regulated Landfill Disposal Alternative. This alternative considers release of solid materials only to EPA/State-Regulated RCRA Subtitle D facilities. This approach would prevent solid material from licensed facilities from entering general commerce, thus limiting the potential for radiation dose to the general public. Also, limiting disposal of released solid materials to an EPA/State-Regulated landfill would place a smaller economic burden on licensees than disposal of all potentially clearable solid materials at a licensed LLW disposal site. (Some potentially clearable solid material would still go to a LLW facility if it was above the dose limit.) However, this alternative would allow higher radionuclide concentrations because a greater amount of activity could be released to landfills than the amount that would be released to general commerce under the Unrestricted Release Alternative.

The next alternative considered was the LLW Disposal Alternative, also referred to as Prohibition. In this alternative, all potentially clearable solid material would be prohibited from general commerce. The solid material would be required to be disposed of in a LLW disposal site. This approach would prevent potentially clearable solid material from licensed facilities from entering general commerce, thus limiting the potential for public exposure to radiation. However, if all potentially clearable material (which has no, or very small amounts of, radioactivity and which has some economic value) is sent to LLW disposal sites, this would be costly to licensees. Furthermore, there is a large impact on LLW disposal capacity - the solid materials to be generated from the existing commercial nuclear reactors would represent more than the existing LLW disposal capacity.

After assessing the above alternatives, NRC considered the Limited Dispositions Alternative. Under this alternative, potentially clearable solid material (concrete, steel and trash) could be released, if it were below radionuclide concentrations associated with a dose criterion of 1 mrem/yr, but with only certain authorized dispositions to limit the potential for public exposures. Three pre-authorized dispositions are considered in this alternative - RCRA Subtitle D landfill disposal, concrete use in road beds, and the reuse of tools and equipment. Any requests to release material other than the three pre-approved dispositions (for example, soils or industrial uses such as metals in bridges, sewer lines, or industrial components in a factory) or at higher radionuclide concentrations would require case-specific approval.

To minimize the potential impacts of the unlikely release of solid material into other products, the radionuclide concentrations considered in this alternative are based on unrestricted release. The IAEA radionuclide concentrations were chosen to be consistent with national and international numeric guidelines. Another economic benefit is that potentially clearable solid materials could be used under certain authorized conditions, rather than using the more costly licensed LLW disposal facilities. As shown in Table 3-29, the collective dose for this alternative is lower than for the No Action Alternative because exposures to the public are more limited. To ensure that the material releases are occurring to the pre-approved dispositions, there would be licensee recordkeeping and these activities would be evaluated periodically during routine staff inspections at licensed facilities. Also enforcement action would be taken if necessary.

Municipal solid waste operators, EPA and the State agencies have the discretion of allowing or refusing disposals in Subtitle D facilities. Even if allowed, EPA and the State agencies might impose additional constraints on such disposals. Accordingly, the implementation of the rule would have to consider EPA and State agency requirements as well as the concerns of the landfill operators. It is envisioned that some landfill operators might not want to receive such materials, but others would, considering economic factors. At this time, however, it is not possible to determine readily which landfill operators and State agencies might find the NRC rule an effective option.

Most landfills routinely monitor incoming waste shipments for the presence of radioactivity. The radiation monitoring systems typically are installed at the scales where trucks are weighed before being sent to specific waste processing areas. The alarm set-points are set at varying levels, typically at a multiple of ambient background levels. If a waste shipment were to set off an alarm, the shipment is typically set aside and the originator of the shipment is informed of the situation. Also, landfill operators may call the State agency responsible for radiation protection for guidance on how to proceed. Licensees will have to be aware of monitoring practices for incoming shipments to landfills or other destinations as part of their business practices, in addition to complying with the nuclide concentrations in this regulation for release of solid materials from licensed control.

Recommendation

After considering the costs, benefits, and impacts of all the alternatives, the staff has preliminarily concluded that the Limited Dispositions Alternative would ensure that doses are maintained well below levels established to ensure protection of public health and safety and the environment, has among the lowest costs, and its dose criterion is consistent with international guidelines. The No Action Alternative (NRC's current approach) sufficiently protects public health, but there is a need for a risk-informed regulation. Most public commenters were concerned about the Unrestricted Release Alternative because of the increased potential for exposures to consumer products. The EPA/State-Regulated Disposal Alternative would limit the potential for radiation dose to the general public, but the radionuclide concentration limits for only landfill disposal are higher than for unrestricted release. For the LLW Disposal Alternative, there are higher estimated transportation accidents, a large impact on LLW disposal capacity, and a large cost. Thus the Limited Dispositions Alternative is the staff's preliminary recommendation.

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APPENDIX A
SCOPING SUMMARY REPORT

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SCOPING SUMMARY REPORT

Controlling the Disposition of Solid Materials

March 2004

U.S. Nuclear Regulatory Commission
Rockville, MD

1. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) staff is preparing a generic environmental impact statement (GEIS) on the proposed rulemaking on controlling the disposition of solid materials. This rulemaking concerns materials at NRC-licensed facilities that have very low amounts of, or no, radioactivity. The purpose of the rulemaking is to continue to assure the control of the disposition of solid materials in a manner that protects public health and safety and the environment while improving efficiency in regulation. This GEIS is part of the NRC staff's decision-making process.

The NRC, the U.S. Environmental Protection Agency (EPA), the U.S. Department of Energy (DOE) and the States have an interest in the proposed rulemaking and have agreed to participate as cooperating agencies. EPA sets radiation protection standards in the general environment. DOE is preparing a Programmatic EIS on alternatives for disposition of DOE scrap metals at their facilities. Also, the proposed NRC rulemaking could result in related rulemakings in the Agreement States and Suggested State Regulations; the Conference of Radiation Control Program Directors (CRCPD) and the Organization of Agreement States (OAS) have identified the State of Massachusetts as the State representative in the preparation of the GEIS.

The NRC's regulations in 10 CFR Part 51 contain requirements for conducting a scoping process prior to preparation of an EIS. As part of the NRC staff's examination of its approach for control of solid materials, including the scope of an environmental impact statement, the NRC staff sought early input on the major issues associated with this effort. In June 1999, the NRC staff published an Issues Paper (64 FR 35090) for public comment that described issues and alternatives related to the release of solid materials. To provide further opportunity for public input, the NRC staff held a series of four public meetings during the fall of 1999. The NRC staff received over 800 public comment letters and emails from stakeholders representing the metals, metal scrap, and concrete industries; citizens groups; licensees and licensee organizations; landfill operators; Federal and State agencies; and Tribal governments. Comments were also received from stakeholders at the four public meetings. Comments were sharply diverse in the views expressed, and there was support and rationale provided by commenters for a range of alternatives for controlling the disposition of solid materials. On March 23, 2000, the NRC staff provided the Commission with a paper (SECY-00-0070) on the diversity of views expressed in public comments received on the Issues Paper. Attachment 2 of SECY–00–0070 provides a summary of views and comments received; summaries of the comments can also be viewed in NUREG/CR–6682, ''Summary and Categorization of Public Comments on the Control of Solid Materials'' (September 2000). SECY–00–0070 also provided the status of the staff's technical analyses being developed as support for making decisions in this area and noted the related actions of international and national organizations and agencies that could be factors in the NRC staff's decision-making.

To solicit additional input, the Commission held a public meeting on May 9, 2000, at which stakeholder groups presented their views and discussed alternatives for controlling the disposition of solid materials. On August 18, 2000, the Commission decided to defer a final decision on whether to proceed with rulemaking and directed the staff to request that the National Academies conduct a study of alternatives for controlling the disposition of solid materials. The Commission also directed the staff to continue to develop technical information and to stay informed of international and U.S. agency activities in this area. The National Academies study of alternatives for controlling the disposition of solid materials was initiated in August 2000. As part of the study, the National Academies held three information gathering meetings in January, March, and June of 2001, at which it obtained input from various stakeholder groups similar to those that presented information to the NRC staff earlier. Based on these meetings, and on its deliberations on this topic, the National Academies submitted a report to the NRC in March 2002 ("The Disposition Dilemma - Controlling the Release of Solid Materials from Nuclear Regulatory Commission-licensed Facilities"). The report contains nine recommendations on the decision-making process, potential approaches for controlling the disposition of solid materials, and additional technical information needed. One finding of particular note in the National Academies report was that NRC's current approach for controlling the disposition of solid materials protects public health and does not need immediate revamping. However, the National Academies report also states that NRC's current approach is incomplete and inconsistent and concludes that the NRC staff should therefore conduct a process to evaluate a broad range of alternatives to provide clear risk-informed direction on controlling the disposition of solid materials. The report notes that broad stakeholder involvement and participation in the NRC staff's decision-making process on the alternatives is critical as the process moves forward. A summary of the National Academies report can be found in an NRC staff paper, SECY-02-0133, and a link to the National Academies report, itself, is contained in the Background section of the NRC's web page on Controlling the Disposition of Solid Materials (http://www.nrc.gov/materials.html; click on "Controlling the Disposition of Solid Materials" under "Key Issues").

As an additional part of its continuing efforts to solicit stakeholder involvement, the NRC staff published on February 28, 2003, a Request for Comments on the scope of a proposed rulemaking and notice of workshop in the Federal Register (68 FR 9595). In this Federal Register Notice, the NRC staff sought stakeholder participation and involvement in identifying alternatives and their environmental impacts that should be considered as part of a rulemaking and analyzed in a GEIS. The NRC staff also announced in this Federal Register Notice its intent to conduct a workshop to solicit new input with a focus on the feasibility of alternatives that would limit where solid materials could be released. The workshop was held at NRC Headquarters in Rockville, MD May 21-22, 2003. A summary of the results of this workshop is available on NRC's web page on Controlling the Disposition of Solid Materials.

Over 2,600 public comment letters and emails were received in addition to the discussion at the workshop. NUREG/CR-6682 Supplement 1 ("Summary and Categorization of Public Comments on Controlling the Disposition of Solid Materials," March 2004) summarizes the comments received as a result of the NRC staff's request for comment and the workshop discussion. Comments were received from various stakeholder groups, including environmental and citizen's groups, members of the general public, scrap and recycling companies, steel and cement manufacturers, hazardous and solid waste management facilities, the U.S. Environmental Protection Agency (EPA), U.S. Department of Energy (DOE), State agencies, Tribal Governments, scientific organizations, international organizations, and NRC licensees and licensee organizations.

The 1999 and 2003 public comments are summarized in Section 2 of this report. All comments received to date have been considered. The comments have been categorized to ease reader understanding of the issues raised.

The scoping process helped to determine the scope of the GEIS, including significant issues to be analyzed in depth. For example, in response to comments received during the scoping process, the GEIS will include an alternative where the potentially clearable material can only be disposed of in a licensed low-level waste (LLW) disposal facility. Issues outside the scope of the DGEIS have been forwarded to appropriate staff and may be discussed in other parts of the rulemaking package.

Section 3 identifies the issues the GEIS will address, and Section 4 identifies those issues that are not within the scope of the GEIS. Although issues raised during the scoping period will be considered in the preparation of the Draft GEIS, some of those issues will either be analyzed in less detail or will not be analyzed at all, depending on their relevance to the proposed action and the anticipated impacts. Issues that will be considered, but not analyzed in detail, are addressed in Section 4.

2. SCOPING COMMENT SUMMARY

2.1 INTRODUCTION

The comments were extensive and wide-ranging, focusing on specific alternatives and technical issues that should be considered as part of NRC's rulemaking process. In addition, there were numerous comments related to potential impacts on public health and safety as well as on various industries.

Some commenters indicated that there is a significant need to establish a national standard for the release of solid materials, citing a lack of consistency in criteria and problems with implementation under the current system. Others, however, believe that the current system is both protective and easily implement able. These groups cite reports by national and international standards setting bodies that indicate that health risks at dose levels being considered are negligible or trivial. Some commenters suggested that NRC adopt the American National Standards Institute (ANSI) standard N13.12-1999, Surface and Volume Radioactivity Standards for Clearance.

Many commenters stated that there should be no release of solid materials from licensed facilities even if the calculated dose or health risks are low. In particular, potential recipients of solid material, such as scrap, metals, and cement industry representatives, objected to the release of solid materials. These commenters noted that there could be significant negative economic impacts on their industries if consumers had concerns over the presence of radioactivity in products. A large number of citizen groups and members of the public also expressed concern about the health effects of the potential presence of released material in consumer products and recommended that NRC prohibit the release of this material to isolate it from the public. Some of these commenters further suggested that NRC should implement a program to identify and recover all materials previously released under the current regulation.

Commenters also described concerns with a restricted use alternative, citing possible oversight and enforce ability issues. A number of commenters discussed the possible alternative of disposal in either EPA-regulated or NRC/Agreement State-licensed disposal facilities. Most commenters believe that disposal in an NRC/Agreement State-licensed disposal facility is the most appropriate alternative.

A number of commenters provided input on the National Environmental Policy Act (NEPA) process which governs the development of the Generic Environmental Impact Statement. Still more commenters weighed in on NRC's rulemaking process.

2.2 NO ACTION/CURRENT APPROACH

Advantages of Current Approach

Protective: The current approach protects public health and safety; released materials are monitored; no one has been placed at risk from release of materials; the National Academies report concluded that it protects public health.

Current approach is useful: It has been a useful tool for 20 years; there is common understanding on how to use it; it is easier to implement than a dose-based approach because exposure pathways do not have to be calculated; the National Academies report concluded that it is workable.

Disadvantages of Current Approach

Criteria not risk-based: They are currently based on instrument detection capabilities and concentrations in effect since 1974; the NAS report notes that the criteria are not explicitly risk-based.

Not a good regulatory framework: The current approach does not provide an adequate or logical regulatory framework, and does not provide clear guidance.

Not cost-effective and a waste of resources: The current approach can cause substantial additional cost and resources, especially at decommissioning, and may cause replication of effort from previous submittals. Without clear guidance some material is currently disposed of as radioactive waste even though there is not enough radioactive material to cause an exposure. This is an inappropriate use of resources.

Implementation is inconsistent: There can be fluctuations in background, different geometries and nuclides, differences in instrumentation approaches and efficiencies, analytic techniques, and inconsistencies in use of the “non-detectable” guideline. It is slow, resource intensive, can be difficult to implement, and can cause questions. This is also noted in the NAS report.

Volumetric contamination not considered: Volumetric contamination is not considered; this is also noted in the NAS report.

Decision criteria needed: Materials need to be released from facilities each day (and more material will be available for release in the future because of decommissioning) and improved decision criteria are needed about what should be done with these materials.

Current standard can be redundant: It can entail redundancy of oversight between the NRC and State agencies.

Cumulative Impacts: Cumulative impacts are not considered.

General Opposition to the Current Approach

No records: There is concern that NRC allows release (and possible recycle) of solid material based on case-by-case considerations under Regulatory Guide 1.86. There is also concern that people had been exposed without their knowledge and whether there are records of material released so far. Any releases should be tracked and records kept available to the public.

Not safe: The current approach is unsafe, and unacceptable to the metals industry and the public. There are no scientific data or proof available to show that what has been released so far using Regulatory Guide 1.86 levels has not harmed the public. This approach should cease.

Warning labels: There must be warning labels at a minimum so these products could be avoided.

Outdated: Regulatory Guide 1.86 is out of date and should not be updated or used because it lacks the full force and legitimacy of a final rule done under the Administrative Procedures Act (APA).

Being misused: Regulatory Guide 1.86 was developed based on criteria for decontamination of buildings and not for releasing materials involving intimate public contact. Regulatory Guide 1.86 should not be misused to allow releases into the marketplace or converted to dose basis.

Do not use: Regulatory Guide 1.86 should be removed from licenses so that licensees cannot release radioactive wastes into garbage for landfills or the marketplace.

2.3 DOSE-BASED REGULATION ON UNRESTRICTED USE

In general, comments on the dose-based regulation on unrestricted use alternative can best be characterized by stakeholder grouping. Therefore the comments in this section are presented by stakeholder group.

2.3.1 Citizen Groups and General Public

Unrestricted Release of Contaminated Materials

General opposition: Several commenters generally indicated that they were opposed to releasing materials for unrestricted release.

Health/Risk Considerations

NRC performance goal: NRC should do its job and abide by its own performance goal of protecting public health and safety for both present and future generations by preventing exposures to unjustified practices; NRC should not shift its responsibility to reducing the burden on industry.

Precautionary principle: Based on uncertainties of risk, and unexpected outcomes, the prudent course of action would be to bar distribution of radioactive materials into the public domain.

Psychological impacts: NRC should consider impacts on citizens and their confidence; radiation in products will contribute to pessimism about our culture and economic system.

Cannot reverse releases: As more is learned about the risks of low-level radiation (e.g., bystander effect), we will not be able to reverse the effects of materials already released.

Mixing materials: Large amounts of material will be released and more highly contaminated material will be mixed with this material to ensure compliance with any established standard.

Other organisms: Release of this material will increase background levels in the environment and will be bad for the environment; additional analysis and supporting evidence regarding how other organisms are being protected is required.

No safe dose of radiation: Low levels of radiation cannot be proven as trivial, and we do not know specific health effects at low doses of radiation. Low levels of radiation can have long term health effects and can sometimes be more harmful per unit of exposure than higher levels of radiation. Every additional exposure, no matter how small, increases the chances for, and numbers of, cancer.

NRC studies biased: The studies NRC depends on are biased and not publicly acceptable (e.g., International Commission on Radiological Protection (ICRP) studies). The 2003 Recommendations of the European Commission on Radiological Risk (ECRR) address health effects of low dose radiation and document criticism of the 1988 ICRP low dose models and failures of the Hiroshima study to predict consequences of exposure; this document indicates health risks are 100 times greater than predicted by current radiation limits.

Other studies cited: Other studies of health effects of low level radiation were noted which show that there is no safe dose of radiation below which no damage results and have confirmed ways that radiation alters cells. These studies should be considered by NRC; they have been ignored to date. These studies include: (a) indications of effects from depleted uranium in weapons; (b) medical studies that show that radiation is riskier than previously assumed; (c) the book "No Immediate Danger" by Rosalie Bertell documents that there is no safe level of radiation and predicted the increase in certain health effects that we have now (and also "Uncertain Science and Failure of Trust"); (d) studies by Gofman and others conclude that all radioactive contamination is cumulative; (e) those by independent scientists, including Dr. Alice Stewart, Morgenstern, Kadheim, Bulakova, Wing, Feuerhake, Wright, Viel, and the BEIR V Committee; (f) studies of Japanese atomic survivors bear out that radioactivity released slowly over time is more dangerous than a quick high dose; (g) J. Kahn article in NY Times (6/17/03) on lung damage to Chinese workers; and (h) cancer incidence rates are rising, especially at sites with radioactive contamination.

Long-term risks: These risks are long term risks and it is not known what the risk would be to future generations, including genetic and reproductive capabilities.

Linear No Threshold (LNT) model: NRC has acknowledged the validity of the LNT model of human exposure which holds that any increase in dose, no matter how small results in an increase in risk. Therefore, the NRC's mission to ensure adequate protection of public health and safety must restrict all radioactive material from general commerce and require disposal in a licensed LLW disposal facility.

Sensitive populations: Some populations have higher sensitivities to radiation and must be protected, even if their dose is less than the critical group.

Dose from man-made nuclides: The risk from man-made nuclides is not comparable to that from naturally occurring ones because internal doses (which can occur from recycled products) can be more damaging than external ones; also, man-made nuclides bond to DNA and certain human organs in ways that naturally occurring ones, to which life on earth has adapted, do not.

Unwanted risks: The risks being considered here expose the public without their consent and are unwanted, avoidable, involuntary, and unnecessary (unlike the dose a person gets from medical treatments), even if they are small, especially since the practices are unjustified.

Cannot accurately predict doses: Computer models cannot accurately predict all doses to the public (especially when considering the different nuclide behaviors and half-lives and associated risks in the environment and in humans). Doses cannot be measured, and thus projections of reasonable/acceptable risks are meaningless. Also, doses may be higher than estimated because some mills may receive a higher amount of metal from licensees than estimated in NRC's technical analyses. There may be unexpected outcomes and untraceable impacts. RESRAD is not reliable. Not all isotopes present are considered. Validation with data from actual releases should be done. The total quantity of material to be released in commercial products is uncertain and therefore it is unclear how NRC can reasonably evaluate health impacts, including the ability to determine how much is in the environment at any time. Analyses will not be able to determine the total dose, non-fatal cancers, reduced immunities to other health problems, non-cancer health effects, cumulative effects, impacts from multiple exposures, or effects to children or adults working with the materials.

Worker risks: Releases of solid materials will expose workers at steel mills, scrap metal facilities, road construction, sewer workers, etc. to potentially significant levels of contamination; they should not be exposed to any additional risk levels. Steel workers are an unprotected workforce from this hazard and are not routinely monitored for radioactive contamination, do not receive hazardous duty pay or long term medical monitoring, and might have to choose between their job security and radiation exposure.

Risk too high: The risk of exposure to 1 mrem/yr is that 1 of every 28,600 exposed will have a fatal cancer; these risks are too high, especially when projected over the U.S. population.

Do not add to background: The fact that we receive a dose from background does not justify adding more dose even if it is less than background; no dose above background is acceptable.

Synergistic effects: We do not know, and analyses will not be able to determine, synergistic interrelationships between dose and other hazardous impacts.

Other standards: The fact that there are air and liquid emission standards does not justify allowing more releases of solids into consumer products.

Current practice is no justification for release: The fact that material is released now is not a justification for releasing more material.

Consumer Products/Isolation

Unnecessary risk: Introduction of radioactive waste materials into consumer products (in particular products in the home, in home construction or in roadways, or playgrounds) poses unnecessary risks to workers and the public and the potential for multiple exposures.

No direct benefit: There are no direct benefits from releasing materials to the public.

Consumers would be unknowing: Labels would be needed to identify products made from released material, otherwise people would be exposed without any warning; There would probably not be any labels on the consumer products so there would be no way for consumers to know what dose they are getting.

Right-to-know and choose: The individual should have the right to choose the risk to which they are exposed.

Cost-benefit and Liability Considerations

No societal benefit: It should not be assumed that operation and decommissioning of reactors are socially justified nor that the releases are therefore justified. People get no direct personal benefit from the releases.

Rule aids industry at public expense: A rule is just an economic aid to the nuclear industry. Reducing costs of compliance to licensees should not be one of NRC's major considerations on this matter. Saving licensees money on waste disposal (for a relatively small amount of material) comes at too high a price, i.e., human health and socioeconomic costs. Most Americans do not have adequate health insurance to deal with the consequences of increased unnecessary radiation exposures. Those generating material should pay for disposal of it as part of the cost of doing business; NRC should protect the public instead.

Do not transfer problem: NRC should not transfer its problem of what to do with this material by passing the problem to scrap dealers and steel manufacturers, which could put them at legal and financial risk; consumers would avoid products made from recycled metals, resulting in more resources being expended to make products with virgin uncontaminated ores.

Burden: The burden of calculating releases would be reduced if material is simply not released.

Liability: There would not be any clear liability as to who is responsible for materials released once they have gotten into the public sector.

Tracking Released Materials

Cannot measure doses: Dose-based release standards cannot be physically measured, verified, or enforced, and each consumer product cannot be monitored. Thus, releases cannot be tracked and consumers will not know their dose from recycled products. So, even though NRC says the dose limit is only 1 mrem/yr, how can this be trusted when it cannot be verified?

Public will not know dose: A person would have no way of knowing what products contain radioactive material. There should be labels on any products made so that consumers can know what dose they are getting and can control it.

Need for safeguards/no detectable radiation: NRC should not allow releases that are not tested or safeguarded and should not allow detectable materials to be released.

Security issues: There should not be additional releases in this time of increased security concerns; radioactive materials released from licensed facilities will make it more difficult for efforts by local, State, and Federal agencies to detect dirty bombs. Materials in the nation's scrap could affect Homeland Security technology where road monitors will be reading levels in vehicles.

Detectors are not reliable: It is not clear if detectors can reliably survey materials and protect the public - NRC will not be able to measure releases accurately or enforce criteria because field conditions do not fit computer models and monitoring low levels of radiation near background to assure compliance is difficult and uncertain; large pieces of equipment can have complicated geometries (and workers will tend to avoid these areas - uncertainties are several percent for simple geometries and will be even higher for more complex geometries); non-uniform contamination; hot spots in large piles of scrap metal can be missed; equipment can malfunction; there are problems of false negatives; and there are issues of sorting materials.

Improper releases: Improper releases and mistakes cannot be avoided, especially when there are large volumes being handled, there is a lack of resources, and there is a need to survey quickly.

Multiple exposures: A person could be exposed to many items because once the material is released it will not be controlled.

Material in environment: Released material cannot be tracked especially over long time periods which will be an environmental headache for years to come.

Penalties: There should be penalties to those releasing material in violation of any standard.

Public Confidence

NRC has a goal of increasing public confidence: NRC should abide by its own safety goal of increasing public confidence by keeping this material out of the public domain.

NRC's sincerity in protecting public health is questioned: NRC tries to downplay hazards associated with this material; people are given incorrect information about potential risks from this material. NRC says it is safe but cancers continue to occur.

Dose assessments are suspect: Computer codes, and dose and pathway models are not trusted and can be manipulated so that predicted doses meet limits; supporting analyses for this rulemaking were prepared by nuclear advocates.

Economics may influence technical accuracy: Workers at licensed facilities cannot be trusted to detect radiation in releases because of carelessness or because it may not be in the best economic interests of the licensee; this could result in substantial amounts of material being released in violation of whatever standard is set.

Past issues have contributed to mistrust: Licensees and DOE cannot be trusted because workers have been misled about radiation hazards in the past and because other rules have not always been followed, and because DOE has failed to manage material safely. Thus, it is not clear if a rule in this area would be followed. There is little public trust in DOE. NRC must consider in its rulemaking the limitations of the entities responsible for releasing materials.

Failure of orphan source program: NRC has failed on the orphan source problem and there is no reason to believe that more problems would not occur.

Unreported releases are problematic: There have been unreported releases at NRC licensed facilities and NRC must fully disclose all metals that have been released and are currently in consumer products.

2.3.2 Metals Industry

Release of Contaminated Material

Radioactively contaminated scrap metal (from impacted or restricted areas) should not be released into the stream of commerce: The metals manufacturing industry suggests that the definition of radioactive contaminated scrap metal should be that which originates in impacted or restricted areas. Scrap metal is not considered to be radioactively contaminated if it does not originate from restricted or impacted areas, was never in such areas, and can be certified as never having been exposed to radiation. Scrap metal not originating in impacted or restricted areas can be released providing that NRC requires at least one of the following safeguards: (a) where there is clear process knowledge that the scrap metal is not originating from radiological areas and the license certifies that the scrap has not been radioactively contaminated; (b) stringent radiation surveys of the scrap metal shows it does not exceed dose-based clearance standards or background radiation levels for the area from which it is released (whichever is lower), or (c) the scrap metal is manifested, labeled, and tracked.

Criteria for release should be agreed upon by stakeholders: The scrap metals industry noted that any new regulation for the release of material that is contaminated at low levels must be based on criteria acceptable to affected stakeholders. Before criteria could be established, stakeholders should review several issues, including: (a) the effect of contamination on employees and equipment; (b) the capability to detect radioactivity in material; (c) potential uses of recycled material acceptable to affected industries and the general public; and (d) the potential to assure that such material could be used only for the purposes acceptable to the affected industries and the general public. There is probably a substantial amount of material at licensed facilities that has never become contaminated with radioactive material. While this material could be recycled, all affected stakeholders would need to agree on a measurable definition and acceptable means for proving and documenting that such material did not become contaminated by radioactive material and that the material did not become mixed with contaminated material at any time prior to release.

Health and Environmental Considerations

Worker health risks: There may be health risks to workers because of radionuclides in the steel mill (including the baghouse dust), even if in small concentrations, that may build up over time; loss of control of orphan sources; and illicit trafficking of materials.

Public safety risks: Steel may be used in applications that might not be safe to the public.

Lack of environmental benefit: There would be little environmental benefit of recycling of metals from licensed facilities because the amount of such metal is small compared to the total feedstock and the impact would be less than 1 percent per year and would not affect the amount of mining conducted.

Cost-benefit Considerations

Property contamination: There will be increased risk of property contamination at metals companies, including on equipment and in byproducts, and in generation of mixed wastes.

New regulatory requirements: If the steel industry has to handle radioactive material, it may also be required to comply with more stringent regulatory requirements governing worker exposure.

Legal liabilities: This would increase metals industry liability in potential civil suits.

Large economic impacts - product de-selection: There could be a very large economic impact on steel industries because consumers (who are their customers) do not want products because of concerns, even if only perceived, over presence of radiation and will de-select products. Such impacts could include loss of revenue and jobs if customers refuse to buy products made with metals. The resulting impact on the steel industry could be as high as $600 million even if there was only a 1 percent reduction in purchases.

Lack of trust: Recycling of metal from licensed facilities undermines public trust in the safety of consumer products. Perhaps safe levels can be set, however the marketability of products will be set by public perception and it is unlikely that the public will accept products that they use each day containing what will be characterized in the media as "radioactive material." There is a sense of risk from uncertainty and the public will feel that any risk is not worth it no matter how low a standard is set, and will not trust government to tell them what is safe.

Business disruption/orphan sources: The history of problems with loss of control of orphan sources has resulted in significant decontamination costs at steel mills; the presence of additional radioactivity would affect metals companies ability to detect and intercept orphan sealed sources.

Need to mine virgin ore: Public perception could influence industry to mine more virgin ore to vouchsafe that metals used in consumer products do not contain radioactive materials.

Shifting responsibility: The issue and problem of what to do with this material should not be shifted to the commercial metals industry but rather dealt with at the source by the generators of the material.

Small economic benefit to recycle: The amount of recycled steel from NRC-licensed facilities is so small that the economic advantage of recycling it is small and there exists an oversupply of most of these metals (ferrous metals are not likely to be affected although copper and nickel producers could be).

Acceptance Criteria

Steel mill detectors: Detectors are set at low dose rates that will alarm at levels near an NRC standard that might be promulgated (these detection systems are used because of previous problems with orphan sources). Steel and scrap yard detectors are becoming even more sensitive. The metals industry does not have the capability to distinguish the source of the alarm and hence it will reject the entire shipment.

Rejection of shipments: The steel industry would likely reject shipments of material released from NRC licensees even if the material is in compliance with an NRC standard.

Financial liabilities: The metals industry cannot take the financial liability of allowing radioactive material into their mills and exposing individuals and incurring economic loss.

2.3.3 Cement Industry

Release of Contaminated Materials

General opposition: There should be no release of materials for unrestricted uses in commerce and be recycled into concrete and other like products.

Health/Risk Considerations

Public health: Public exposure to products made with concrete is high, including use of concrete in drinking water reservoirs, tanks, and pipes, in residences, schools, and office buildings, and in driveways, sidewalks and train stations. In addition, there can be exposures to concrete masons in the concrete industry.

No benefit: Acceptance of radioactive material has no benefit to the cement and concrete industry but only possible endangerment to the industry’s workers and customers.

No extra doses: Exposures from other solid materials would add to potential radioactive doses from concrete products. Preventing additional exposure to the public from man-made sources in consumer goods is in the best interest of the public and should be NRC’s primary activity in carrying out its Congressional mandate to protect public health and safety.

Cost-benefit Considerations

Large economic impact - product de-selection: Any real or perceived public health risks posed by radioactive consumer goods, regardless of how slight the risk is, will not be tolerated by consumers who will be concerned about health effects despite scientific evidence. Consumers will not find the benefits of recycling by release of solid material from NRC licensees into commerce as persuasive reasons to accept the perceived additional exposures. These consumers will decide not to purchase these goods, as they will not wish to live or work in a building containing material recycled from licensees. This will translate into loss of market for the cement industry and threaten viability of the cement industry. The cement industry wants to be able to fully disclose to customers the origin and any radioactivity level and hazard from material - failure to do so will cause fiscal harm to the cement industry.

Costs for detectors: Increased potential for the release of radioactive material for reuse in the cement and concrete industry will cause them to incur significant additional expenses for surveillance for incoming radioactive material as well as management of any radioactive materials. Cement companies do not have the instruments and personnel training necessary to do these surveys and the industry would incur significant expenses for purchase of radioactivity monitoring equipment, training for personnel, facility modifications to segregate material, disposal costs for “orphan” radioactive material, liability insurance, and legal costs.

Shift of economic burden: A rulemaking will effectively shift the economic burden of disposal of the solid materials from the NRC licensees to the industries that would receive these wastes as recyclable material. This appears unfair considering that the licensees profited from the producing of these wastes.

Low economic benefit: The economic value for used concrete used as a fill material for aggregate is very low compared to virgin materials.

Public issues: NRC should practice gaining the public’s trust on issues where the potential adverse economic effects are limited to its licensees’ businesses before attempting a rulemaking that could have adverse economic effects on businesses outside of the licensees.

Potential for Rejection of Material

Need for detectors: Concrete dealers might begin to use detectors for screening because it is likely they will have similar concerns as the steel manufacturers regarding consumer unwillingness to purchase their products if there are concerns about the products containing radioactivity.

Potential Use of Fly Ash

Use of fly ash: The Issues Paper noted that the dose from use of recycled coal ash in concrete block as permitted by EPA can be about 3 percent of natural background (about 10 mrem/yr)). One reason fly ash is used in concrete is that in 1983 the EPA issued guidelines requiring purchase of cement containing fly ash in both government and the private sector. The guidelines were a response to a directive from Congress to provide some relief to companies that generate fly ash in coal generated electricity with regard to disposal of this high volume, low-hazard waste. Indicating at this time that EPA has set a precedent such that the radioactivity levels in fly ash are appropriate seems egregious. It may be that, if the government had made a greater effort on public participation on this issue originally, the public's sensitivity to unnecessary radiation exposure might have prevented this use of fly ash.

2.3.4 Licensees, including Universities, Medical facilities, Fuel Cycle Facilities, and Nuclear Power Plants

Safe Criteria Can and Should be Set

There is a need for a clear dose-based standard: A dose-based standard is needed for the unrestricted re-use or disposal of solid material. This standard should clearly define a dose level (1 mrem/yr) at which protection of public health and safety is assured without the need for continued regulatory oversight.

No unrestricted release for direct recycling: No generic permission for unrestricted release of licensed solid radioactive material for the purpose of direct recycling should be allowed.

A regulatory framework is needed for recycling: A regulatory framework for case-by-case consideration of proposals for recycling of materials so as to consider specific details involved and allow request for public notice (i.e., for general uses or for conditional or restricted uses) should be implemented.

Guidance is needed: Regulatory guidance should be developed to describe acceptable methods for demonstrating with reasonable assurance that materials released for reuse or disposal are actually directed to those purposes and not diverted to recycling.

Specific criteria should be established: Criteria for unrestricted release of solid materials, based on a dose/risk standard that is inherently safe and cost-effective (like 1 mrem/yr), should be developed.

Adopt the ANSI N13.12 standard: NRC should adopt ANSI N13.12, which ensures the public will not receive doses in excess of 1 mrem/yr and does not impose unnecessary regulatory burdens.

There is a need for flexibility in the standard: Flexibility for special circumstances currently in 10 CFR 20.2002 should be preserved.

Health/Risk/Environmental Considerations

Risks are trivial: Safe criteria can be set. The doses and risks being considered are very low and scientific bodies such as the National Council on Radiation Protection and Measurements (NCRP) (see NCRP Report No. 116), the ICRP, and EPA indicate that levels around 1 mrem/yr are negligible or trivial in risk considerations; the NAS recommendations provided similar information.

Risks may be nonexistent: There is considerable scientific uncertainty as to whether any risks exist at all at these levels; there may be no risk at these levels. Diagnostic medical procedures give patients between 500 to 1000 mrem without adverse effects; therapeutic procedures give a dose of 10,000 mrem or more without adverse effects. Health effects below 10 mrem are either too small to be observed or are non-existent.

Small fraction of background: The doses being considered would be a small fraction of background variations and would be well below doses received in routine activities of life; everyday sources of radiation (such as environmental radiation, home building materials, travel in airplanes, certain foods) contain radiation levels at or above these levels but do not have a social mandate that they be regulated.

Suggested standards are a fraction of other standards: The levels suggested are a fraction of other similar standards including EPA's 4 mrem/yr in drinking water; 10 mrem in air; and CERCLA cleanup standards. In addition, NRC currently has standards of 100 mrem/yr as a public protection value, 25 mrem/yr for decommissioning and 5 mrem/yr in airborne effluents.

Offsets other impacts: There is an environmental impact of having to replace the material which is thrown away at a LLW site, instead of reusing it in some way.

Cost-benefit Considerations

Cost of LLW disposal is significant and unjustified: Disposing of very low activity material with low potential risk in LLW burial grounds is very costly and imposes unnecessary financial burden on businesses and the economy. The cost impact of having to send very low activity waste to LLW can have a severe economic impact on small businesses, universities, and medical facilities and hospitals that handle and use radioactive materials. Health care will be negatively affected by a rule that is unreasonably stringent.

Waste of resources: Disposing of very low activity in LLW sites poses unnecessary burden on precious natural resources (land at an LLW site) which could be used for more beneficial purposes.

Societal benefits: There is a benefit that society has realized from productive use of these materials in medicine, research, product development, and power production. Release of low activity materials is part of that cost-balancing equation. There is a societal benefit in reusing the material.

International issues: There will be a large negative economic impact on U.S. trade with other countries if the international community establishes criteria and the U.S. does not have a standard or has a much more stringent standard.

Reduction of burden: The regulatory burden of the current system would be reduced because a simple standard could be established, compliance could be easily verifiable, and there would be fewer requests for approval of alternative criteria for disposal.

Public Confidence

Clear standard would boost public confidence: A standard would increase public confidence because there would be clear safety criteria.

Suggested Approaches for Unrestricted Use

Base on steel mill detectors: Materials for release should be sent through portals having the same detection levels as steel mills.

Record-keeping: There should be complete and careful record-keeping of releases so that the end user knows the identity of the material. Other comments noted that there is not a need to document every item that enters and exits a restricted or radiation controlled area, and if an item is surveyed to well-defined standards then there is not a benefit to document every release.

Inventory criteria: Generators should maintain disposition inventories and verify compliance with the yearly limit prior to disposition.

ANSI N13.12: Criteria should be set based on ANSI N13.12 which is a national consensus standard addressing the safe release of solid materials. According to the National Technology Transfer Act, NRC is required to use such a technical standard unless it is inconsistent with applicable law or otherwise impractical. Also, the screening levels in ANSI N13.12 should be used.

Criteria that is 'safe', 'clean', 'non-rad': Criteria should be set at, and define, a level at which the material is no longer considered to be radioactive and/or can be defined to be "clean" and should indicate unequivocally that the standard is safe.

Dose criteria: Suggestions include: (1) 1 mrem/yr consistent with NCRP; (2) 1-10 mrem/yr; (3) between 1 and 5 mrem/yr consistent with Appendix I to 10 CFR Part 50, 10 CFR Part 20, and 40 CFR 190; (4) 1 mrem/yr and a second level of 10 mrem/yr to allow storage of materials with dose of 10 mrem/yr or less for onsite storage; (5) consistent with EPA drinking water standards and current airborne effluents; and (6) 10 mrem/yr consistent with statistical variation of background in U.S.

Implementation of standard: Several issues were discussed: (1) the ability to implement the standard should be considered. The standard must be low enough to protect the public yet not so low as to be unworkable with common field instruments or such that survey costs could be significant; e.g., need to consider if there are hand held instruments that can measure at these levels. It must be clear to the public that whatever standards are developed can be measured so that materials can be controlled to the standard; (2) levels in the range of 1-10 mrem/yr are practical; (3) criteria below 1 mrem/yr may cause detection problems; (4) should address survey procedures; (5) there is a need to consider ability to measure specific nuclides, e.g., natural uranium; (6) the rule should allow process knowledge in evaluating materials in a survey; and (7) for fuel cycle facilities, the standard must consider variability between natural background and how it affects the nuclides they handle.

International compatibility: Criteria should be consistent with international standards.

Site-specific criteria should be established: Site-specific criteria should be able to be set based on release scenarios.

Concentration levels: Criteria should be based on concentration levels that are reasonable and tied to a dose level.

Clear, practical criteria are important: Criteria should be practical and clear and the theoretical risk should be balanced by observed risk.

Use of dose to average member of the critical group: Criteria should be based on an average member of the critical group and not on a maximally exposed individual.

2.3.5 Health Physics Society and Individuals

Rule should be dose-based and establish a brightline: A rule should be developed containing a dose-based criteria for unrestricted use of materials that are inherently safe and thus warrant no further control for radioactivity. Rules governing release of solid material should establish a bright line that distinguishes between what is and what is not radioactive from the standpoint of requiring regulatory control.

Adopt ANSI N13.12: The use of the dose limits and derived screening criteria of ANSI N13.12 are appropriate: ANSI N13.12 (1) is based on sound science, provides a risk basis, and is protective of public health; (2) contains criteria for release of volumetrically and surgically contaminated materials; (3) is a voluntary consensus standard which the National Technology Transfer and Advancement Act of 1995 requires Federal agencies to use unless inconsistent with applicable law or otherwise impractical; (4) considers detection capability; and (5) allows for clearance on a case-by-case basis.

Establish instrument performance standards: Instrument performance standards should be established that readily demonstrate the safety of associated NRC rules on release of solid material.

Health/Risk Considerations

Negligible risk: ANSI N13.12 is consistent with the NCRP and with international scientific organizations which recognize 1 mrem/yr as a negligible individual dose.

Background levels: Man-made radioactive material should be considered in comparison with natural background, and material should not be considered radioactive it if does not contribute significantly to the radiation exposure we already receive from background (levels being considered are only 0.3 percent of background);

Background variation: People are exposed to wide variations in background each day from place to place with no discernible effect on health. It is illogical to say any amount of radiation is unacceptable because we live in a sea of radiation.

Small fraction of limits: Even if a person receives multiple exposures, they will total only a small fraction of 10 CFR Part 20 limits.

__Cost-benefit Considerations__

Waste of resources: Trying to achieve a zero risk is a waste of finite financial resources which should not be spent on trivial risks when there are other real risks that need addressing.

Societal benefits: Nuclear power stations provide safe clean energy and uses of radioactive material in medicine and research is vital to the U.S. economy and public health, and disposition of the materials used is part of that consideration.

__Tracking Released Materials__

Criteria must be measurable: Values must be detectable and measurable to allow compliance.

2.3.6 States, State Organizations, State Employees

__Suggested Standards__

Dose-based limits are appropriate: A regulation limiting unrestricted releases to a dose-based level that is protective of public health and safety is appropriate.

Adopt ANSI N13.12: NRC should adopt the procedures and standards of ANSI N13.12. NRC should develop and implement guidance that endorses ANSI N13.12 in implementing a rule.

Designation as clean is appropriate: Below a certain level of radioactivity, in a manner similar to DOT, it should be considered that the material is no longer radioactive; levels should be designated as clean and safe for unrestricted use.

Free release is appropriate in non-impacted areas: If a facility can demonstrate that an area was not impacted, free release should be allowed.

Concentration and volumetric limits should be adopted: A value of 1 mrem/yr was suggested as a dose criteria; specific concentration values should be included for solids similar to 10 CFR Part 20 for liquids and gases. There should also be volumetric limits.

There is a need for case-by-case determinations: There should also be case-by-case determinations for concentrations greater than the table values for small volumes with restricted uses by the licensee or other unique cases such that the dose is less than 10 mrem/yr.

Adopt a dose-based standard for soils: A standard should be in terms of dose for free release of soils.

__Concerns with Landfills__

Similar to background: Levels being considered are near background which we are routinely exposed to.

Risk is trivial: Studies of dose do not confirm that any risks exist.

Cost-benefit Considerations

LLW disposal creates an unreasonable burden: The impact of having to dispose of all solid materials as LLW, even if they are at very low levels, would be prohibitive.

LLW disposal is a waste of funds: Many licensees are government facilities; spending money on needless disposal will waste money and delay needed cleanups or waste money that could be used for other programs.

Societal benefit: All people have benefitted from programs at licensed facilities that generate the solid materials.

Consumer reaction: The impact of consumers de-selecting products is overstated because consumers will not be aware of levels.

Overall impacts: The amount of contaminated metal to be recovered is very small compared to the overall volume of available clean scrap metal. The economic benefits to a few large licensees in salvaging a relatively small amount of material may not be justified in terms of societal or socioeconomic costs.

2.4 DOSE-BASED REGULATION ON CONDITIONAL USE

Advantages of Restricted Use

Limited exposures: Restricting use to only certain non-licensed uses would result in the material not ending up in consumer uses and would provide a risk-basis for any conditional uses.

Feasibility of Restricted Use

Too many possible uses: Developing a generic radiation criterion may be problematic due to the broad nature of potential conditional uses; conditional use is not covered in ANSI N13.12 because conditional use possibilities are unlimited; conditional uses should be defined for specific cases.

May not be acceptable to public: The public will not accept contaminated scrap metal in products in commerce, regardless of what products they are.

Hard to enforce: The process of making sure materials went to prescribed use would be difficult to enforce and it is not clear that institutional controls would work to limit where the material goes; scrap generated during operations generally goes to a variety of products and end users.

Burden on NRC and industry: The conditional control process would be complicated and a burden on NRC and the nuclear industry; such a process might only work if some entity (like

DOE or NRC) took licensing responsibility to assure that the material is processed as required and is not used for a prohibited purpose.

Burden on States: There could be additional burden on State and local regulatory authorities. There would be a need for a system of tracing and accountability. This could be very expensive and could create a new class of licensee that would have to be inspected. There could also be issues that arise when such materials cross State lines.

Not economically viable: This approach may not be economically viable because the limited quantities involved from licensed facilities would not be sufficient for a mill to run economically.

Dependence on market forces: Market forces should determine if restricted use is practical.

International commerce: Unlike some other countries (France did establish restrictions on use), in the U.S. the destination of material cannot be stipulated unless it is designated as a form of hazardous or radioactive waste.

Health and Safety Considerations

Risks to workers: Restricted use in certain ways (e.g., industrial products, construction fill, roads, bridges, airplanes, sewer lines, girders) is unacceptable because it would still result in doses to workers (who usually do not come in contact with radiation hazards) and the public; also impacts on these people would be too hard to predict.

Responsibility for restrictions: It is not clear who would have responsibility for restrictions, (i.e., be legally tasked with, be able to take on the expense or liability of enforcing conditions. It is not clear how entities would be selected and/or notified of their responsibilities.

Trust issues: Recent history shows that there should not be a presumption of honesty in the industry with regard to restricting the materials' use.

Restricting use to licensees: Even restricting material to licensed use would require close monitoring and tracking to assure it does not get released which would be expensive. Also, even within the nuclear industry there could be concerns about additional worker exposure.

Unauthorized Materials might be released: There is no assurance that material would be limited to its authorized use immediately upon release or for decades afterward, and would need to be tracked for years. Material is recycled many times over and would eventually be released for unrestricted use after restrictions end before all radionuclides decay. There would be no mechanism to track the end uses of recycled materials to guarantee that they do not get into consumer products and no way for people to know what dose they were getting.

Dose-based Criteria for Unrestricted Use Needed

Unrestricted use criteria needed: Even with restrictions on use, there would still need to be an unrestricted use criteria defined for when the authorized use ended because restricted use is really a delayed release of solid materials for unrestricted use and the material will eventually be released after the restrictions end.

Just set unrestricted criteria: NRC should just pursue a solution for an unrestricted use criteria. It is premature and too difficult to try to also pursue a restricted use approach at the same time.

More useful standard: Setting an unrestricted use standard would provide a more universal standard with regard to applicability and is the more conservative approach. Although release limits would be lower for unrestricted use, such limits would be more useful and simple to apply under an assumption that the material might wind up at any destination and would not rely on future controls.

Define where control ends: Points in the process would need to be defined to indicate where authorized use would begin and licensed control would end.

Suggested Approaches for Restricted Use

Set a regulatory process: A rule should lay out a regulatory framework and process for restricted or conditional use similar to the 10 CFR 20.2002 process so that conditional use situations can be characterized and dealt with on a case-by-case basis rather than in a generic standard. Such a process would require a reasonable demonstration that impacts of unrestricted recycling on the metals industry would be avoided. Such a rule could be written to "not exclude" conditional use and not define conditional uses in detail but require a thorough review and approval process, including an IS, if necessary. This approach would be a more effective way of fostering public confidence.

Permit conditional recycling: Recycling should be expressly permitted as a conditional use for material that goes to scrap steel businesses or into consumer products.

Only allow in licensed use or at DOE: Material should be conditionally recycled only to another licensed use or within the DOE (e.g., waste containers, shielding blocks, etc). This may be the only acceptable approach. It was suggested that such a scheme can already exist under NRC's regulations and it is not necessary for NRC to conduct a rulemaking. However, a comment noted that there is too much material potentially available for release for it all to be used as shield blocks at DOE facilities.

Dedicated facility: A dedicated facility could be used to melt and handle these materials as a licensed NRC facility. Metals would be refined and melted and also cleaned up by a regulated facility. In this type of scenario, the dedicated melted products could be regulated.

Other considerations: In setting restrictions, there is a need to consider such aspects as the type of material, and the type and nature of authorized uses.

Tracking Released Materials

System of controls for tracking materials: It is not clear that the necessary controls can be put into place to monitor and track material released from licensed facilities, and, therefore, it cannot be assured that the steel industry will not be burdened with material with higher levels of contamination.

Must be practical: Criteria must be practical to use. Any criteria should indicate how MARSSIM would be applied. Licensees' monitoring capabilities will need to be evaluated and upgraded for demonstrating compliance with dose-based criteria in a rule and guidance.

Put concentrations in guide: A standard should not reference activity-concentration limits. These should be in guidance similar to the license termination rule.

Reporting: There must be reporting requirements and a strategy to stop release of material if levels exceed limits.

Liability insurance: There must be liability insurance for businesses and the public if they are affected economically or socially.

2.5 DISPOSAL IN AN EPA-REGULATED LANDFILL

Rationale for Disposal in Regulated Landfills

Currently protective: Conditional and other case-by-case releases of radioactive materials, after surveys, to landfills have already taken place under 20.2002; this process has worked well to protect the public, environment, and solid waste facilities.

NORM allowed: RCRA (Resource Conservation and Recovery Act) Subtitle D facilities are currently used for management of NORM.

RCRA Subtitle C disposal is safe: Disposal in a RCRA Subtitle C facility is safe, viable, and effective in controlling where material goes. RCRA Subtitle C facilities are highly regulated and have appropriate performance assessment, radiation safety programs, and environmental monitoring. Doses would be less than public exposure requirements and much less than background. Existing processes permit NORM to be sent to RCRA Subtitle C facilities (which contributes larger, yet acceptably safe radiation levels). RCRA Subtitle C facilities can be evaluated generically. RCRA Subtitle C has proper treatment, storage, and disposal requirements and subjects its permitees to stringent controls to ensure that hazardous materials are not released to the environment (EPA's RCRA Sect. 3004(a), 40 CFR Parts 264 and 265). These facilities would protect public health and safety and be appropriate for scrap metal. Controls include leachate control, storm water control, prohibition on liquids, collapse prevention, security, inspections, training, quality assurance, closure and post-closure, financial assurance, and deed restrictions.

RCRA Subtitle D disposal is safe: Disposal in RCRA D disposal facilities can also be sufficient to isolate scrap metal from the public and provide protection of public health and safety (EPA's RCRA Sect 4001, 40 CFR 258). RCRA D disposal facilities are subject to some but not all of the same requirements as RCRA C facilities, including leachate control, run-off control, groundwater, security, inspection, training, cover material, location, records, closure and post-closure, and financial assurance.

State issues: A dose-based standard for disposal at landfills should be permitted as long as it is not prohibited by applicable State, local, or Federal agency requirements.

Landfill disposal is cost effective: The NAS report noted that disposal of this material in landfills would be cost-effective.

Standards exist: Dose-based standards already exist for this disposal method.

Limits exposure: Release to RCRA Subtitle D landfills would limit public exposure, further protect public health and safety and be cost-effective. RCRA sites are suitable because site characteristics and engineered features at these sites will assure protection of public health and safety.

Scenarios can be modeled: Landfill scenarios can be modeled because they are comparatively limited and have been modeled for concrete. DOE has already performed analysis of disposal of low concentrations of nuclides in RCRA Subtitle C and D facilities.

Protects LLW site resources: Existing LLW site capacity is limited; the ability to send material to EPA-regulated sites safely lets LLW sites appropriately handle more contaminated material.

Health and Safety Considerations

Landfills not designed for radioactivity: No radioactive materials should be allowed in landfills because landfills were never intended and not designed to receive, contain, monitor, or isolate radioactive materials. They can leak into groundwater and drinking water and contaminate soil, air, and plants for generations and cause health risks, especially in nearby towns.

Time periods for containment: Even the most technologically advanced landfills leak over time. Also, they have much shorter institutional periods thus allowing long-lived radioactivity to leak soon after required oversight is eliminated.

Concerns about RCRA Subtitle C sites: Disposal in a RCRA Subtitle C site would only subject the material to hazardous waste controls and not to controls specific to radioactive wastes which have different characteristics. Also, disposal in a RCRA Subtitle C site could result in mixing radioactive material with hazardous wastes increasing the potential migration of materials and health risks due to synergy between the materials.

Concerns about RCRA Subtitle D sites: Standards for RCRA Subtitle D facilities are inadequate to protect the public health and safety from radioactivity that is volatile or not short-lived. There are fewer controls at RCRA Subtitle D sites making leakage more likely.

Present landfill designs inadequate: EPA's present landfill requirements are inadequate; radioactivity should not be added.

Amounts of waste: There may be no limit on the amount of waste sent to a landfill; landfill managers may not even know radioactive material is being deposited there.

State issues: The current case-by-case releases to landfills may cause State or local concerns.

Feasibility, State Issues, Cost-benefit Considerations

Increased costs: A township objected to disposal in RCRA Subtitle D sites and noted that it is implementing a radiation monitoring program for incoming trash to keep out radioactive materials and their task and expense will increase if NRC allows release to landfills. This option can be very costly, and could require licensing of EPA landfills which could be more expensive than LLW disposal.

Costs of cleanup: It is not clear who would pay the costs of cleanup and health if a landfill leaked; it is likely that communities would have to pay.

A license currently being sought: Another commenter noted that WCS in Texas is currently seeking a State license for this approach.

Incineration: Issues of incineration are not discussed in NRC's documents.

11e.2 material issues: There would be regulatory issues of disposal of 11e.2 byproduct materials in landfills.

Landfill disposal would add to existing siting problems: Most landfill projects are already controversial. An NRC rule in this area, and adding radioactive waste to landfills, could have an impact by making the siting of new landfills more difficult.

State issues: Municipal solid waste landfills (RCRA Subtitle D) are regulated by federal, State, and local authorities and even if there are any federal requirements, all landfills still have to comply with State and local requirements. The degree to which States have the ability to handle or dispose of radioactive wastes varies widely and makes if difficult to categorize problems that might result from restricting materials to landfills.

State requirements: Many States have specific exclusions for all radioactive waste other than NORM or household products. California legislatures have already rejected this alternative. A rule allowing volumetric contamination in small amounts could cause problems at RCRA Subtitle D sites and with State regulators because controls are not in place at RCRA Subtitle D sites to provide assurance that contamination would not leach (therefore, release concentrations should be sufficiently low to prevent such problems, e.g., NRC has already approved exemptions and general licenses for a number of consumer products containing radioactivity - this information should be added to this evaluation). Most State agencies and local authorities have banned radioactive wastes from municipal landfills or have more stringent requirements than Subtitle D. Therefore not all municipal landfills will be able to accept cleared material. A full assessment of available permitted capacity must be made. It must always be possible for other levels of government to make independent judgement and decisions regarding more stringent standards. Nothing should be preemptive of this basic government right.

State prohibitions: Disposal of solid materials that have been released for unrestricted use should be acceptable at municipal waste landfills meeting 40 CFR Part 258, however some States and localities have prohibitions against such disposal; therefore NRC should coordinate with States before bringing waste to a facility to assure it meets acceptance criteria.

Overlapping responsibilities: There may be difficulties in overlapping responsibilities between NRC, State and local agencies with regard to impacts on landfill management.

RCRA Subtitle D sites: NRC should take care in proposing blanket approval for disposal in RCRA Subtitle D sites since not all of these sites meet 40 CFR Part 258 standards and even those that qualify to accept certain exempt materials do not have to meet any minimum standards for design or groundwater protection as in 40 CFR Part 258 although they have stringent groundwater requirements. EPA has guidelines for industrial waste management but they are not mandatory.

Potential problems: Potential problems associated with restricting materials to landfill disposal include: (1) local constraints such as State law or land use permits conflicting with landfill disposal; (2) segregation of released material from natural material is difficult when material goes to a landfill; (3) contaminated concrete may get recycled for use in aggregate by a landfill; (4) a waste acceptance method and risk assessment method should be formalized for both unrestricted use and release for disposal; and (5) minimizing the volume of low-level waste should be an overriding consideration.

Suggestions for Standards

No operational changes: No change to operations and no special features should be needed.

No changes: For a release criterion to be accepted, the level should be low enough that there will not be any special monitoring or treatment of leachate, groundwater, or landfill gases, i.e., presence of this material must not change a RCRA Subtitle D landfill into something other than a RCRA Subtitle D landfill. That is, it must be demonstrated that no adverse impacts will result by considering normal operation and closure of solid waste management facilities and by showing the regulators and operators of the facilities that these wastes will not change the operation and closure requirements of the facility. For example, considerations should include whether leachate in the leachate collection system and gas in the gas collection system, and whether groundwater, should be monitored for nuclides and whether the wastewater facility will still accept the leachate. Also a rule would have to consider landfill closure requirements and that the landfill would not be maintained beyond the normal period (for both RCRA C and D facilities).

Should be at clearance levels: Material that goes into a RCRA Subtitle D site should be at clearance levels and there should not be any extra controls required; it was noted that a release to landfills is essentially an unrestricted release. At a 1 mrem/yr level, one would not expect to affect operations of landfills. Facilities do not want to manage materials that are regulated as radioactive. A dose criterion of 1 mrem/yr is suggested. Based on this, a table of release concentrations for solids and volume limits could be adopted similar to those in 10 CFR Part 20. A 1 mrem/yr criterion would be sufficiently conservative to protect public health even if all potential exposures are not known.

Minimizing problems of diversion: The effect of diversion of material away from a landfill could be minimized by having the same 1 mrem/yr dose limit for recycle and for landfills. Material going to a RCRA Subtitle C site is manifested to make sure it goes where it should.

Consider unique aspects of facilities: NRC should consider the unique operation and closure features of landfill facilities. Due to differences in RCRA Subtitle C and D sites, different regulatory approaches for such facilities should be considered, e.g., use of RCRA Subtitle C landfills might be authorized by a generic rule after appropriate evaluation whereas use of RCRA Subtitle D should only be allowed after case-by-case evaluation of specific applications.

General license: A general license specifying the required permit requirements to be included in an existing RCRA permit is a more cost-effective and efficient solution; these requirements could be worked out in an EPA/NRC Memorandum of Understanding. NRC should not regulate these facilities.

Exemptions: It may be possible to provide exemptions or release concentrations at sufficiently low levels to prevent problems of concerns about radioactive materials in leachate, etc, by use of the approach of exemptions and general licenses in use currently for a number of consumer products.

NRC licensing: Some said NRC should license landfill disposal sites; others said NRC should not be involved.

Estimating limits: A dose-based set of limits should be derived by licensees for individual landfill characteristics (subject to approval). RESRAD and D&D pathway analyses are needed for implementation.

ANSI N13.12: A simple multiple of the ANSI unrestricted release value could be used.

International harmonization: Criteria should be consistent with international initiatives and State guidelines.

Consistency with EPA regulations: A rule should be consistent with EPA. NRC should adopt EPA risk ranges since EPA seems to have final authority for closure on most sites and 1 mrem/yr should be within what would be acceptable to EPA.

Case-by-case: Case-by-case determinations should be allowed at concentrations higher than in a table for small volumes and restricted uses at 10 mrem/yr.

Suggestions for Developing Criteria

Needed analyses: Landfills need to be part of NRC's assessment process, including analysis of operations, leachate collection, air emissions, and closure. NRC should do research to ensure landfills are acceptable for this material.

Consensus with EPA: In developing landfill criteria, NRC should consult and develop consensus with EPA in developing a suitable regulatory framework for safe disposal of solid material at RCRA sites. EPA has begun studying this option. NRC should also consult with State agencies, as appropriate.

Basis needed: It was also noted that material should not be restricted to landfill disposal unless there is a health and safety basis for not permitting unrestricted use.

Agency cooperation: NRC and licensees can work with States regarding this alternative once NRC has established safe levels for release of materials destined for disposal at landfills.

2.6 DISPOSAL IN AN NRC/AGREEMENT STATE-LICENSED LOW-LEVEL WASTE DISPOSAL SITE/PROHIBITION

Advantages of Prohibition on Releases

Prohibit any detectable material: Specifically prohibit de-regulation of any material with detectable radioactivity.

Isolate material: Only prohibition where the material is isolated from the public and sent to licensed LLW is reasonable and protective; no additional exposures are acceptable. Material should be prohibited from going to consumer products, industrial products, or landfills and incinerators, etc. In general, comments supporting prohibition also cited the reasons for opposing unrestricted use listed in Section 2.3 of this report.

Cost Savings: Prohibition of releases would represent a cost savings for NRC because dose calculations for case-by-case releases would not have to be done.

Prohibition not addressed: The prohibition alternative is not fairly addressed in the issues paper.

Disadvantages of Prohibition on Releases

Unreasonable costs: Sending very low contaminated materials to LLW disposal would have the negative impact of incurring very high costs to dispose of this material in LLW, harming society by significantly increasing the cost of goods and services provided by use of nuclear technologies, and depleting limited LLW space unnecessarily without a commensurate increase in protection of public health.

Unreasonable to ignore background radiation: It is unreasonable to prohibit releases of such slight amounts because it ignores reality that radiation is a fundamental part of the world we live in, and that there are radiation levels naturally in air, water, food, earth and background which vary widely in space and time; these levels completely overshadow annual exposures being considered here.

Wasteful of resources: Prohibition would be wasteful of valuable resources.

Societal impact: Biomedical research could be curtailed or stopped if all materials (e.g., boxes for equipment unpacked within controlled areas) have to go to LLW disposal.

Material excluded: Any prohibition alternative must consider excluding items that have no history of exposure to licensed radiological operations because these should be of no concern to NRC, e.g., fences around sites. NRC would need to consider what is the boundary between things that could be released and those that would go to LLW; e.g., would the entire restricted area be affected, including administrative offices, etc.

International issues: A standard in European countries of, for example 10 uSv/a (1mrem/yr), would mean that U.S. authorities need to consider what would happen to material imported to the U.S. under an NRC standard which prohibited release, i.e., would NRC have to license such material imported into the U.S.

Impractical: Total prohibition could be impractical because more mobile materials might be included along with fixed, discrete items.

2.7 OTHER ALTERNATIVES

Revise Part 61: The rulemaking should focus on improving storage at Part 61 LLW facilities.

Start over: None of the alternatives are any good; NRC should develop better ways to maintain control and stop development of the rulemaking.

Recapture: There should also be a full reporting on, identification of, and recapture of any material released so far. There needs to be assurance that previous situations of release where people were not informed would not happen again. Specifically there should be a report on a tracking of health effects subject to review by independent scientists and studies and such information should be provided to the public. Other commenters suggested that the recapture approach be rejected because there is no evidence that any member of the public has been placed at significant risk and that recovering all items is unreasonable. Others noted that orphan source recovery is beyond the scope of this effort.

Intermediate facility: Solid material with very low amounts of radioactivity could be sent to an intermediate disposal facility, such as the Envirocare disposal facility in Utah; or some other interim storage facility.

General license: An approach that uses general licensing could be used.

Varying standards: Different standards could be established for reuse and disposal due to inherent differences between reuse of materials and disposal in landfills. There could also be some mix of restricted and unrestricted options to give licensees flexibility. Different standards could be based on: (a) the fact that material at nuclear facilities is separated based on whether it came from restricted areas or unaffected areas; (b) there is a range of material at nuclear power plants that includes institutional trash, asphalt, concrete, roofing and scrap metals, and materials available for re-use (e.g., trucks, scaffolding, computers) that could be treated differently; (c) some material could be cleared but other material, like potentially recyclable steel, would not be released or could be restricted as to its use once released.

Pilot program: Use of a pilot program for control of different materials might be appropriate.

2.8 STATE/FEDERAL/INTERNATIONAL ISSUES

State and Federal Agency Issues

EPA landfill issues: NRC should consult with EPA and appropriate State agencies to coordinate development of a suitable regulatory framework for disposal of solid materials at RCRA sites

DOE facilities should be included in analysis: DOE facilities should be included within the scope of an NRC rulemaking because an NRC rulemaking will affect DOE facilities as DOE will likely try to be consistent with whatever NRC proposes and DOE possesses a large amount of waste material. Also, some material from DOE sites is controlled through NRC and Agreement State licensed facilities. Also, DOE noted that its goal is to maintain standards consistent with standards that apply to the commercial sector.

Compatibility issues: There should be consistency between all States to avoid difficulties with interstate commerce. Some noted that a rule must be compatible with State requirements. There was discussion of what authority Agreements States will retain and whether they could continue current practice or be more restrictive. It was noted that many States have set standards for NORM. States should not be required by the level of compatibility to approve conditional use. States should have flexibility in application so that case-by-case evaluation may still be performed by a State.

Other agencies: NRC must work with DOE, EPA, the Department of Defense (DOD), and the Department of State (DOS), to establish a uniform system of standards, to harmonize method of calculations and dose/risk standards, and to get public confidence.

EPA role: NRC has worked with EPA to develop technical bases and EPA is not developing a standard in this area because of higher priorities related to orphan sources. While some said this is EPA's responsibility and NRC should not do this effort, it was also noted that NRC is within its jurisdiction to develop standards in this area for its licensees.

Other organizations: Business and industry representatives and State regulated landfill operators must be involved.

International Issues

Harmonization is needed: Any NRC standard should be consistent with the international initiatives.

Consider international implications: The international implications of setting a standard should be considered and NRC should consult and coordinate with international agencies and organizations in its rulemaking. Currently, some members of the European Community [European Union] have established clearance criteria that allow for unrestricted use of inherently safe sources of radioactivity; such practices should be evaluated by NRC. NRC should make an effort to assure reasonable consistency between an NRC rule and international initiatives so as to avoid developing an inconsistent NRC standard that can have diverse impacts on international trade or which unnecessarily restricts trans-boundary commerce.

Availability of material: Other countries do not have the capability to replace metals as easily as the U.S. and need to develop standards in this area; the U.S. imports material derived from recycled radioactive material.

NRC leadership: With regard to international standards setting, NRC should take a leadership role in what a standard should be. Some commenters noted that this should involve taking a lead with regard to the approach suggested by the metals industry and other commenters suggested this should involve an approach of not permitting release.

Disallow international standards: NRC should not follow international standards if they permit releases.

Reject international shipments: Regardless of what other countries may do, the Customs Service should reject any shipment of metal that sets off a sensor set at background. Commenters suggested that this is needed due to the incidents of illicit tracking of radioactive sources across borders and illegal trade and is needed to better safeguard our borders.

2.9 NEPA AND PROCEDURAL ISSUES

Stakeholder Involvement

Comment period: The comment period should be extended for this environmental scoping process.

Burden on stakeholders: It is an unjustified regulatory burden on the public for them to have to prove negative health effects at low doses.

Inadequate process: The enhanced participatory process is not adequate; the Advanced Notice of Proposed Rulemaking process was skipped and there were not enough public meetings. The NRC did not seriously consider critical technical comments by one invited expert participant. The scoping process has not lived up to the NAS recommendations to include the maximum number of stakeholders nor has it seriously addressed concerns of those opposed to unrestricted use.

Lack of stakeholder involvement: The Commission said that it held several meetings in 1999-2000, however the public boycotted those meetings.

Task force: Commenters noted that NRC should form an advisory task force of stakeholders (of metals industry, licensees, and consumers, convened with NRC assistance), which would report to the NRC on matters like which industries might take which materials and possible criteria based on clarification of critical issues, review of all factors, and dialogue between stakeholders. It should be noted however that the Nuclear Energy Institute (NEI) noted that their comments were developed with assistance of an industry task force of reactor radiation safety managers and Health Physicists, were reviewed by nuclear fuel cycle and materials licensees, and NEI comments reflect insights gained from listening to other stakeholders at public workshops. Also, the Metals Industries Recycling Coalition (MIRC) noted that their comments come from an ad hoc coalition of metals industry trade associations, including copper, brass, nickel, specialty steels, and steel manufacturers, all of whom represent major recycling industries.

Basis for decisions: NRC should not make decisions on unfounded fear. NRC should state clearly that its standard is safe and communicate clearly that NAS says the current practice is safe, so as to not undermine public confidence and possibly do economic harm to licensees.

Inadequate number of public meetings: Comments for obtaining additional public input noted that there should be regional workshops in communities, four additional meetings, meetings in each State, evening meetings, and public hearings. Additional meetings should give special attention to tribal interests, relying on State assistance for outreach, using tools like television, magazines, and including having NRC staff meetings be open to the public, chat rooms on specific topics and issues, notifying interested groups by email of meetings, and posting discussions information on the website. It was also noted that NRC should consider having public meetings that concentrate on specific issues and having small group discussions on issues with reports to larger groups. There should also be a systematic method for the public to get questions answered by NRC.

BRC Policy: The public has spoken in opposition before on the below regulatory concern (BRC) policy and on other previous efforts in the late 1970's and early 1980's. This resulted in passage of the Energy Policy Act in 1992 revoking BRC. NRC should not try again with this similar effort which will have the same result.

Individual's rights: In evaluating any alternative, the right of the individual to decide and choose, or not choose, the risk of exposure should be considered.

Stakeholder consensus: Stakeholders should be allowed to agree upon facts and parameters and acceptable methods of dealing with materials and NRC should implement such a finding.

Other rulemakings: NRC ignored public comment and did not adopt their recommendations on the decommissioning rulemaking in the early 1990s.

Need for open process: Public perception concerns can be treated by following an open public process that addresses public concerns as they are identified by developing a safe practical standard, and by defending the standard as fully protective.

State issues: The rights of State and local governments to impose stricter standards and any possible limitations thereon under the interstate commerce clause should be considered.

Conflict of Interest Issues

Contractors: Full disclosure of all contracts and contractors supporting the rulemaking is requested with respect to their histories and potential for conflict of interest (COI). This includes S. Cohen & Associates (SC&A) and other contractors doing work for NRC.

Independence of other organizations: Other scientific organizations supporting release of solid materials are not independent of NRC.

SAIC COI: SAIC did basic work for NRC in preparing NUREG-1640, but SAIC was found to have a COI; NUREG-1640 should not be used.

Form and Presentation of Material

The term "radioactive" should be used when referring to the materials being discussed; also, the amounts, long-lived nature, and hazard of the materials, and prior efforts in this area (e.g., BRC), should be more clearly stated.

Clarity of discussions: Discussions should be understandable, and make clear NRC's role and legal authority in this area.

Clarification of impact: NRC should clarify whether what it is proposing would result in releasing more material and what would be different in society.

FAA approach: It may be appropriate to develop a result similar to when the Federal Aviation Administration (FAA) determines that certain standards and activities are safe.

Discussion of present situation: Discussions should make clear that the levels of radiation being discussed are small and that materials are being released every day. The benefits of nuclear technology and the fact that the U.S. imports materials derived from recycled radioactive material should be noted.

Decision-making Process

Ignoring prohibition: The NRC is ignoring written feedback received in the majority of comments demanding a complete prohibition on releasing solid materials.

Ignoring other studies: The NRC is not reviewing critically any work done by those opposing release standards or participating in developing standards that prohibit release.

Harmonization: The NRC is relying on harmonizing with standards that it itself has participated in.

Decision is predetermined: This process has a predetermined outcome and is therefore illegitimate and flawed. The government is doing what industry wants for their economic benefit; and NRC is not seriously considering the option of isolating radioactive wastes and is not evaluating it with the same rigor in its contractor studies or its NEPA analysis - thus the NEPA analysis is flawed. Options in the June 1999 Issues Paper pre-suppose that some releases, either detection-based or dose-based, will take place; and more recently the February 28, 2003 Federal Register Notice and other discussions reiterate the Commissions support for release of solid materials. Because this process is predetermined, the environmental community boycotted the Fall 1999 public meetings rather than legitimize the process. The process is predetermined because the June 30, 1998, Staff Requirements Memorandum (SRM) directs the NRC staff to promulgate a dose-based rule for clearance of material.

Additional Technical Basis Needed

Additional analyses needed: Until more analyses of technical information and more extensive research and study of effects, etc, are complete, NRC should put this process on hold and suspend releases unless there are ironclad assurances that the plan is totally safe. Otherwise, many situations have been proven to be dangerous after they were allowed or after long term exposure.

Analysis should be complete before rule is proposed: The timing of the reports on soil analyses and technical support for NEPA and cost-benefit analyses is very important and these reports should be done before the draft of any rule.

Other Issues

Allow market to work: NRC should set health-based standards and allow the market to work within the bounds of the standard.

Lawsuit: There would be a class action suit against NRC if it goes ahead with this plan.

State regulations will be enforced: Sixteen States have passed laws and regulations more restrictive than NRC's mostly with intent to continue regulatory control if NRC deregulates.

2.10 RULEMAKING PROCESS

Advantages of NRC's Rulemaking Process

Clearly defined standard needed: A dose-based standard is needed (for unrestricted use or for specific uses such as re-use or landfill disposal) that clearly defines a level: (1) at which protection of public health is assured without the need for continued regulatory oversight or licensing; or (2) that distinguishes between material considered radioactive and non-radioactive from the standpoint of regulatory control; or (3) at which any material released is clean and safe.

Risk-informed: A dose-based standard reflects risk-informed regulation and NRC's risk-informed performance philosophy and can be consistent with other dose-based standards currently used to protect the public.

Consistent and usable: A national standard is needed that provides consistency, is technically defensible and safe, can be readily implemented, and includes volumetric contamination; standards in various States are different around the country.

Public confidence: The rulemaking process would provide for public participation; it could increase public confidence in the regulatory process because the standard would be clear as to safety and would be more consistently applied.

CRCPD: The E-23 Committee recommends a rulemaking should be done to develop a dose based standard.

Cost-effective: A dose-based standard would be cost effective compared to the status quo of making case-by case determinations and would reduce unnecessary regulatory burden.

Scientific basis: A dose-based standard could provide an appropriate scientific basis for consistent regulations.

International: A dose-based standard would be supportive of international initiatives.

Disadvantages associated with rulemaking

Dose is not measurable: With a dose-based or risk-based standard, the doses and risks cannot be modeled accurately, or be measured, verified, enforced, or trusted (unlike the current approach which can be measured).

Deregulation of wastes: A rulemaking would put standards in place for release that would expand the amount of material the public is exposed to. A rule would result in deregulation and redirection of large amounts of wastes to unlicensed, unregulated destinations, these wastes would have been required under present policies to go to a regulated Part 61 LLW site.

Contamination of consumer products: A rulemaking would permit release of large amounts of waste material into consumer products; radioactivity at any level in these products is not acceptable.

No public benefit: A rule would only benefit the licensees and there would be no benefit to the general public.

Lack of trust: Past failures by NRC in keeping radioactive materials from being improperly released argue against having a release rule.

Too burdensome: The cost of analysis and regulatory approval is too great.

Not accurate: Volumetric monitoring methods are not perfected.

Case-by-case reviews: If a regulation is adopted, would this eliminate the capability to request "case-by-case" reviews?

Scope of Rulemaking

Origin of material: The Federal Register Notice notes that solid material in "restricted" or "impacted" areas are covered by requirements; however the rule should provide for control of <u>all</u> licensed and/or potentially radioactive material regardless of where it is on the site, including licensed material that may be stored in unrestricted or controlled areas.

Limit rule to volumetric contamination: NRC might consider only rulemaking for volumetric contamination.

Criteria should be market-based: NRC should set health-based standards and let the market work within the bounds of a standard.

Consistency with license termination rule: There needs to be a connection between any standard developed and the criteria of the license termination rule.

Other materials: NRC should clarify whether this rulemaking applies to liquids and sludges.

3. SCOPE OF THE DRAFT GEIS

The National Environmental Policy Act (NEPA) (Public Law 91-90, as amended), and the NRC's implementing regulations for NEPA (10 CFR Part 51) prescribe in general terms what should be included in an IS prepared by the NRC. Regulations established by the Council on Environmental Quality (40 CFR Parts 1500-1508), while not binding on the NRC, provide useful guidance.

The Draft GEIS analysis will include a consideration of the economic, technical, and other benefits and costs of the proposed action, and alternatives to the proposed action. Due consideration will be given to compliance with environmental quality standards and regulations that have been imposed by Federal, State, regional, and local agencies having responsibility for environmental protection, including any applicable zoning and land-use regulations and water pollution limitations or requirements established or imposed pursuant to the Federal Water Pollution Control Act. The environmental impact of the proposed action will be considered in the draft analysis with respect to matters covered by such standards and requirements regardless of whether a certification or license from the appropriate authority has been obtained. While satisfaction of NRC standards and criteria pertaining to radiological effects will be necessary to meet the licensing requirements of the Atomic Energy Act, the draft analysis will, for the purposes of NEPA, consider the radiological effects of the proposed action and alternatives.

The issues to be analyzed in depth in the Draft GEIS include the impacts and costs associated with rule alternatives for controlling the disposition of solid materials at licensed facilities. Information will be developed on (a) types and contamination levels of solid materials present at licensed facilities and potentially available for release; (b) pathways of exposure to, and environmental impacts of, solid materials released from licensed facilities; (c) regulatory alternatives and methods of approach for analysis of the alternatives; and (d) costs and benefits of the alternatives. The Draft GEIS will also include a detailed discussion of the need for the proposed action.

The Draft GEIS will recognize other studies related to the control of solid materials, including the National Academies report completed in March 2002. This report contains nine recommendations on the decision-making process, potential approaches for controlling the disposition of solid materials, and additional technical information needed. In addition, other scientific organizations are engaged in similar processes. Recognized radiation protection standards organizations like NCRP, ICRP, and ANSI have issued findings about possible criteria for controlling the disposition of solid materials. International agencies (such as the International Atomic Energy Agency and the European Commission) as well as other individual nations, are in the process of establishing standards for controlling the disposition of solid materials. These efforts are significant for the NRC because inconsistency in standards between the U.S. and other nations can result in confusion regarding international trade, in particular if materials released under other nations' regulations arrive as imports in the U.S.

The NRC identified reasonable alternatives to the proposed action during scoping. The DGEIS will include consideration of both radiological and nonradiological impacts associated with the proposed action and the reasonable alternatives. The DGEIS also considers necessary monitoring, potential mitigation measures, unavoidable adverse environmental impacts, short-term uses of the environment and the maintenance and enhancement of long-term productivity, irreversible and irretrievable commitments of resources, and cumulative impacts. The following topical areas and issues will be analyzed in the Draft GEIS.

- ***Public and Occupational Health and Safety.*** The potential human health impacts of the alternatives on workers and the general public will be evaluated for normal operations (including handling, transfer, inspection activities, and end uses) and decommissioning. Potential exposures to radioactive elements and to chemicals will be considered.

- ***Transportation.*** The transportation impacts of shipping released materials under each alternative will be discussed. The impacts of transportation will be evaluated in terms of radiological exposure risk to the population during normal transportation (including handling, transfer, and inspection) and under credible accident scenarios. The non-radiological impacts of transportation will also be evaluated.

- ***Water Resources.*** The Draft GEIS will assess the potential impacts of the alternatives on surface water-and groundwater resources.

- ***Air Quality.*** Potential air quality impacts of each alternative will be evaluated in the Draft GEIS. The evaluation will include potential impacts for both radiological constituents and other air pollutants.

- ***Waste Management.*** Waste management was identified as a significant issue by many commenters. The Draft GEIS will document the quantities, types, treatment, and disposal of the various released materials. The Draft GEIS will also consider the disposal capacity impacts associated with the disposal of materials at both EPA-regulated landfills and LLW disposal facilities.

- ***Cost-benefit Analysis.*** The Draft GEIS will include a cost-benefit analysis that assesses the environmental and other costs and benefits of each of the alternatives.

4. ISSUES OUTSIDE THE SCOPE OF THE DGEIS

The NRC has made a determination that some issues are associated with small or no impacts. For this reason, these issues will not be addressed in detail in the GEIS. These issues include:

- Soils
- Ecological resources
- Environmental justice
- Land use
- Visual/scenic resources
- Noise
- Historical, archaeological and cultural resources

Also, the GEIS will not address the impacts of terrorism as the staff does not consider these impacts to be reasonably foreseeable as a result of the proposed action.

APPENDIX B
CURRENT NRC APPROACH

Currently NRC generally addresses the release of solid material on a case-by-case basis using license conditions and existing regulatory guidance. In each case, material may be released from a licensed operation with the understanding and specific acknowledgment that the material may contain very low amounts of radioactivity, but that the concentration of radioactive material is so small that its control through licensing is no longer necessary.

The case-by-case approach includes guidance that is applicable to equipment and material with radioactivity located on the surface or within the material or equipment itself. However, there are differences in the application of this guidance between reactor licensees and materials licensees, which is explained below.

1. Release of Solid Materials with Surface Residual Radioactivity

1.1 All Licensees

Criteria which licensees must use in determining whether the material may be released are approved for use by the NRC during the initial licensing or license renewal of a facility, as part of the facility's license conditions or radiation safety program. The licensees' actions must be consistent with the requirements of 10 CFR Part 20 (see e.g., Subpart F of Part 20 (10 CFR 20.1501)). Thus, the licensee performs a survey of the material prior to its release.

1.2 Reactor Licensees

Reactor licensees typically follow a policy that was established by Office of Inspection and Enforcement Circular 81-07 and Information Notice 85-92. Under this approach, reactor licensees must survey equipment and material before its release. If the surveys indicate the presence of AEA material above natural background levels, then no release may occur. If the appropriate surveys have not detected licensable material above natural background levels, the solid material in question does not have to be treated as waste under the requirements of Part 20. The fact that no radioactive material above background is detected does not mean that none is present; there are limitations on detection capability. In practice, the actual detection capability of survey instruments are typically consistent with those contained in Regulatory Guide 1.86.

1.3 Materials Licensees

In the non-reactor materials license context, NRC usually authorizes the release of solid material through specific license conditions. One set of criteria that is used to evaluate solid materials before they are released is contained in Regulatory Guide 1.86, entitled "Termination of Operating Licenses for Nuclear Reactors." A similar guidance document is Fuel Cycle Policy and Guidance Directive FC 83-23, entitled "Guidelines for Decontamination of Facilities and Equipment Prior to Release for Unrestricted Use or Termination of Byproduct, Source or Special Nuclear Materials Licenses." Both documents contain a table of surface contamination criteria which may be applied by licensees for use in demonstrating that solid material with surface contamination can be safely released with no further regulatory control.

Although Regulatory Guide 1.86 was originally developed for nuclear power plant licensees, the surface contamination criteria have been used in other contexts for all types of licensees for many years. By setting maximum allowable limits for surface contamination, Regulatory Guide 1.86 implicitly reflects the fact that materials with surface contamination below those limits may be released without adverse effects on the public health and safety.

2. Release of Solid Materials with Volumetric Residual Radioactivity

In the case of volumetrically contaminated materials, NRC has not provided guidance like that found in Reg Guide 1.86 for surface contamination. Instead, NRC has treated these situations on an individual basis, typically seeking to assure, by an evaluation of doses associated with the proposed release of the material, that maximum doses are a small percentage of the Part 20 dose limit for members of the public. Thus, the NRC practice over the years has been to allow the release of material with slight levels of volumetric contamination based on a case-by-case evaluation. These evaluations follow guidance discussed in the June 1999 Issues Paper (NRC 1999b) and in three All-Agreement States letters (STP-00-070, STP-01-081, STP-03-003), dated August 22, 2000, November 28, 2001, and January 15, 2003, respectively.

2.1 All Licensees

Licensees have used the specific process set out in 10 CFR 20.2002 to seek approval for alternate disposal methods of solid material. The release of material using the 10 CFR 20.2002 process is consistent with other disposition provisions in Part 20 that allow for the unrestricted release of material (e.g., 10 CFR 20.2003 and 10 CFR 20.2005). With regard to evaluation of 10 CFR 20.2002 requests, the guidance that NRC has used to evaluate these requests has evolved over time in response to increases in technical capabilities and changes in the regulations. In the mid-1980's, NRC used several documents including NUREG-1101, Vol. 2 (Onsite Disposal of Radioactive Waste - Methodology for Radiological Assessment of Disposal by Subsurface Burial), NUREG/CR-3332 (Radiological Assessment - A Textbook on Environmental Dose Analysis), and NUREG/CR-5512, Vol. 1 (Residual Radioactive Contamination From Decommissioning). Most of the alternate disposal requests involved burying the waste on-site or at off-site locations (e.g., landfills). In 1988, NRC promulgated the rule on “General Requirements for Decommissioning Nuclear Facilities” (Timeliness rule). In part, this rule required licensees to submit evaluations of inactive areas of sites including former burials under 10 CFR 20.302 and 20.304. Additional clarification was provided in Information Notice 96-47. In 1996, NRC developed a preliminary Screening Methodology for evaluating former burials (61 FR 56716). After issuance of requirements in Subpart E of 10 CFR 20 in the License Termination Rule (LTR) in July 1997, NRC concluded that the screening methodology did not always produce a dose below the unrestricted dose limit when a more rigorous methodology was used, and the screening methodology was never finalized.

The current guidance document that would be used to evaluate doses associated with 20.2002 requests is NUREG-1757, Volume 2 (Consolidated NMSS Decommissioning Guidance:

Characterization, Survey, and Determination of Radiological Criteria), dated September 2003. This NUREG provides guidance on complying with Subpart E of Part 20, and represents the current state of thinking for dose assessments. The guidance in NUREG 1757, Volume 2, was based substantially on guidance in NUREG-1727 (NMSS Decommissioning Standard Review Plan), dated September 2000. Prior to this NUREG being finalized, NRC issued interim guidance entitled "Preliminary Guidelines for Evaluating Dose Assessments in Support of Decommissioning," dated February 11, 1999. Thus, the standard practice over the years has been to allow the release of material with slight levels of volumetric contamination based on a case-by-case evaluation.

2.2 Reactor Licensees

For reactor licensees, the disposition of volumetrically contaminated materials is being implemented under the provisions of Information Notice No. 88-22: Disposal of Sludge from Onsite Sewage Treatment Facilities at Nuclear Power Stations. Certain materials may be surveyed using a representative sample and gamma spectrometry analytical methods. The provision requires that materials can be released if no licensed radioactive material above natural background levels is detected, provided the radiation survey used a detection level that is consistent with the lower limit of detection values used to evaluate environmental samples. NRC guidance states that the lower limit of detection (LLD) to be used for radiation surveys is the "operational state of the art" LLD values given in the Standard Radiological Effluent Technical Specifications (RETS) for environmental samples taken as part of the licensee's radiological environmental monitoring program.

The environmental LLDs are contained in Regulatory Guide 4.8, "Environmental Technical Specifications for Nuclear Power Plants," and in a Branch Technical Position (NRC 1979). They are also contained in NUREG-1301, "Offsite Dose Calculation Manual Guidance: Standard Radiological Effluent Controls for Pressurized Water Reactors," and NUREG-1302, "Offsite Dose Calculation Manual Guidance: Standard Radiological Effluent Controls for Boiling Water Reactors." There are several different acceptable survey applications of the environmental LLDs and applications have included a variety of environmental media including soils, sediments, liquids and slurries.

2.3 Materials Licensees

For materials licensees, the disposition of volumetrically contaminated materials is being implemented under the provisions of the December 27, 2002, NRC Memorandum "Update on Case-Specific Licensing Decisions on Controlled Release of Concrete from Licensed Facilities," (referenced in STP-03-003). This memorandum indicates that controlled releases of volumetrically contaminated concrete may be approved, pursuant to 10 CFR 20.2002, under an annual dose criterion of a "few mrem."

3. Agreement State Practices for Releasing Solid Materials

As part of the technical basis development for the control of solid materials, NRC obtained information from the Agreement States on their practices with respect to the release of surficially and/or volumetrically contaminated materials for unrestricted use. The responses indicate the States vary in their approaches. The types of criteria applied on a case-by-case basis include use of levels that are indistinguishable from background, use of guidelines similar or equivalent to Regulatory Guide 1.86, and use of dose-based analyses. The approaches listed below were identified by one or more Agreement States in their responses to the All Agreement States letter SP-99-074, dated November 2, 1999:

- Materials to be released must be indistinguishable from background. The level used for background could be based on NRC guidance such as Regulatory Guide 1.86.

- Radioactive material can only be transferred to persons licensed to receive it. Therefore, licensees cannot release either surficial or volumetric contaminated solid materials for unrestricted use.

- NRC guidance documents are used to determine, on a case-by-case basis, whether radioactive materials (e.g., dirt, resins, asphalt, concrete, metals) can be released for unrestricted use. This includes but is not limited to NRC guidance documents such as Regulatory Guide 1.86, Policy and Guidance PG-8-08, Policy and Guidance Directive FC 83-23, NUREG/CR 5849, and computer models such as RESRAD, and DandD.

- Regulatory Guide 1.86 is used but the contamination limits for the second group of nuclides in Table 1 are increased by a factor of ten.

- In addition to meeting specific surface contamination limits similar to Regulatory Guide 1.86, porous materials (e.g., concrete), which are to be released for unrestricted use, shall be evaluated to determine whether radioactive materials have penetrated to the interior of the material. If radioactive contamination has penetrated into the material, analysis of the average concentration, in picocuries per gram, shall be made. The material may be released for unrestricted use if the radionuclide concentrations do not exceed the limits specified for soil (which preclude a member of the public from receiving a total effective dose equivalent in excess of 25 mrem/year from all pathways (excluding radium and its decay products)).

- Volumetric releases are based upon a concentration equivalent to the 10 CFR Part 20 values for water converted to grams rather than volume.

- Releases can be based on a life-time fatal cancer risk of 1.0E-6. One State identified used a risk criterion of 1.0E-4.

- Use of maximum doses included 1, 10, 15 or 25 mrem/yr.

- Allowance of up to 8 pCi/gm of Co-60 in soil. Allowance of 5 pCi/gm of Cs-137 in flue dust.

- Requirements that no licensee may possess, receive, use, or transfer licensed radioactive material in such a manner as to cause contamination of soil or vegetation in unrestricted areas that causes a member of the public to receive a total effective dose equivalent in excess of 25 mrem/year from all pathways (excluding radium and its decay products).

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APPENDIX C
LETTERS FROM COOPERATING AGENCIES

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From: Richard Ratliff <Richard.Ratliff@tdh.state.tx.us>
To: "'Phyllis Sobel'" <PAS@nrc.gov>
Date: 9/4/03 12:33PM
Subject: RE: Scope of Work for Clearance Rulemaking

Phyllis, Mr. Michael Whalen with the State of Massachusetts, Radiation Control Program has agreed to represent the states on this work group. His E-mail address is: michael.whalen@state.ma.us ,and his telephone number is: 617-427-2944. I advised Michael of the September 10th conference call. Please let me know if you have any questions. Richard

CC: "'michael.whalen@state.ma.us'" <michael.whalen@state.ma.us>, "Pearce O'Kelley (E-mail)" <okelletp@dhec.sc.gov>, "Ron Fraass (E-mail)" <rfraass@CRCPD.ORG>

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

JAN 29 2004

OFFICE OF
AIR AND RADIATION

Mr. Lawrence E. Kokajko, Chief
Environmental and Performance Assessment Branch
Office of Nuclear Material Safety and Safeguards
Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Mr. Kokajko:

In response to your letter of invitation we, the U.S. Environmental Protection Agency (EPA), would like to accept your request to become a cooperating agency on the Nuclear Regulatory Commission's (NRC's) development of a rulemaking controlling the disposition of solid materials. We understand this role to be consistent with regulations developed by the Council on Environmental Quality that implement the National Environmental Policy Act (NEPA). More specifically, we expect our involvement to focus on the review of various drafts of the Generic Environmental Impact Statement (GEIS), review of associated documents, and participation on relevant working and managerial steering groups.

By assuming this role as a cooperating agency, EPA believes that it can contribute to the review of the NRC effort. EPA's role as a cooperating agency does not imply EPA's endorsement of NRC's selection of specific approaches, alternatives or options. EPA will conduct independent reviews of the Draft and Final EIS, and associated documents, in accordance with Section 309 of the Clean Air Act, 42 U.S.C. 7609. The following addresses the specific roles of the respective agencies.

EPA understands its responsibilities as a cooperating agency to be as follows:

- EPA will participate on working groups and managerial steering groups related to this rulemaking effort;
- EPA will provide timely review of documents and written comments to NRC on the GEIS and associated documents;
- EPA recognizes that the comments it provides to the NRC are advisory; and
- Given resource limitations and other practicalities, EPA commits to work within NRC's EIS preparation schedule to the extent practicable.

EPA understands NRC responsibilities as the lead agency to be as follows:

- NRC will forward all comments it receives from working group members during preparation of the draft EIS as well as make available all comments it receives during the formal EIS comment period;

- NRC will consult with EPA but will retain sole responsibility for selecting the regulatory approach and among regulatory options.
- NRC will give EPA preliminary copies of the Draft and Final EIS, and associated documents, for review and comment prior to final lead agency approval and distribution of the documents.

The above lists seek to clarify the respective responsibilities and expectations of the two agencies. Adam Klinger will serve as the contact person and he and members of his staff will serve as resources on this effort. He can be reached at 202-343-9378. We have had initial conversations with Phyllis Sobel as the staff project lead and will coordinate accordingly.

We thank you for the opportunity to participate in this manner and believe that such interaction will improve communication and coordination of Federal radiation-related initiatives.

Sincerely,

Frank Marcinowski, Director
Radiation Protection Division
Office of Radiation and Indoor Air

Department of Energy
Washington, DC 20585

DEC 1 8 2003

Martin J. Virgilio, Director
Office of Nuclear Materials Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555-0001

Dear Mr. Virgilio:

This is in response to the August 6, 2003, letter from Mr. L. Kokajko of your office to Mr. A. Wallo inviting the U.S. Department of Energy (DOE) to participate as a cooperating agency in the U.S. Nuclear Regulatory Commission's (NRC) preparation of the Generic Environmental Impact Statement (GEIS) regarding the control and disposition of certain solid material. We understand that this GEIS is in support of the NRC's enhanced participatory rulemaking on alternatives for controlling the disposition of solid materials that originate in restricted or impacted areas of NRC-licensed facilities, and that have no, or very small amounts of, radioactivity resulting from licensed operations.

For the reasons cited in your letter concerning DOE's experience and efforts in the control and release of property containing residual radioactivity, we agree that it is both reasonable and beneficial for DOE to participate as a cooperating agency in this EIS process. Participating as a cooperating agency will help DOE stay apprised of the relevant issues and provide a mechanism for DOE to contribute its expertise to the review process, while ensuring effective communication between our agencies. Cooperating agency status will also assist DOE in its own EIS process involving DOE scrap metal, which, as your letter correctly notes, is a separate, ongoing effort. As a cooperating agency, DOE will, as appropriate and subject to the availability of personnel resources, participate in the GEIS process by providing requested information and data as available, and reviewing the GEIS and supporting materials.

The Office of Air, Water and Radiation Protection Policy and Guidance will serve as DOE's principal point of coordination for DOE participation in the GEIS. Accordingly, please contact Stephen Domotor (202-586-0871) of that office to initiate coordination and information exchange on the GEIS for the control and disposition of solid material. Please feel free to contact either Mr. Domotor or Mr. Wallo if you or your staff need assistance.

Sincerely,

Andy Lawrence

Andy Lawrence
Deputy Assistant Secretary
for Environment

APPENDIX D
COLLECTIVE DOSE ASSESSMENTS FOR CONCRETE, STEEL AND TRASH

1. Introduction

The NRC is considering regulatory requirements for the disposition of solid, potentially clearable materials that are under license by the NRC and its Agreement States. As part of its regulatory decision-making process, the NRC evaluates the advantages and disadvantages associated with a range of alternatives. This appendix assesses potential doses to workers and members of the public that could result from the implementation of the alternatives currently being evaluated. Potential collective doses are estimated for each alternative for concrete, ferrous metals[1], and trash. The information in this appendix is based on an evaluation of doses analyzed in part in NUREG-1640 (NRC 2003d), which is discussed in Appendix E.

This appendix summarizes the results of a draft report, available on NRC's webpage, entitled, "Collective Doses Associated with Clearance of Materials from NRC/Agreement State - Licensed Facilities," Rev. 2, December 31, 2003 (SC&A 2003). References in this summary pertaining to additional, detailed information correspond to their respective locations in the above referenced collective dose report (SC&A 2003). The objective of the report was to evaluate and compare the amounts and radionuclide characteristics of potentially clearable material (e.g., different types of metals, equipment, tools, concrete, and trash) and their associated radiation health impacts. For this purpose, assessments are made for the collective doses to radiation workers and members of the public that might result for each of the rulemaking alternatives.

The Draft GEIS defines five alternatives, two of which are subdivided into five options, as follows:

(1) No Action. This alternative is the baseline for comparison of alternatives and generally corresponds to material radioactivity concentration levels specified in Regulatory Guide 1.86 (USAEC 1974).

(2) Unrestricted Release. This alternative places no restrictions on what can be done with material that is released. Considerations for choosing a meaningful range of options for this alternative resulted in specifying 5 dose levels. The options include: zero above background (which was analyzed at 0.03 mrem/yr), 0.1 mrem/yr, 1 mrem/yr, and 10 mrem/yr. A realistic lower-bound dose limit of 0.03 mrem/yr was chosen because it is a small value at, or marginally above, detectable levels. The dose options used the

[1] In the context of this analysis, "ferrous metals" is used as an all inclusive term for all alloys whose major constituent is iron (Fe). Ferrous metals include such metals as carbon steel, stainless steel, forged steel, galvanized steel, cast iron, etc.

normalized doses in NUREG-1640[2] for unrestricted use to derive their respective radionuclide concentrations in specific materials.

(3) Disposal in EPA/State-Regulated Disposal Facility. This alternative places restrictions on the method of material dispositions. Specifically, material could only be disposed of in a RCRA Subtitle D landfill at or below the activity concentrations allowable for a defined dose option. The result is that a greater amount of activity could be released to landfills than the amount that would be released to general commerce under the Unrestricted Release Alternative. The options include: zero above background (which was analyzed at 0.03 mrem/yr), 0.1 mrem/yr, 1 mrem/yr, and 10 mrem/yr. The dose options used the normalized doses in NUREG-1640 for disposal in a RCRA Subtitle D landfill to derive their respective radionuclide concentrations in specific materials. The RCRA Subtitle D regulations encompass both municipal and industrial landfills. Construction and demolition (C&D) or other industrial waste landfills were included in the collective dose report (SC&A 2003). For further discussion of EPA/State-regulated landfills, see Appendix J.

(4) Disposal in a LLW Disposal Facility. This alternative is also referred to as the prohibition alternative, because any of the material considered would be disposed of only in an NRC-licensed low-level radioactive waste (LLW) disposal facility.

(5) Limited Dispositions. In this alternative, solid material would be released, but NRC would allow only certain authorized dispositions to limit the potential for public exposure. All materials to be released would undergo a radiation survey and the measured level of radiation would be compared against the criterion for release for limited dispositions. Solid materials with measured radiation levels below the established criterion would be released for pre-approved limited dispositions, while solid materials with radiation levels above the criterion would be sent to a LLW disposal facility. NRC regulations in 10 CFR Part 20 would be amended to add a regulation on limited dispositions. Any requests to release material other than to these limited end uses or at higher doses would require case-specific approval from NRC.

2. Design Objectives and Overall Approach

The overarching design objectives of this investigation are realism, clear and complete presentation, accuracy, consistency, and full disclosure of uncertainty in the derivation of the collective doses associated with each rulemaking alternative. In addition, the approach is required to be consistent and compatible with the methods used to derive individual normalized doses as provided in NUREG-1640 (NRC 2003d).

Consideration was given in the calculation of the collective doses to all categories of NRC/Agreement State licensees, a full range of exposure scenarios and/or population groups,

[2] "Radiological Assessments for Clearance of Materials from Nuclear Facilities - Main Report." NUREG-1640, Volume 1. Washington, DC: U.S. Nuclear Regulatory Commission, 2003 (NRC 2003d).

and a broad range of materials (ferrous metal (including steel), copper, aluminum, concrete, and trash). Since the number of categories and subcategories of licensees, types of materials, and exposure scenarios/population groups that can contribute to the collective doses is very large, the number of categories that are explicitly included was selected based on the following criterion:

- Capture enough of the categories and volume of material, and associated radionuclide inventory, and resultant collective doses associated with each rulemaking alternative for the preponderance of materials considered for disposal. If the exposure scenarios chosen are realistic, then these collective dose estimates can be used to provide very representative information on the dose impacts of the alternatives.

In the process of performing the analysis, secondary objectives included the following:

- Disclose which categories of NRC licensees and which materials are anticipated to be responsible for most of the collective doses.

- Create a mosaic of exposure categories that reveal the scenarios/population groups that are anticipated to experience the largest collective doses.

These objectives were achieved by using a combination of scoping/screening analyses and detailed calculations. The scoping calculations were generally deterministic and used to obtain a reasonable upper bound for the category selected. The detailed calculations could only be done when significant amounts of information were available, and over a realistic range of scenario specific situations. Then, performing random sampling over a very large number of potential exposure realizations, the collective dose can be estimated statistically (Monte Carlo method). This type of collective dose estimate has significant generic applicability because it is a valid representation of an average, or expected, value and its attendant range of uncertainty. As demonstrated through the scoping/screening calculations, steel, concrete, and trash were found to be the dominant sources of potentially clearable material in terms of volume of material, radionuclide inventory, and potential collective dose. In addition, the collective doses associated with end-use products made from recycled released steel were found to be responsible for the overwhelming majority of the collective doses.

The criteria for selecting the categories of recycled products to include in the collective dose assessment are described in Section 9.1 of the collective dose report (SC&A 2003). The criteria and methodology used to select categories of recycled products were specifically developed so as not to underestimate the collective dose. Also, for the collective dose assessment for the No Action and Unrestricted Release Alternatives it is assumed that the entire available inventory of solid material was used in the production of recycled products, and that none of the available inventory of solid material was disposed of in landfills, an assumption that maximizes the collective dose. Thus, although some specific types of products that could be made from recycled solid material may not be explicitly included in the collective dose assessment, the assumption that the entire available inventory of solid material is recycled accounts for the impact of the recycling on the collective dose (SC&A 2003).

All categories of licensees, types of materials, and exposure scenarios/population groups were addressed, but not to the same level of detail. As indicted above, a primary difference between the detailed analyses and the scoping/screening analyses results is that the detailed analyses are considered realistic estimates of the collective doses and sufficiently developed to be provided as a function of time, while the scoping/screening analyses are considered upper-end estimates of collective doses and cannot be represented as time dependent.

The analytical approach used in estimating collective doses from the use of products involved tracking and accounting for the inventories of radioactivity as materials moved from the point of release at licensees, to the incorporation of radioactivity in products or through the environment, and ultimately to dose receptors. In order to do this, 'reference' products (e.g., the generic category representing cars) were developed that are assumed to be representative of all products of a given type (e.g., the end product, namely the specific product being considered, such as "a car"). For example, a reference automobile was assumed that is representative of all types of automobiles (including pickup trucks, sport utility vehicles, etc.). The total collective dose remains the same, whether it is distributed over one car, two cars or 50 cars. This methodology is based on the assumption that, as the end-product concentration for a given amount of released radioactivity goes down, the number of individuals using that end-product goes up proportionally. In other words, the product of the concentration times the number of end-product users is always a constant. Analytically, when all the small contributions are added, it validates the methodology of calculating the collective dose from a single reference product. That single reference product is assumed to be representative of all products of that type.

For metals, the modeling is a cumulative total of all source terms and pathways having significance. For example, for power reactors, the source term is available for 50 years (or until the reactor is decommissioned) and it's cumulative effects carried out for an additional 250 years. For everything else, because the available data was not sufficiently as refined, bounding, realistically, conservative estimates were made.

Since the detailed analysis employs probabilistic methods, uncertainty in quantities of material and the collective doses associated with the rulemaking alternatives are explicitly addressed by assigning uncertainty distributions to the input parameters, which are used throughout the calculations, and yield results that are presented as uncertainty distributions that disclose the mean, median, standard error of the mean, and the 5th and 95th percentile values for the results of the calculations.

For further elaboration on methodology, it is emphasized that the scoping/screening analyses do not employ probabilistic methods to assess uncertainties. Instead, a semi-quantitative analysis/discussion of the uncertainty in the analysis is provided which discloses the uncertainty in the quantities of material and collective doses in a less rigorous manner than those used in the more elaborate Monte Carlo analyses. In general, the scoping/screening analyses are designed to demonstrate that a given category of licensees, type of material, or exposed population group are not important contributors to the overall quantities of material or collective doses associated with each rulemaking alternative. As such, simplifying assumptions are used that provide a high level of assurance that the collective doses and quantities of materials are not underestimated.

As a final point, it is important to recognize that the concept of uncertainty, when addressing collective doses, is different from the concept of uncertainty when addressing individual doses, as was done in NUREG-1640. In NUREG-1640, the uncertainty analysis was concerned with estimating the uncertainty and mean values of the normalized doses to the individuals that comprise the critical groups. This report is concerned with the mean values and the uncertainty in the mean of real, but unknown, collective doses to population groups. It is not concerned with the variability of the doses to the individuals that comprise a given population group.

From a statistical perspective, NUREG-1640 (NRC 2003d) is concerned with the mean and standard deviation of the doses to individuals, while the collective dose report (SC&A 2003) is concerned with the mean and standard error of the mean of the collective doses to a given population group. This difference is important because individual variabilities within a population group "average out" when deriving the collective doses, resulting in uncertainties in the collective doses for a given population group that are relatively small as compared to the variabilities and uncertainties associated with the doses to the individuals that comprise the group.

The difference in these two concepts is equivalent to asking the question "what is the variability of the heights of the individuals that comprise the population of the U.S.," as opposed to asking the question "what is the uncertainty in the average height of the individuals of the U.S. population." In the case of the former, the variabilities are very large (the range of heights of adults likely span several feet). In the case of the latter, there is a real, but unknown average height of adults in the United States. Estimates of that value are based on measurements made on a sample of the total population, and the uncertainty in that value is probably less than a few inches.

3. Scrap Metal, Concrete, and Other Potentially Clearable Materials

The calculation of the amount and activity of potentially clearable material focused on commercial nuclear power plants, because they were determined to generate a major fraction of the total mass of potentially clearable materials from the decommissioning of all licensed facilities (96 percent of all ferrous metals and 99 percent of all concrete). The total mass of copper and aluminum from all licensed facilities combined is estimated to be less than 2 percent of the total mass of ferrous metals from nuclear power plants. Therefore, copper and aluminum were addressed by a deterministic scoping analysis.

Materials from nuclear power plants were characterized as clean, potentially clearable, or contaminated. Contaminated materials are expected to be disposed of as low-level radioactive waste (LLW), although some portion may be releasable if decontaminated. It is anticipated that some fraction of the potentially clearable materials would be disposed in a LLW facility under one or more of the regulatory alternatives being considered in this study. In addition to ferrous metals and concrete, the analysis also considered trash generated from operating nuclear power plants since some of this trash is generated within the restricted or impacted areas.

In addition to providing estimates for the expected masses of materials from boiling-water reactors (BWRs) and pressurized-water reactors (PWRs), the report also develops mass-to-surface area ratios. These ratios were needed to convert mass-based normalized effective dose equivalents (EDEs) to surficial dose factors. The analysis also determined contamination distributions needed to assess the impact of various regulatory alternatives on the mass of releasable materials and presents data on the fractional mix of radionuclides expected in the potentially clearable materials.

It was estimated that about 2 million metric tons of ferrous metals, 20 million metric tons of concrete, and about 200,000 metric tons of trash might fall within the scope of the proposed rule. About 45 percent of the radioactivity in these materials is from Co-60, with Cs-137 contributing another 16 percent.

4. Radionuclide Composition of Releasable Material Produced from Light-Water Reactors as a Function of Time

This information is presented, in part, in the form of curves that depict the volume of a given type of material on the y-axis and the radionuclide levels of the material on the x-axis. Then, using the normalized doses in NUREG-1640, or the explicitly defined clearance levels defined in Regulatory Guide 1.86 (USAEC 1974), the quantity of material and radionuclide composition of the potentially clearable material were calculated for the following four cases:

- Case A—Use NUREG-1640 material-specific limiting scenario normalized EDEs[3] for concrete and ferrous metals and trash limiting scenario normalized doses.

- Case B—Use NUREG-1640 (and trash) material-independent limiting scenario normalized EDEs.

- Case C—Use NUREG-1640 Municipal Solid Waste (MSW) landfill (Subtitle D) material-specific limiting scenario normalized EDEs for ferrous metals and concrete and limiting trash surrogate normalized doses.

- Case D—Use NUREG-1640 industrial landfill (Subtitle D) material-specific limiting scenario normalized EDEs for ferrous metals and concrete and limiting trash surrogate normalized doses.

This was accomplished by dividing the rulemaking alternative (in units of mrem/yr) by the normalized doses (in units of mrem/yr per pCi/g) to yield the release levels, (in units of pCi/g). Once the release level is determined for a given material and rulemaking alternative, curves were used to determine the quantity and radionuclide composition of the releasable material for a given alternative and case.

[3] NUREG-1640 provides normalized doses based either on the recommendations in ICRP Publication 26 (ICRP 1977) referred to as Effective Dose Equivalents (EDEs), or on the recommendations in ICRP Publication 60 (ICRP 1991) referred to as Effective Dose. This report uses the normalized EDEs.

Monte-Carlo calculations were employed to provide statistical representations for the mean value of the total collective dose and its range of uncertainty. The potential variability of the differing radiological source terms was included in these calculations, and the end results incorporate the uncertainty over all variable parameters considered, including this parameter.

The mean values of the total calculated activity in the releasable material are shown in Table D-1 for all four cases analyzed. As Table D-1 shows, the release of trash generates the largest amount of activity for three of the four cases analyzed. Only when the material-independent concentration limit (based on NUREG-1640) is used (i.e., Case B), is the activity generated dominated by the release of concrete. The activity in material released as a function of time is shown in the collective dose report (SC&A 2003).

Table D-1 Mean Value of Total Activity Released (Ci)

	Regulatory Options				
Case	**0.03 mrem/yr**	**0.1 mrem/yr**	**1 mrem/yr**	**10 mrem/yr**	**No Action**
All Material					
Case A	0.848	3.36	41.14	538.29	4.33
Case B	0.177	0.449	2.23	6.11	
Case C	1.27	4.48	45.55	549.35	
Case D	0.927	3.57	41.99	541.09	
Ferrous Metal					
Case A	0.092	0.395	2.86	12.74	1.76
Case B	0.008	0.048	0.745	4.33	
Case C	0.484	1.46	7.09	23.81	
Case D	0.138	0.550	3.54	15.55	
Concrete					
Case A	0.168	0.401	1.49	1.73	0.243
Case B	0.168	0.401	1.49	1.73	
Case C	0.201	0.460	1.67	1.73	
Case D	0.201	0.460	1.67	1.73	
Trash					
Case A	0.588	2.56	36.79	523.81	2.32
Case B	0.00001	0.00005	0.0015	0.043	
Case C	0.588	2.56	36.79	523.81	
Case D	0.588	2.56	36.79	523.81	

The mean values of the total calculated mass of the releasable material are shown in Table D-2 for all four cases analyzed. As Table D-2 shows, the release of concrete generates the largest mass of material for all of the cases analyzed. The mass of material released as a function of time is shown in SC&A 2003. For the dose options analyzed, there is very little difference in the mass of material released. This is also true for the other three cases analyzed. The reason for this is that there is a large mass of material at very low concentrations that would be released under any regulatory alternative, but as the regulatory alternatives become more liberal, the additional mass of material at the higher releasable concentrations is much less.

Table D-2 Mean Value of Total Mass of Material Released (million t)

Case	Regulatory Options				
	0.03 mrem/yr	0.1 mrem/yr	1 mrem/yr	10 mrem/yr	No Action
All Material					
Case A	16.0	19.1	21.9	22.3	18.3
Case B	15.5	18.4	21.4	22.1	
Case C	17.2	19.9	21.2	22.3	
Case D	16.7	19.5	22.0	22.3	
Ferrous Metal					
Case A	0.970	1.49	2.20	2.45	2.06
Case B	0.441	0.786	1.74	2.30	
Case C	1.57	2.00	2.38	2.48	
Case D	1.10	1.62	2.26	2.47	
Concrete					
Case A	15.0	17.6	19.6	19.8	16.2
Case B	15.0	17.6	19.6	19.8	
Case C	15.6	17.9	19.7	19.8	
Case D	15.6	17.9	19.7	19.8	
Trash					
Case A	0.014	0.021	0.041	0.066	0.020
Case B	0.0002	0.0004	0.002	0.006	
Case C	0.014	0.021	0.041	0.066	
Case D	0.014	0.021	0.041	0.066	

In SC&A 2003, Chapter 3 and Appendix A, detailed statistical data analysis was performed to determine the potential amounts of material considered releasable versus their associated levels of (measured) surface radioactivity. This type of distribution provides quantitative information on the shape of the probability distribution that characterizes the range of radioactivity levels likely to be found for the inventory of materials considered for release. The probability of finding contamination was mostly found to be very low and within the range of background radiation (approximately a null amount of radioactive contribution). Some small amount of material was found to increase beyond this, but within a very narrow range. This small increase, while possibly real, might also be partially caused by measurement uncertainty at these very low radiation levels. Beyond that range, there were very small, if any, amounts of material found until a much higher radioactivity level was reached. At this higher level, any materials found would require disposal at an NRC licensed LLW facility. Intuitively, such a probability distribution makes sense because anything that would be considered for release would, from materials process considerations, be expected to have no radioactivity or be at a very low level because of cleanup activities routinely performed as industry practice. Because decontamination is a destructive process, and cleanup efficiencies are usually high, very little, if any radioactivity would be expected to be found for these potentially clearable materials. Beyond this, other potentially radioactive materials would be expected to be at much higher levels, comparable to those requiring LLW disposal. Generally, although from a measurement aspect it is more difficult to demonstrate as well, materials considered for release having volumetric distributions of radioactivity would also be expected to have probability distributions similar to those found for surface radioactivity. Based on all of the above, the total amount of radioactivity from all released materials is expected to be small as compared to that contained in LLW. For example, the amount of radioactivity shipped to the three operating LLW facilities ranges from 1,400 to 420,000 Curies as annual averages. Regarding release, Table D-1 indicates that the estimated Curie inventory is expected to range from 0.2 to 549 Curies, over all regulatory options. Because the collective dose is proportional to the total radioactivity amount available for potential exposures, it also would be expected to be small.

The analysis included the possibility that some small amounts of ferrous scrap could be released after decontamination, based on operating experience with power reactors. For this to occur, the initial contamination levels would have to be relatively low and the decontamination factor high enough in order to meet release criteria. An item, such as a steam generator shell, might be considered worth decontaminating by licensees, given that such services are already available commercially. Generally a decontamination factor (DF) of around 10 is what is considered realistic, although some higher DFs can be achieved in limited specific cases. It is expected, from the aspect of implementation and cost concerns, that generally, based on process knowledge, only those contaminated materials that were within the DF range of 10 would be considered for decontamination. For such cases, it would be expected that any clean material of this type would be in the very low to none range of radioactivity concentration, and could be added to the clearance inventory.

5. Collective Doses Associated with Materials Other than those Modeled for Commercial Nuclear Power Plants

In addition to the release of ferrous metal, concrete, and trash from commercial nuclear power plants, the release of trash and other materials were analyzed for other types of NRC and/or Agreement State licensees. Also, the release of copper and aluminum from nuclear power plants was analyzed. Each of these analyses was performed via a screening (or bounding) calculation that compared the calculated mass and activity of material being analyzed to the mass and activity of ferrous metal, concrete, and trash from commercial nuclear power plants. The results of these scoping analyses are summarized below.

The development of a reference PWR nuclear power plant revealed that the masses of potentially clearable copper and aluminum were very small. (The best data for the analysis were from PWR ferrous metals inventory; BWRs were included via scaling factors.) The analysis also showed that the incremental radioactivity in releasable copper as compared to ferrous metals released under Case A was less than 7 percent for the 1 mrem/yr dose option. Similarly, the incremental radioactivity in aluminum released as compared to ferrous metals released under Case A was less than 0.5 percent for the 1 mrem/yr dose option. The total collective dose is directly proportional to the curie content of the released material. Because the addition of the copper's total radioactivity content is a small percent of the ferrous metal's (7 percent increment), it only has a small contributing effect to the total collective dose. The incremental increases for copper and aluminum are within the uncertainty bound of the analysis, and thus were not explicitly included in the Monte Carlo collective dose calculations but were included in the scoping analyses.

It was estimated that the total mass of potentially clearable trash generated by academic, industrial, government, and other unidentified sources would be about 13.4 times the mass generated by nuclear utilities. However, the activity contained in the much larger volume of the potentially clearable trash from these other licensees was calculated to be 40 percent of the activity in clearable trash from nuclear utility licensees. This increase in releasable activity was not included in the Monte Carlo collective dose calculations but was included in the scoping analyses and derivation of collective doses.

Other nuclear fuel cycle facilities that were analyzed include fuel fabrication facilities, uranium hexafluoride production facilities, and independent spent fuel storage installations (ISFSI). The bounding analysis for fuel fabrication facilities shows that exclusion of these facilities understates the total quantity of radioactivity in released ferrous metals by 3 percent for the 10 mrem/yr dose option, 0.2 percent for the 1 mrem/yr dose option, and has no effect on the remaining three dose options. Also, during the recycling of ferrous metals, uranium and physio-chemically-similar elements, such as zirconium and tungsten, especially with respect to their high refractory properties, partition to the slag and do not contribute to the collective dose in steel end-use products, such as automobiles and structural steel in buildings. For concrete, the impact of excluding fuel fabrication facilities on the quantity of radioactivity in released concrete varies from 6 percent for the zero above background dose option to 0.6 percent for the 10 mrem/yr dose option. The exclusion does not affect the no action results for concrete. Similar results were found from the bounding analyses of the other nuclear fuel cycle facilities.

Non-nuclear fuel cycle facilities that were analyzed include non-power reactors and medical centers. For non-power reactors, it was found that the radioactivity levels in released steel and concrete from all such reactors are very low — a maximum of 0.9 mCi for steel and 12 mCi for concrete for the 10 mrem/yr steel dose option. These quantities of radioactvity would not affect the collective dose results calculated elsewhere in the collective dose report (SC&A 2003) to any measurable degree.

The results of the screening analysis for medical centers revealed that the potential volume of material produced each year by all medical facilities in the U.S. that could be impacted by an NRC rulemaking addressing release could be as high as 38,000 tons/yr for the prohibition alternative (because such licensees could find it more feasible to disposition all materials as prohibited), and the radionuclide inventory in this material is about 1.3 mCi of tritium and 17 mCi of C-14. An upper-bound estimate of the potential collective doses associated with the release of this material showed that the collective dose from potentially released tritium in trash from impacted areas of all medical facilities in the U.S. would be <1 person-rem/yr, and the collective dose from the ingestion of released C-14 would be about 3.3 person-rem/yr. The actual collective doses are expected to be a very small fraction of these upper-bound values. For comparison to the calculated collective dose due to nuclear power reactor licensee operation and decommissioning, the values in Table 5.31 of the collective dose report (SC&A 2003) should be compared to the Case A collective doses reported in Table D-3.

6. Screening of Scenarios

There is a large number of potential exposure scenarios that could be used to evaluate the collective dose to the general public from the release of ferrous metal scrap and concrete rubble from NRC- or Agreement State-licensed facilities. A series of screening analyses was performed to eliminate scenarios that would not make a significant contribution to the total collective dose. These scenarios were selected from the radiological assessments of individuals exposed to materials released from nuclear facilities as presented in NUREG-1640 and in an earlier EPA study (Anigstein et al. 2001). Also included were five additional scenarios characterizing the population exposures to finished steel products.

The aim of the analyses was to calculate the collective doses from the release of 1 kt of released material with a total specific activity of 1 Bq/g, comprising the mix of radionuclides found in releasable material. These normalized collective doses were then ranked in decreasing order and the cumulative collective doses were tabulated. The results of the screening analyses show that, in the case of ferrous metal scrap, only five scenarios, all depicting population exposures to finished steel products, would make significant contributions to the total collective dose. In the case of concrete rubble, only the road use scenario plays a significant role in the collective dose analysis.

These screening analyses address most of the exposure scenarios described in NUREG-1640. Not included in the screening analysis are the scenarios characterizing the consumption of water from wells and surface runoff infiltrated by leachate from landfills or storage piles. These scenarios, which do not readily lend themselves to the deterministic screening analyses applied to the other scenarios, are addressed by the main collective dose analysis described in Section 10. Another class of scenarios omitted from the screening analyses is the population exposures from passing trucks carrying released materials. These scenarios are addressed by the main analysis in Section 10.

7. Collective Radiation Exposures to Workers Implementing the Rulemaking Alternatives at Light-Water Reactors

Two major activities need to be accomplished by radiation workers at licensed facilities when releasing material: (1) the performance of surveys; and (2) the decontamination of material to meet acceptable limits if the licensees elect to perform decontamination activities in support of release (some licensees may deem it not cost-effective to perform any decontamination activities for the purpose of material release).

The analysis of these major activities reveals that the collective exposures from surveying the entire inventory of releasable ferrous metals, trash, and concrete material for release following the Multi-Agency Radiation Survey and Site Manual (MARSSIM) (NRC 1997a) approach would be about 290 person-rem for the entire population of PWRs and BWRs. The overwhelming majority of this collective dose is due to surveys for trash because of the large surface area to volume ratio of trash, as compared to concrete and steel.

The collective exposure estimates are highly dependent on two variables, the exposure rate and unit survey effort. If the material is surveyed in place, where exposures could come from a variety of structures and sources other than the released material, then exposure rates could be higher by at least a factor of 10. If the potentially clearable material is removed from other sources of radioactivity, and the release levels are lower than Regulatory Guide 1.86 levels, then the exposure rates will likely be less than 0.005 mrem/hr above background. Conversations with representatives of the nuclear power industry reveal that, during the license termination process, the potentially clearable material would be segregated from the more contaminated areas and placed in low background areas so that the material could be surveyed with the lowest possible limits of detection. Accordingly, a radiation field of 0.005 mrem/hr above natural background (as used in this analysis) is consistent with this strategy and consistent with the types of radiation fields that may be expected from the material that is being surveyed.

In theory, the level of effort required to perform surveys would be expected to increase as the release level is reduced. However, investigations currently being performed by the NRC reveal that, with the exception of the zero above background dose option, the level of effort to perform surveys (for the radionuclide mix of concern at light water reactors) is expected to be approximately the same for all alternatives; i.e., about 3 minutes per square meter surveyed using conventional pancake probe survey techniques.

The collective exposures to workers performing decontamination in support of release is anticipated to be higher than the exposures from surveys, because decontamination activities are anticipated to be performed in more highly contaminated areas and require a greater level of effort per ton of material undergoing release. Estimates of collective dose associated with decontamination activities in support of release during operations and license termination is about 300 person-rem to decontaminate steel in the population of PWRs or BWRs. The estimated exposure rates and labor hours used in this estimate depend on assumptions regarding how decontamination is performed.

The results are unaffected by the rulemaking alternative, because it is assumed that the level of effort required to decontaminate the material to the release objective is the same for all rulemaking alternatives. This may not be the case for the very low dose options, such as the 0.1 mrem/yr alternative and the zero above background dose option. If it is determined that the level of effort required to achieve these criteria is twice as high, then the collective dose would double. In addition, if it is deemed plausible to decontaminate material that is up to 500,000 dpm/100 cm^2 (i.e., 100 times the limit set by Regulatory Guide 1.86 for Co-60), it is plausible that the radiation field in the vicinity of the decontamination operations could increase by a factor of 10 to 0.5 mrem/hr, thereby potentially increasing the collective dose by a factor of 10.

8. Radiation Doses to Workers Due to the Disposal of Releasable Materials at Licensed Low-Level Radioactive Waste Disposal Facilities

A scoping calculation of the collective doses to radiation workers at licensed LLW disposal facilities due to the licensed disposal of all potentially clearable material was performed. The approach used took advantage of the large amount of data that has been compiled on actual collective doses to radiation workers at LLW facilities, along with data characterizing the quantities of radioactive materials disposed. These data were used to derive empirically determined normalized collective doses to this population group expressed in terms of person-rem per curie disposed. This value was then multiplied by the total radionuclide inventory contained in potentially clearable material to derive the collective dose. In performing these calculations, C-14 and H-3 were not included in the analyses, since these radionuclides are large contributors to the number of curies disposed at LLW facilities, but do not contribute to the collective doses to workers. The results reveal that the collective dose to this population group from the licensed disposal of all potentially clearable material (as may be the case under a prohibition alternative) is less than 1 person-rem.

Because of the incrementally small quantities of radionuclides disposed at licensed facilities associated with release, as compared to the quantity of radionuclides currently being disposed, and the fact that the current doses to the nearby populations are a small fraction of the regulatory standards for offsite exposures set forth in 10 CFR 61 (i.e., 25 mrem/yr (0.25 mSv/yr)), a separate analysis of offsite exposures in the vicinity of LLW disposal facilities associated with release was not considered necessary and is not provided.

9. Collective Doses to Members of the Public from Recycling and Reuse of Released Material

Following release, residual activities in the released material will travel a complex route until final disposal in a landfill or until the radionuclides decay to stable forms. Along the way, some individuals will receive some degree of exposure to the radionuclides in the released material. The exposure scenarios and levels of exposure will vary by radionuclide and the type of released material (i.e., steel, copper, aluminum, concrete, and trash). This section divides the exposed population into population groups within which the individual members are anticipated to experience similar exposure from the released material. In this way, the collective doses to each population group could be estimated as the product of the average dose rate (i.e., rem/hr) to the members of each population group times the collective number of person hours of exposure in the population group.

The potential exposure scenarios vary depending on the type of material released, i.e., metal, concrete, or trash. For metal, the material is assumed to be either recycled or disposed of, as shown on Figure D-1. If it is recycled, then the potential exposure scenarios involve: (1) transportation of the material, (2) use of the products produced from the material, (3) the population surrounding the mill due to air emissions from the mill, (4) use of the slag (as road beds, and people traveling on those roads), and (5) disposal of the dust produced at the mill, as shown on the right side of Figure D-1. If the metal is disposed of in a landfill, it is assumed that it would be transported directly to the landfill, and the only exposures would be during transport and due to leaching of the material from the landfill, as shown on the left side of Figure D-1. As demonstrated by the scoping analysis, doses to workers along the released material's path (i.e., truck drivers, mill workers, landfill workers, road builders, etc.) do not contribute significantly to the collective dose, and are therefore not modeled.

Similar to Figure D-1 for metal, Figures D-2 and D-3 show the scenarios that are included in the collective dose model for the release of concrete and trash, respectively. Note that the section numbers indicated in Figures D-1 through D-3 refer to sections of the collective dose report (SC&A 2003).

Collective dose models were developed, and are described in detail in the report, for each of the exposure scenarios depicted in Figures D-1 through D-3, as follows:

- Exposures to Finished Steel Products
  - Beds
  - Automobiles
  - Office Buildings
  - Office Furniture
  - Home Appliances

- Exposures Due to Disposal of Released Material in a Landfill
  - Municipal Landfills
  - Industrial Landfills

- Exposures to Released Material Used in Road Construction
  - Concrete
  - Slag from Steel Mills

- Exposures to Airborne Releases
  - Steel Mill
  - Incinerator

- Exposures During Transportation
  - To Steel Mill
  - To Landfill
  - To Incinerator
  - To Road Construction Site

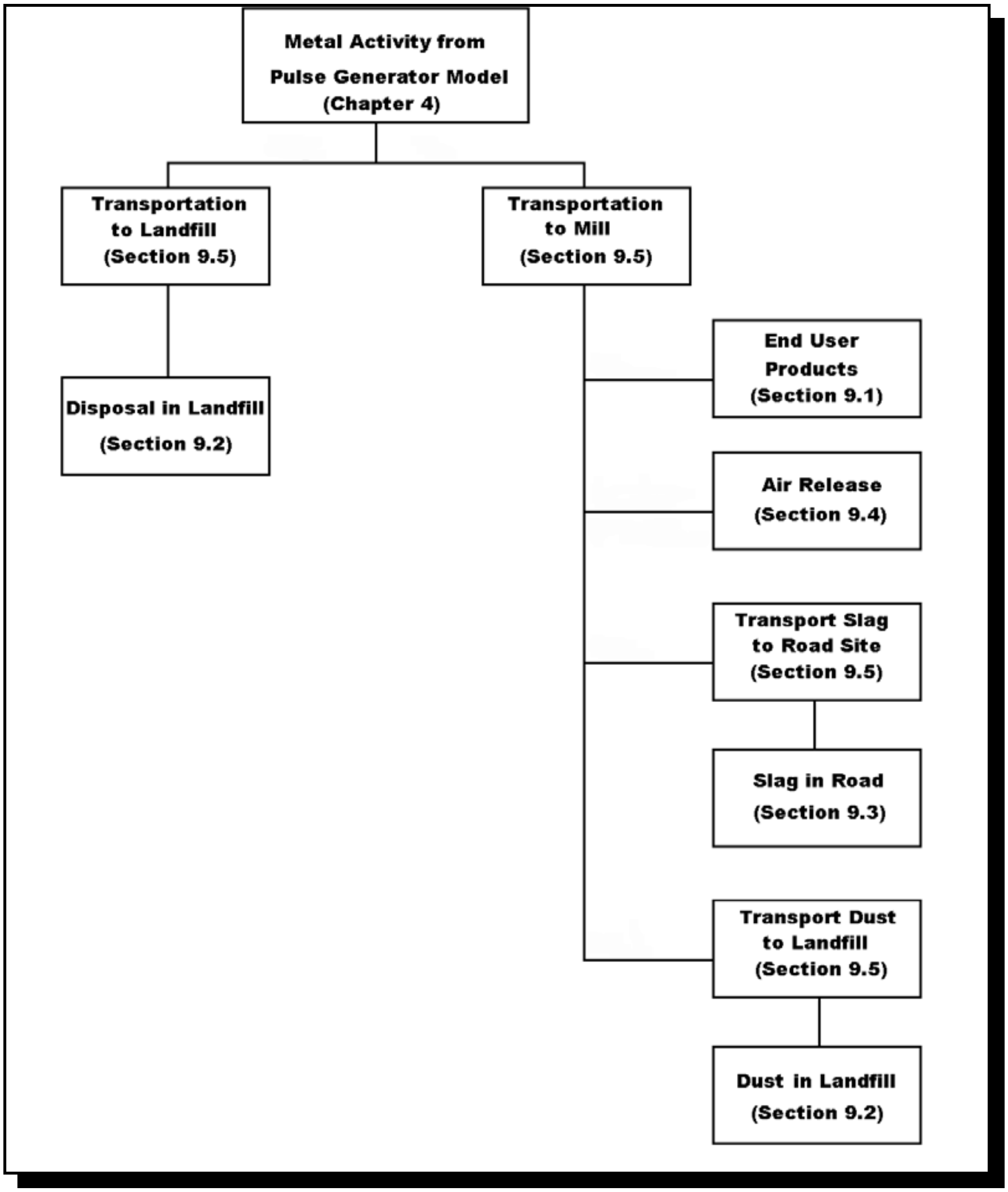

Figure D-1 Integrated Released Metal Collective Dose Model

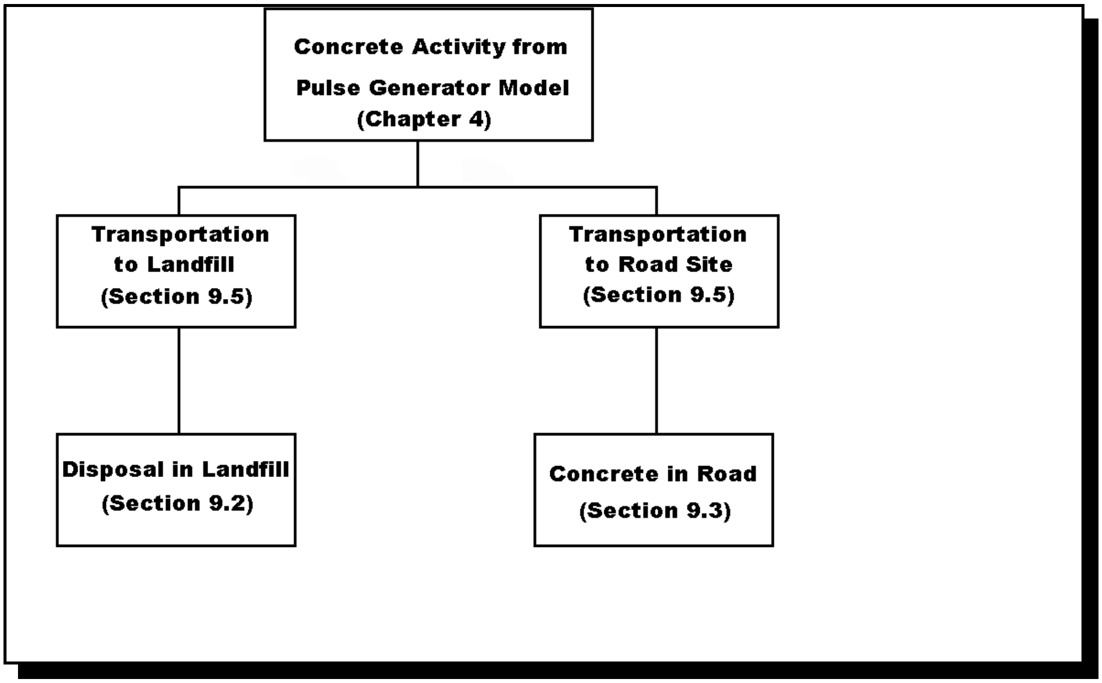

Figure D-2 Integrated Released Concrete Collective Dose Model

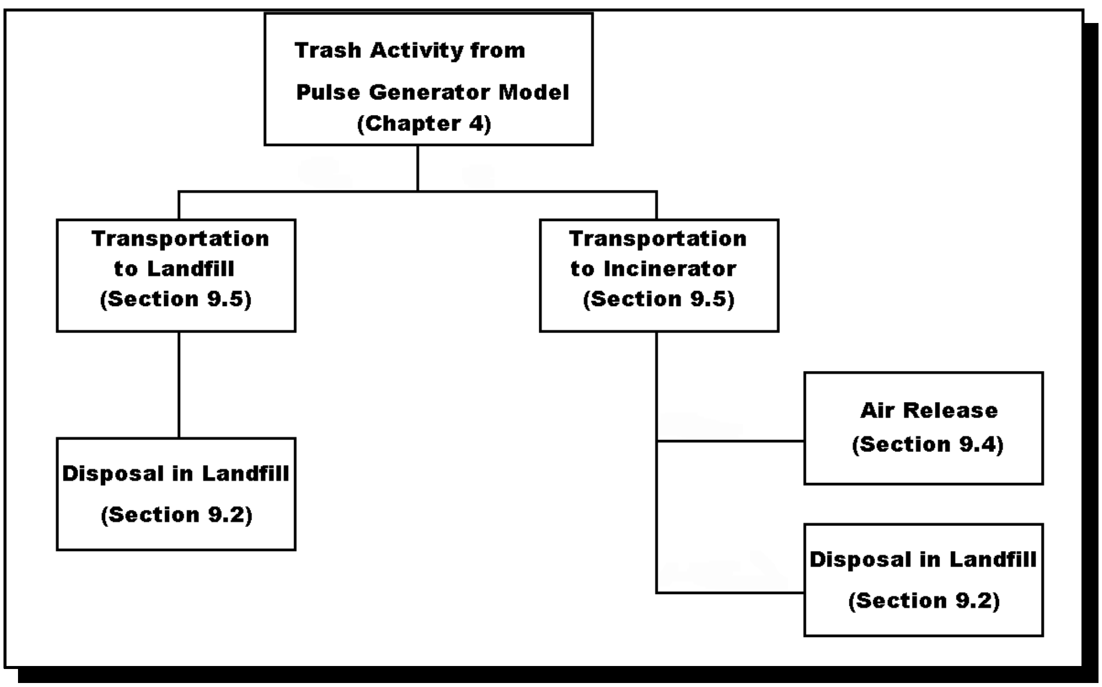

Figure D-3 Integrated Released Trash Collective Dose Model

9.1 External Collective Doses

For discussion purposes, the general form of the equation used to calculate the collective dose due to external exposure from radioactivity in released materials is presented:

$$D_{n,i,ext} = E_i \; O_i \; DF_{n,i} \; A_{n,i} \; \frac{1 - e^{-\lambda_n}}{\lambda_n} \; e^{-\lambda_n t} \qquad \text{D-1}$$

where:

$D_{n,\,i,\,ext}$	=	collective dose from radionuclide n and product i (person-rem)
E_i	=	average exposure duration to product i (hr/yr)
O_i	=	average occupancy/usage of product i (people)
$DF_{n,\,i}$	=	external collective dose factor for radionuclide n and product i (rem/hr per Ci)
$A_{n,\,i}$	=	activity of radionuclide n that is present in product i (Ci)
	=	integrating factor over a one year period for radionuclide n
λ_n	=	radiological decay constant for radionuclide n (yr^{-1})
t	=	time after release when exposure occurs (yrs)

To calculate the total collective dose, the terms in Equation D-1 would need to be evaluated for each specific case and summed over all cases for each of the times, products, radionuclides, and licensees.

One of the keys to evaluating the terms in Equation D-1 is to identify or calculate the appropriate values for the various parameters. The EPA's Exposure Factors Handbook (EPA 1987) was used as the primary source of most of the exposure duration data. The occupancy factors came from various sources, depending on which type of product was being modeled. For example, the occupancy factor for automobiles was taken from the 1995 Edition of "Nationwide Personal Transportation Survey." (DOT 1997)

Perhaps the most important parameter is the product-specific dose factor ($DF_{n,\,i}$). In short, single reference products were developed for each type of end product (including their mass and geometry) and the MCNP computer program was used to calculate dose factors for each reference product. See Sections 9.1.2 through 9.1.7 of the collective dose report (SC&A 2003) for the specifics of how the dose factors were developed for each end-use product.

9.2 Collective Doses Due to Food

The general form of the equation used to calculate the collective dose due to the consumption of food and water containing residual radioactivity from released material is:

$$D_{n,i,ing} = DF_n \; A_{n,i} \; e^{-\lambda_n t} \qquad \text{D-2}$$

where:

$D_{n,\,i,\,ing}$	=	collective dose from radionuclide n and product i (person-rem),
DF_n	=	ingestion dose conversion factor for radionuclide n (rem/Ci),

$A_{n,i}$ = amount of radionuclide n from released material that is present in product i (Ci),
λ_n = radiological decay constant for radionuclide n, and
t = time after release when exposure occurs (yrs).

As with external dose, to calculate the total collective dose, the terms in Equation D-2 would need to be evaluated and summed over all cases, for each of the foods, radionuclides, and licensees.

The ingestion dose conversion factors used in this analysis were taken from EPA's Federal Guidance Report No. 11. The key to solving Equation D-2 is the calculation of the amount of activity that is present in each food type ($A_{n,i}$). The specific methodologies used to estimate the activity in food are presented in detail in the report. The total activity was apportioned to the various potential pathways. For example, based on national averages, a certain percentage of ground water was apportioned for use as potable water, and then a certain percentage of that potable water was apportioned as drinking water. In that fashion, the activity consumed via the drinking water pathway was calculated.

10. Collective Doses Associated with Materials from Commercial Nuclear Power Plants

The results of the calculation of the activity and mass of the released material are presented above in Section 4, while the deterministic results of the collective dose scenario screening calculations are presented above in Section 5. This section focuses on the results of the probabilistic calculation of the collective doses using Monte Carlo methods for materials from commercial nuclear power plants.

The detailed probabilistic analysis was performed for five cases – the four material release cases, plus a Case C2 in which the trash is assumed to be incinerated, with its ash being disposed of in a landfill. Table D-3 presents the collective dose from all released materials for all regulatory options.

For Cases A and B, the collective doses are dominated by the external exposure of the population to released ferrous metal. Because Co-60 (with a 5-year half-life) is the primary radionuclide that partitions to the metal from the mix being used in this analysis, the exposure rapidly decreases when there is no new material being released. The other primary radionuclide from the mix (Cs-137) partitions primarily to the dust at the steel mill, and, for this analysis, the dust is assumed to be disposed of in a landfill, which is very unlikely to result in exposures to a large segment of the population (see the following discussion for Cases C and D).

For Cases C and D, all of the released material (ferrous metal, concrete, and trash) is assumed to be disposed of in a municipal or industrial landfill. The exposure of industrial workers (e.g., scrap truck drivers, landfill operators) is a primary contributor to the collective dose for these cases. The only potential pathway for cases C and D for exposure of other members of the general population is via the leaching/ground-water pathway. Since it frequently takes ground water a very long time to travel to surface water or to a well, many of the shorter-lived radionuclides will have significantly decayed before they have an opportunity to expose the population. Also, even those radionuclides with long half-lives that travel relatively fast through the unsaturated zone (e.g., I-129 and C-14) take more than the 250 years to reach the accessible environment, which is the maximum assessment period of the analysis (SC&A 2003). The contribution of the longer-lived radionuclides beyond 250 years is a very small fraction of the total collective dose associated with all radionuclides.

Case C2 used the same activity release distribution as calculated for Case C, but assumed that all trash would first be sent to an incinerator, with the resulting ash and any air pollution control device media being sent to a landfill (i.e., any activity that is not released via the stack of the incinerator was assumed to go to a landfill). Comparing the Case C2 to Case C collective doses in Table D-3 shows that the portion of the released activity that escapes the incinerator's air pollution control device results in exposures that are about three orders of magnitude higher than if the released activity is sent directly to a landfill.

As with the activity and mass results, additional details regarding the calculated collective doses resulting from material being released are provided in the collective dose report (SC&A 2003), including a breakdown that provides the mean, standard deviation, median, 5th percentile and 95th percentile values annually for each material type, regulatory option, case analyzed, and year of the analysis.

Table D-3 Mean Collective Dose Results (person-rem)

Case ID	Regulatory Options				
	0.03 mrem/yr	**0.1 mrem/yr**	**1 mrem/yr**	**10 mrem/yr**	**No Action**
All Material					
Case A	2.07E+02	8.88E+02	6.40E+03	2.84E+04	3.93E+03
Case B	2.16E+01	1.13E+02	1.68E+03	9.68E+03	3.93E+03
Case C	1.20E-01	3.46E-01	1.70E+00	6.43E+00	3.78E-01
Case C2	1.62E+01	7.01E+01	1.01E+03	1.44E+04	6.35E+01
Case D	5.29E-02	1.69E-01	1.01E+00	4.82E+00	3.78E-01
Ferrous Metal					
Case A	2.05E+02	8.81E+02	6.38E+03	2.84E+04	3.92E+03
Case B	1.88E+01	1.07E+02	1.66E+03	9.65E+03	3.92E+03
Case C	9.42E-02	2.84E-01	1.38E+00	4.63E+00	3.43E-01
Case C2	9.42E-02	2.84E-01	1.38E+00	4.63E+00	3.43E-01
Case D	2.70E-02	1.07E-01	6.86E-01	3.02E+00	3.43E-01
Concrete					
Case A	2.76E+00	6.54E+00	2.39E+01	2.78E+01	3.91E+00
Case B	2.76E+00	6.54E+00	2.39E+01	2.78E+01	3.91E+00
Case C	2.41E-02	5.53E-02	2.00E-01	2.09E-01	2.92E-02
Case C2	2.41E-02	5.53E-02	2.00E-01	2.09E-01	2.92E-02
Case D	2.41E-02	5.53E-02	2.00E-01	2.09E-01	2.92E-02

Table D-3 Mean Collective Dose Results (person-rem) (continued)

Case ID	Regulatory Options				
	0.03 mrem/yr	0.1 mrem/yr	1 mrem/yr	10 mrem/yr	No Action
Trash					
Case A	1.77E-03	6.90E-03	1.24E-01	1.58E+00	6.60E-03
Case B	2.71E-08	1.49E-07	4.75E-06	1.19E-04	6.60E-03
Case C	1.77E-03	6.90E-03	1.24E-01	1.58E+00	6.60E-03
Case C2	1.60E+01	6.98E+01	1.01E+03	1.44E+04	6.31E+01
Case D	1.77E-03	6.90E-03	1.24E-01	1.58E+00	6.60E-03

11. Collective Doses for IAEA RS-G-1.7 Clearance Levels

This section addresses collective doses for the IAEA clearance levels, which were published in Radiation Safety Guide No. RS-G-1.7 (IAEA 2004). As was described earlier, all collective doses were initially derived using release levels from NUREG-1640 and its supplement on trash (NRC 2003c, 2005c). The IAEA clearance levels are based on a deterministic analysis, while NUREG-1640 release levels were developed using a Monte Carlo method. As is noted earlier, the Draft GEIS focuses on impacts associated with materials that are expected to be released from nuclear power plants. As a result, radionuclide distributions and their relative fractions (mix) reflect those commonly found at both pressurized and boiling water reactors. Because the amounts of materials expected to be released from nuclear power plants are dominant, the Draft GEIS assumes that impacts associated with such releases are bounding and envelope those of other types of licensees.

The derivation of collective doses based on IAEA clearance levels relies on the application of adjustment factors to scale the collective doses derived from NUREG-1640. The adjustment factors take into consideration differences between the release levels of NUREG-1640 and clearance levels of the IAEA safety guide. The adjustment factors were developed for each type of material considered in the Draft GEIS (metals, concrete, and trash). Two other methods were considered but rejected as the chosen method provides reasonable estimates of adjusted collective doses given the differences in the modeling approaches between NUREG-1640 and the IAEA safety guide and associated uncertainties in model assumptions and parameters. One method considered the use of a qualitative analysis, where the discussions would address only the direction and magnitude of changes in collective doses by comparing the release and clearance levels of the most commonly found radionuclides (e.g., C-14, Co-60, Sr-90, or Cs-137). This method was not used because it does not offer the means to quantify differences in collective doses. Another method considered a series of duplicate Monte Carlo analyses of all collective doses by applying the IAEA clearance levels without using any information from NUREG-1640. This method was rejected because of the necessity to develop probability distribution functions for the assumptions and parameters used in the IAEA deterministic analysis.

The development of the adjustment factors is based on a procedure described in MARSSIM (NUREG-1575, Sect. 4.3.4, p.4-9 (NRC 2001)). The procedure involves deriving a gross activity concentration, C_{ga}, taking into account the release or clearance level of each radionuclide assumed to be present in each type of material and their relative fractions (SC&A 2003). The expression is:

$$C_{ga} = 1 / [(f_1 / CL_1) + (f_2 / CL_2) + ... + (f_n / CL_n)]$$

C_{ga} = gross activity concentration of the radionuclide mix, given the relative fraction of each radionuclide and IAEA clearance or NUREG-1640 release level, pCi/g

CL_i = clearance or release level, pCi/g, for radionuclide i, for a given dose, and relative fraction f_n

f_n = radionuclide fraction, unitless

The calculation is performed twice, once for NUREG-1640 release levels, and again for the clearance levels of IAEA RS-G-1.7. The resulting gross activity concentrations are compared and ratioed to derive an adjustment factor, as follows:

$$AF = C_{ga,\ IAEA} / C_{ga,\ NUREG\text{-}1640}$$

As derived using NUREG-1640, the collective doses are best estimates, based on a Monte Carlo analysis, and, consequently, the results reflect uncertainties associated with the statistical distributions of model parameters, including radionuclide mix. For example, it is known that the distribution of radionuclides and their relative mix would vary among nuclear power plants. At some power plants, Cs-137 may be more prevalent than Co-60, for instance. At other plants, the opposite may be true given different operational histories. A limited sensitivity analysis was conducted to assess differences in adjustment factors when changes are made to the radionuclide mix. Of the 17 radionuclides making up the mix used in the collective dose analysis, three comprise nearly 80% of the activity; they are Fe-55, Co-60, and Cs-137. New adjustment factors were derived for the entire distribution of 17 radionuclides by interchanging the relative fractions of these three radionuclides. These changes mimic alternate conditions where the relative mix may be different.

Table D-4 presents the resulting changes in gross activity concentrations and corresponding adjustment factors. A review indicates that the resulting adjustment factors vary from 1.2 to 2.3 over all four cases, with an average of 1.9 ± 0.5. For the three alternate cases, the adjustment factors vary from 1.2 to 2.2, with an average of 1.7 ± 0.5. The results indicate that changes up to a factor of three in the relative mix (0.46/0.15) yield lower adjustment factors than the base case. Lower adjustment factors imply that collective doses normalized to RS-G-1.7 clearance levels would be in closer agreement to those derived using the release levels of NUREG-1640.

In light of the above discussions, the uncertainties associated with collective doses derived using NUREG-1640 release levels are not translatable with the adjustment factors developed herein. As a result, collective doses representing IAEA clearance levels are assumed to be best single estimates, given the lack of information on the derivation of the IAEA clearance levels.

Table D-4 Adjustment Factors Versus Changes in Relative Mix of Three Radionuclides

Parameters	Radionuclide Mix			
	Base Case	**Case 1**	**Case 2**	**Case 3**
Fe-55	0.18	0.18	0.46	0.15
Co-60	0.46	0.15	0.18	0.46
Cs-137	0.15	0.46	0.15	0.18
RS-G-1.7 gross activity concentration (pCi/g)	3.8	3.8	6.3	3.7
NUREG-1640 gross activity concentration (pCi/g)	1.7	3.1	3.5	1.7
Adjustment factor (RS-G-1.7 / NUREG-1640)	2.3	1.2	1.8	2.2
Ratio of adjustment factors to the base case	1	0.52	0.78	0.96

Table D-5 summarizes the results and presents the adjustment factors for each material (concrete, steel, and trash) and a material independent case. A review of the results reveals some differences in adjustment factors, with NUREG-1640 and RS-G-1.7 being alternatively more limiting depending on the type of material. For concrete, the results indicate that RS-G-1.7 yields a more liberal gross activity concentration (3.8 pCi/g), while NUREG-1640 is more permissive for steel (9.1 pCi/g) and trash (4,070 pCi/g). For the material independent case, NUREG-1640 is limiting at 1.7 pCi/g. The adjustment factors for concrete and the material independent case are identical. This is because the material independent case is based on the most limiting clearance levels, which are those assigned to concrete. It should be noted that the results for trash are not directly comparable as RS-G-1.7 does not address materials that fit the definition of trash generated by nuclear power plants. Accordingly, the adjustment factor for trash is arbitrarily assigned to unity. In addition, the adjustment factor for concrete is rounded off since the method used and the data do not provide this level of precision.

Table D-5 Derived and Applied IAEA RS-G-1.7 and NUREG-1640 Adjustment Factors

Case	Concrete	Ferrous Metals	Trash	Material Independent
RS-G-1.7 gross activity concentration (pCi/g)	3.8	3.8	3.8	3.8
NUREG-1640 gross activity concentration (pCi/g)	1.7	9.1	4,070	1.7
Derived adjustment factors (RS-G-1.7 / NUREG-1640)	2.3	0.4	0.001	2.3
Limiting case	NUREG-1640	RS-G-1.7	RS-G-1.7	NUREG-1640
Applied adjustment factors	2	0.4	1	2

The adjustment factors are used to scale the collective doses generated with the release levels of NUREG-1640. The results imply that RS-G-1.7 collective doses for concrete are expected to be higher than that of NUREG-1640 release levels by a factor of about two. An adjustment factor of two is assigned to the case illustrating releases of material based on the most restrictive release criteria (i.e., material independent case). However, collective doses for ferrous metals, based on

RS-G-1.7 clearance levels, are expected to be lower by a factor of about 0.4. For trash, collective doses are assumed to be identical since an adjustment factor of one was arbitrarily assigned to trash.

12. Collective Doses Associated with the Reuse of Equipment

Collective doses associated with the reuse of equipment were evaluated for two categories of equipment, large and small. The approach used in estimating collective doses relies on a scoping analysis as practices associated with the reuse of equipment are known to be highly variable. For example, it is known that different types of equipment and tools are used in radiologically controlled areas and later taken out. The types of equipment that could be potentially released from nuclear facilities for reuse in an environment free of radiological controls ranges from small items, such as hand tools, to very large ones, such as mechanized equipment and industrial vehicles. The following are examples of potentially reusable equipment, tools, and miscellaneous items:

- small hand tools (wrenches, screw drivers, etc.) and power tools (drills, saws, etc.)
- electrical equipment, such as control panels, motors, pumps, and generators
- office furniture (desks, chairs, filing cabinets, etc.) and office equipment (copiers, computers, printers, fax machines, etc.)
- construction equipment, such as scaffolding, noise or dust-control barriers, wheelbarrows, etc.
- mechanized equipment, such as trucks, backhoes, bulldozers, and other vehicles
- materials and supplies for use in their original forms, but taken out as excess, such as piping, tubing, electrical wiring, floor covering, ductwork, sheet metal, pipe hangers, light fixtures, wall board, and sheet glass.

It should be noted that these examples are assumed to characterize as well the profile of equipment, tools, and miscellaneous items that may be released by other types of licensees.

It is recognized that the release of equipment is an extremely dynamic process involving different types of facilities and activities, such as routine operations, research and development, major and minor power plant outages, refurbishment, decommissioning, etc. In addition, this process is taking place simultaneously at thousands of facilities across the nation and conducted every hour of the day and every day of the week. As a result, it is not possible to define what types of objects and how many are routinely used in radiologically controlled areas, and what fraction is surveyed and released for reuse *versus* those that are discarded as LLW.

As is noted earlier, the GEIS focuses on impacts associated with materials that are expected to be released from nuclear power plants. As a result, radionuclide distributions and their relative fractions reflect those commonly found at both pressurized and boiling water reactors. Because the amounts of equipment and tools being routinely released from nuclear power plants are dominant, the GEIS assumes that impacts associated with such releases are bounding and envelope those of other types of licensees.

In practice, equipment and tools are surveyed before being taken out of radiologically controlled areas. The survey consists of conducting a scan with a portable radiation survey meter (e.g., gas flow proportional detector) and taking wipes to assess the presence of removable surface activity. The presence of radioactivity on wipes is evaluated using separate instrumentation (e.g., bench top beta or alpha particle counter). Some survey methods involve the introduction of the item into an instrument (e.g., gamma tool monitor) that measures radioactivity *in toto* from all external and internal surfaces. Depending on the results of the survey, the items are either cleaned to meet release criteria, not taken out of the controlled area and set aside for later use in the same work area, or simply discarded as LLW. Together, these ALARA practices are expected to mitigate the presence of residual radioactivity on released items and should result in residual levels that are well below release criteria.

Dose factors and their corresponding release levels, for both large and medium-sized equipment, were taken from the NUREG-1640 Supplement on Reuse (NRC 2005d). In addition, the analysis includes the clearance criteria approved by the International Atomic Energy Agency (IAEA) in "Radiation Safety Guide RS-G-1.7" (IAEA 2004). Since the IAEA criteria present only volumetric clearance levels, surficial clearance levels were derived by applying a mass-to-surface ratio (from NUREG-1640) to the IAEA clearance levels (NRC 2003d). This aspect is discussed later. The case addressing the No Action Alternative (status quo) assumes that current practices result in an annual dose of about 1 mrem. This is because the release level of 6,980 dpm/100 cm^2, derived for Co-60 and small equipment, is not much different than the 5,000 dpm/100 cm^2 limit defining current practices, i.e., both yield an annual dose of about 1 mrem (see discussion in Appendix B discussing current practices). However, for large equipment with a limit of 600 dpm/100 cm^2, the difference is attributed to the scenario developed in the Supplement to NUREG-1640 (NRC 2005d). This scenario considers a driver in a cab of a vehicle with all internal surfaces having residual radioactivity levels at the release criteria for Co-60.

Given that no specific information is available on the type of equipment that might be released for reuse and the frequency of their reuse, the analysis applies broad assumptions in estimating collective doses. The dose factors developed for the file cabinet are assumed to be representative of medium-sized equipment, such as bookcases, lockers, tool cabinets, outer cases of welding machines, work benches, and other objects with similar geometries, dimensions, and surface areas. In addition, the dose factors derived for the file cabinet are assigned to hand tools and other similar small objects. This approach is deemed to be generically appropriate because it relies on the full range of exposure pathways (i.e., external, inhalation, and incidental ingestion) that workers would encounter while using smaller equipment, hand tools, and small items (NRC 2005d). Another justification for this approach involves the difficulty in defining a representative set of items that would be typical of hand tools routinely subjected to release. Defining a representative set of hand tools would imply a degree of specificity that would be difficult to justify since alternate cases could be made with equally powerful technical arguments.

Another complication revolves around defining the inventory of residual radioactivity associated with released equipment and materials. The inventory is directly proportional to the surface area (cm^2) of each item and release level (dpm per 100 cm^2 or pCi/cm^2) for a given dose level. The product of the two would yield the inventory (dpm or pCi). However, this is not a simple problem since first one would need to identify all types of equipment or items that might be released, and define the surface area of each item. The surface area is also difficult to determine. For example, should the area include all surfaces (external and internal) or just external? Are there areas that are inaccessible to the survey method but are suspected of having some residual levels of activity? How would one define the total surface of inaccessible areas? Should equipment or items characterized by complex physical configurations be released using only volumetric release levels? What fraction of equipment and items used by the nuclear industry could be considered complex in configuration? Given the lack of specific information in addressing these questions and associated uncertainties, even if they were answerable, the scoping analysis applies the release level as a surrogate for the inventory of residual radioactivity. For example, if one were to assume that 3,000 dpm/100 cm^2 were associated with an annual dose of 1 mrem, then it follows that 300 dpm/100 cm^2 would result in an annual dose of 0.1 mrem, other aspects being equal. This ratioing is applied to each dose level and its corresponding release level; thereby, leading to a comparison of collective doses relative to the 1 mrem dose option and its release level.

In converting the volumetric IAEA criteria to surficial release levels, a mass-to-surface ratio is defined using the information presented in Appendix A to NUREG-1640 (NRC 2003d). In simple terms, the mass-to-surface ratio ($gram/cm^2$) is defined as the total mass (grams) of an object divided by its total surface area (cm^2), or equivalently, the product of the density and its effective thickness, i.e., $gram/cm^3$ x cm. A review of the data presented in NUREG-1640 indicates that mass-to-surface ratios vary significantly, depending on the type of equipment or item. For equipment with complex configuration, one would expect that there may be portions of the equipment with different features, each with its own mass-to-surface ratio. For example, a tank might have four mass-to-surface ratios, one for the wall making up the body of the tank, another for access openings and connection flanges, another for its support skid, and a fourth one that is an overall average for all features of the tank. Table D-6 illustrates the variability of mass-to-surface ratios for some ferrous metal components found at typical power plants.

A review indicates that ratios vary from about 2 to nearly 80 g/cm^2, with an overall average of about 5 gm/cm^2 as being representative of both types of plants. It is recognized that there may be circumstances when mass-to-surface ratios will be different. For example, some types of ventilation ductwork may be built with a thinner gauge of sheet metal or a valve body may be made of cast iron with thicker walls, all resulting in different ratios than that listed here. However, such case-specific differences are not expected to yield a much different average as the associated amounts of metal for such extreme cases are expected to make up a small fraction of the total inventory of released ferrous metals. Accordingly, the value of 5 gm/cm^2 is assumed to be a representative estimate for the purpose of bounding collective doses.

Table D-6 Mass-to-Surface Ratios for Some Steel Components Found at Power Plants

Item/Component	Minimum (gm/cm^2)	Maximum (gm/cm^2)	Average (gm/cm^2)	Notes
Tanks				
BWR	2.2	54.3	9.8	
PWR	2.6	52.9	11.3	
Piping				
BWR	5	56.6	13	
PWR	2.5	27.6	6	
Rebars	1.9	11.3	5.4	Over 11 sizes
HVAC Ductwork				
BWR	--	--	1.3	Average
PWR	--	--	1.1	" "
Valves				
BWR	10.3	79.9	38	External surfaces only
PWR	10.3	63.2	29.5	" " "
Structural steel	3.8	21.9	10	Total surface area
Pipe hangers	1.8	19.9	7.5	Weighted average
Heat Exchangers				
BWR	--	--	2.5	Aggregate average
PWR	--	--	3.1	" "
Overall average				
BWR	--	--	4.5	Aggregate average
PWR	--	--	5.1	" "

In light of the lack of specific information, average collective doses were estimated using the following general expression:

$$D_{ave} = L\,(C_{RU}/C_{RL})\,W\,K\,N_e\,IF_i\,D_i\,R^{-1} \qquad \text{Eq. 1}$$

where:

D_{ave} = average collective dose, person-rem, with each nuclide at the release level

L = dose limit, mrem/year, corresponding to release level, dpm/100 cm^2, summed over all radionuclides I

C_{RU} = reuse release level, dpm/100 cm^2, for dose limit, mrem/yr, summed over all radionuclides I

C_{RL} = reference release level, dpm/100 cm^2, for reference dose limit of 1 mrem/yr, summed over all radionuclides I

W = effective workforce assumed to reuse equipment, persons

K = conversion factor, 10^{-3} rem per mrem

N_e = number of equipment or items assumed to be release and reused

IF_i = integrating factor for radionuclide I, integrated over useful life of equipment, yr

IF_i = $[1 - \exp(-\lambda\, t_a)] / \lambda$, where;

t_a = time of integration for assessment period, year

λ_i = decay constant for radionuclide, I

D_i = decay factor from time of release to beginning of assessment period, as defined below

D_i = $\exp(-\lambda\, t_s)$, where;

t_s = elapsed time from release to beginning of assessment period, year

R = activity profile adjustment factor, max-to-mean surface residual radioactivity levels, unitless

The number of work-hours that workers are assumed to handle reused items is based on 2,080 hours per year adjusted for the fact that about 25% of the time is spent on administrative and support functions that do not require the use of any equipment. In addition, the analysis assumed that some equipment that are used are not a product of release, meaning that such equipment is of other origins and were never introduced in any radiologically controlled areas. This fraction was assumed to be 25% for both large and small equipment, lacking specific data. Given that such equipment is expected to have a productive life cycle, a useful life of 14 years was assigned for large equipment and three years for small equipment. The duration of the useful life of equipment is driven by operational conditions and economic considerations, taking into account replacement costs and cost of repairs, amortization, and cost of money. These factors are expected to be different among facilities. For large equipment, the useful life is assumed to be twice that of the typical amortization schedule of seven years for capital expenditures. This assumes that once amortized, the equipment is used for another seven years before being declared worn out and discarded. For small equipment, such as hand tools, the useful life (3 years) assumes that once worn out, these items are discarded given that replacement costs are usually less than repair costs.

The determination of the number of workers using equipment and items after release is complicated by the lack of information characterizing practices at various facilities. For example, the type of equipment and tools used during routine operation is expected to be different than that used during maintenance or plant outages. Similar differences would be expected between refurbishment and decommissioning. In all cases, the size of the work force would vary as well. Lacking specific information, the approach considers occupationally exposed workers as a surrogate for the population that might be using released equipment and tools. The worker population that uses equipment and tools in radiologically controlled areas can be considered to be the same population that uses released equipment. This assumption is valid because once equipment and tools are released and workers are out of a radiologically controlled area, it does not matter whether the use of the equipment is associated with the same worker or any other worker. The analysis is insensitive to the origin of the worker, and considers only that a "worker" uses equipment and tools that have been released. Accordingly, the use of radiation workers is deemed to be a surrogate in determining the size of the workforce as there is some information on the number of workers employed by the nuclear industry.

The number of workers is based on the NRC REIRS database (NRC,2003e). A review of the database indicates that about 108,000 workers at reactors and 11,800 at materials sites are badged and report exposures under the provisions of 10 CFR Part 20.2206. The number of workers from Agreement State (AS) licensees was estimated by ratioing the number of licenses between the AS and NRC data. Based on NUREG-1350 (NRC 2002c), the ratio was estimated to be 3.3 (16,253/4,922), thereby giving a total of material 38,900-badged workers. The total size of the workforce of both NRC and AS licensees is estimated to be 150,000 workers (108,000 + 38,900, rounded off). A further evaluation of the database indicates that for about 50% of the workforce, all exposures or doses are reported as “non-measurable.” This information indicates that a portion of the workforce, although required to be badged, perform duties in radiologically control areas that may not require “hands-on” activities. Such types of workers may include supervisors, security, engineers, inspectors, janitors, etc. Accordingly, some of that workforce might not perform “hands-on” functions in radiologically control areas and it is then unlikely that they would be using released equipment. Nevertheless, it is assumed that 25% of the work force is using large equipment, and 75% of the workforce is using small equipment, including hand tools and small items. The resulting assumptions and estimate of the size of the work force using released equipment are summarized in Table D-7.

Table D-7 Major Assumptions Used in Deriving Collective Doses Due to Reuse

Parameter	Large Equipment	Small Equipment	Notes
Annual work-hours	2,080	2,080	Assumes a full work year
Admin./Support functions	0.25	0.25	Time away from released equipment
Equipment distribution	0.25	0.25	Fraction of time using equipment of other origins
Annual work-hours per worker	1,040	1,040	Contact time with released equipment
Size of work force	150,000	150,000	Potential number of workers using equipment
Incidental workers	0.25	0.75	Fraction using released equipment
Effective work force	19,000	56,000	Aggregate number of workers using released equipment
Equipment useful life (years)	14	3	Time over which dose is integrated
Elapsed time from release to start of exposure (years)	0	0	Assumes no radioactive decay before use
Number of pieces of equipment in use per person	1	1	Dose multiplier - see text for details

Collective doses are based on the presence of 17 radionuclides commonly found at nuclear power plants, as beta, gamma, and alpha emitters (Table 3.21, SC&A 2003). No credit is taken for radioactive decay from the time of release to the beginning of the assessment period. Three sets of radionuclide distribution-weighted gross activity release levels were derived for both, large and small equipment, and one using IAEA Radiation Safety Guide RS-G-1.7 for both small and large equipment.

Release levels were derived for both small and large equipment using a procedure described in MARSSIM (NUREG-1575, Section 4.3.4, page 4-9 (NRC 2001a)). The procedure involves deriving a gross activity concentration, C_{ru}, taking into account the release or clearance level of each radionuclide assumed to be present and its relative fraction (SC&A 2003). The expression is:

$$C_{RU} = \sum C_i \qquad \text{Eq. 2}$$

where

C_{RU} = release level, dpm/100 cm^2, for dose limit, mrem/yr, summed over all radionuclides I

C_i = weighted concentration for the given mix and dose option, where;

$C_i = 1 / [(F_1/L_1) + (F_2/L_2) + \ldots\ (F_n/L_n)]$

F_n = relative fraction of radionuclide I, unitless

L_n = limit for radionuclide I, and given dose option

Collective doses were adjusted to represent average surface activity profiles of equipment being released. The adjustment applies a correction factor, max-to-mean surface residual radioactivity levels to release criteria. A single average factor was used in the calculation as opposed to applying a factor for each dose option. This approach was used because there is not enough information to develop a more definitive activity profile at each dose option.

The factors are as follows:

Dose Options	Max-to-mean factor
10 mrem/yr	21.6
1.0 mrem/yr	7.1
No action, 1 mrem/yr	5.4
0.1 mrem/yr	3.3
0.03 mrem/yr	2.6
Average factor	8

These observations indicate that residual radioactivity profiles on equipment and tools can vary depending on licensee practices. This analysis assumes that residual radioactivity profiles are characterized by a continuous spectrum, bounded by a range defined by non-detectable levels on the low side and release levels on the high side. Within this spectrum, the average is assumed to be the best single estimate of residual radioactivity levels. It should be noted that other max-to-mean factors might in fact be observed in isolated instances, depending on the situation of a specific licensee, and it may be difficult to narrow these ranges and provide a more robust estimate of the variability and best estimate of the average. Nevertheless, it is not plausible to assume that equipment and tools would be characterized only by higher activity profiles and would be released routinely by every licensee. Accordingly, this adjustment yields average collective doses for the exposed population of workers and not doses to the average member of the critical group.

The number of pieces of equipment being reused by each worker after release could be different between small and large equipment. The collective dose is assumed to be directly proportional to the total number of items being used at any one time. In considering large equipment, such as vehicles and mechanized equipment, it is assumed that a worker can only operate one piece of equipment at a time. Accordingly, the dose multiplier is assumed to be one for such a case. For small equipment, such as hand or small power tools, etc., it is conceivable that a worker could use a number of items or at least be surrounded by several such small tools while working. Accordingly, the dose multiplier could be greater than one in such instance. As noted earlier, the dose factors derived for the file cabinet are assigned to hand tools and other similar small objects. The large surface area of the file cabinet is assumed to represent a collection of small tools. For example, the surface area of a typical screw driver was estimated to be about 120 cm^2. Other tools could be physically larger than a screw driver, such as power tools, shovel, etc. Accordingly, the large surface area of the filing cabinet (about 3 m^2) makes up for the presence of numerous smaller tools being used or located in the immediate vicinity of a worker. For example, if the average total surface area of an average hand tool were 1,000 cm^2, this would correspond to the exposure associated with approximately 30 tools, based on the surface area of the file cabinet (derived as: $3\ m^2 \times 10^4\ cm^2/m^2 \div 1{,}000\ cm^2$) with other factors being equal. This approach is deemed to be adequately conservative as it retains the full range of exposure pathways (i.e., external, inhalation, and incidental ingestion) that workers would encounter while using hand tools and other small items. Accordingly, the dose multiplier for hand tools and small items is assumed to be one as well.

The results are presented in Tables D-8 and D-9. A review of the results indicates that for large equipment, collective doses vary from less than 1 to about 150 person-rems. For small equipment collective doses range from less than 1 to about 160 person-rems. At a release dose of 1 mrem/year, collective doses are about 15 person-rems for large equipment and 16 person-rems for small equipment.

The reason for the small differences in doses is the influence of competing factors. The competing factors include the useful life of equipment, 14 years for large equipment and 3 years small equipment; number of workers assumed to use released equipment, 19,000 for large equipment and 56,000 for small equipment; and assumed average residual surface radioactivity profiles, 140 dpm/100 cm^2 for large equipment and 1,600 dpm/100 cm^2 for small equipment. A shorter useful life tends to result in lower collective doses, a higher number of worker yields higher collective doses, and higher residual radioactivity profiles result in increased collective

Table D-8 Collective Doses Associated with the Reuse of Large Equipment From Nuclear Power Reactors

Reg. Dose Option	Assumed Criteria Profile (dpm/100 cm²)		Collective Doses (person-rem)
	Mean	Max	Mean
IAEA RS-G-1.7	530	4,200	56
10 mrem/yr	1,400	11,000	150
1 mrem/yr	140	1,100	15
No action/Status quo	630	5,000	66
0.1 mrem/yr	14	110	1.5
0.03 mrem/yr	4.2	34	0.4

Note: Mean and max profile based on SC&A 2003, Table 4.4, p.4-8 and 4-9.
Collective doses are expressed only as averages since collective doses reflect impacts to the expected population of workers and not to the average member of the critical group.
For the "no action" case, the regulatory dose is assumed to be the same as the 1 mrem/yr option.
The IAEA volumetric criteria were converted to surficial limits using a mass-to-surface ratio of 5 g/cm^2.

Table D-9 Collective Doses Associated with the Reuse of Small Equipment From Nuclear Power Reactors

Reg. Dose Option	Assumed Criteria Profile (dpm/100 cm²)		Collective Doses (person-rem)
	Mean	Max	Mean
IAEA RS-G-1.7	530	4,200	5
10 mrem/yr	16,000	130,000	160
1 mrem/yr	1,600	13,000	16
No action/Status quo	630	5,000	6
0.1 mrem/yr	160	1,300	1.6
0.03 mrem/yr	49	390	0.5

Note: Mean and max profile based on SC&A 2003, Table 4.4, p.4-8 and 4-9.
Collective doses are expressed only as averages since collective doses reflect impacts to the expected population of workers and not to the average member of the critical group.
For the "no action" case, the regulatory dose is assumed to be the same as the 1 mrem/yr option.
The IAEA volumetric criteria were converted to surficial limits using a mass-to-surface ratio of 5 g/cm^2.

doses. Another reason for differences is that collective doses, based on IAEA and NUREG-1640 clearance and release levels, reflect different analytical approaches. The IAEA clearance levels are based on a deterministic analysis, while NUREG-1640 release levels were developed using a Monte Carlo method.

As was noted earlier, a simplified approach was used in assessing collective doses and several assumptions were made without the benefit of supporting information. As a result, the collective dose estimates incorporate some uncertainties. The uncertainties are associated with the characterization of practices involving the release and reuse of equipment; the types of equipment that may be released *versus* those may be discarded as radioactive waste; physical features of released equipment and small items; how equipment are used after having being released; variation in the distribution of radionuclides and relative mix and their combined effect on the total inventory of residual radioactivity; and size of the workforce postulated to use equipment that have been released. In all cases, values were assigned to parameters using engineering judgement without the benefit of supporting data from licensees. Finally, the assessment focuses on the nuclear power industry because of the larger workforce and greater amounts of equipment being released and reused. However, it is recognized that the reuse of released equipment and materials is occurring in other industrial sectors, but the amounts of materials subject to release and associated workforce are expected to be smaller than that of the nuclear power industry. Accordingly, the collective doses estimated in this analysis are assumed to be bounding, even though there may be isolated differences in some instances, such as radionuclide distribution, type of equipment, and size of the workforce, among others.

13. Collective Doses for Trash Incineration Workers

As with prior assessments, a scoping analysis was performed to assess collective doses to incinerator workers processing trash released from nuclear power reactors. The amounts of trash and levels of residual radioactivity reflect estimates associated with each regulatory dose option described earlier. Collective doses were estimated using the following general expression:

$$D_{iw} = E_{iw}\, C_i\, L\, T\, W\, K$$

where:

- D_{iw} = collective dose due to incineration, person-rem
- E_{iw} = dose rate during handling, mrem/yr per pCi/g, summed over all nuclides
- C_i = trash gross activity concentration, pCi/g
- L = trash labor productivity rate, person-hours per ton of trash
- T = tonnage of trash, metric tons
- W = work hours per year, 2,000 hours
- K = conversion factor, 10^{-3} rem per mrem

The total trash tonnage and concentrations are based on data presented in Table 4.4 of the SC&A report (SC&A 2003). The productivity factor to process trash is based on a labor rate of 0.5 person-hour per ton, assuming an incinerator with an average design capacity of 500 tons per day (NRC 1984). The levels of effort to process trash were estimated to range from 7,000 to 33,000 person-hours. The dose factor is estimated to be 2.44 x 10^{-4} mrem/year per pCi/g, assuming the combined presence of 17 radionuclides, as beta, gamma, and alpha emitters (SC&A 2003, NRC 2005c). The presence of these radionuclides reflects a specific mix based on nuclear utility data. Four radionuclides make up most (about 83 percent) of the activity assumed to be present in trash; they are, in decreasing order, Co-60, Fe-55, Cs-137, and Cs-134. The dose factor assumes

2,000 hours per work year. The dose factor includes various functions, such as handling of the trash, loading the incinerator with trash, and during routine servicing or maintenance. The gross activity concentrations of the trash define two conditions, mean and maximum. The conditions reflect a distribution of trash concentrations truncated at the upper end by activity levels defined for each regulatory dose option. Activity levels above these are assumed to be out of the realm of possible release since higher concentrations would warrant classifying trash as low-level radioactive waste. The mean concentration is assumed to represent a trash concentration within the distribution defined at its lower bound by essentially non-detectable levels and the regulatory dose option for upper activity levels. The maximum concentration represents the upper end of the distribution of activity levels, as defined for each regulatory dose option.

The results are presented in Table D-10. The results indicate that collective doses are low, expected to be less than 0.03 person-rem for the 10 mrem/year dose option. All other collective doses are lower by orders of magnitude. Collective doses are expected to vary because of several factors. As described earlier, the amounts of releaseed trash are expected to vary, both among power plants and as a function of time. Similarly, the levels of residual radioactivity and the associated mix of radionuclides will vary as well. For example, the spectrum of radionuclides associated with a major plant outage is different than that found during routine operations. Moreover, the handling and processing rates of trash at incinerators are anticipated to differ, thereby yielding working conditions that might differ from that assumed here in deriving dose factors. Finally, this analysis assumes that all trash generated by power plants would be incinerated, while this is not expected in practice since not all landfills use incineration as a precursor to disposal. For example, only landfills servicing large metropolitan centers are expected to use incineration. For rural areas, trash is typically buried as there may not be enough of a trash volume to warrant the use of incineration. It is expected that these variations would negate one another, thereby leading to conditions where concentrations might be higher, but are associated with smaller quantities of trash. Accordingly, it is expected that the collective doses estimated in this analysis represent central estimates, while recognizing that at times doses may be slightly lower or higher depending on specific conditions.

Table D-10 Collective Doses of Incinerator Workers Processing Trash from Nuclear Power Reactors

Reg. Dose Option	Trash Tonnage (metric tons)	Mean and Maximum Trash Gross Concentration (pCi/g)		Person hours	Collective Doses (person-rem)
		Mean	Max		Mean
10 mrem/year	66,000	7,825	41,604	33,000	3.2 E-02
1 mrem/year	41,000	898	4,160	20,500	2.3 E-03
No action	20,000	114	382	10,000	1.4 E-04
0.1 mrem/year	21,000	121	416	10,500	1.6 E-04
0.03 mrem/year	14,000	43	125	7,000	3.7 E-05

Note: Trash tonnage and gross concentrations taken from SC&A 2003, Table 4.4.
Labor hours based on 0.5 person-hour per ton and an average incinerator design capacity of 500 tons per day. The trash processing rate is taken from NUREG/CR-3585, Table C-4.

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APPENDIX E
MISCELLANEOUS DOSE TOPICS

This appendix discusses the following dose topics:

- The dose assessment analysis in NUREG-1640 and a comparison of those results to international guidance.
- Sources and typical annual doses from background radiation.
- Collective dose due to background radiation.
- Exposures from multiple sources derived from the release of materials from licensees.

E-I RADIOLOGICAL ASSESSMENTS FOR THE RELEASE OF MATERIALS, INCLUDING COMPARISON OF NUREG-1640 RESULTS WITH INTERNATIONAL GUIDANCE

1. INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) has independently assessed potential doses to individuals that could result from the release of solid materials, with the results expressed as normalized activity levels, as Bq/g and Bq/cm^2. The analyses were conducted for ferrous metals, copper, aluminum, and concrete, with the results reported in NUREG-1640 (NRC 2003d). One of the main objectives of these assessments was to identify the critical group and quantify the mean dose to that group using realistic exposure scenarios. Normalized dose factors were calculated for 115 radionuclides and for each material. These assessments are intended to be supporting of the technical basis for a rulemaking on controlling the disposition of solid materials. The design objectives, the analytical approach, and results of the analyses were compared to guidance from the European Commission (EC) and International Atomic Energy Agency (IAEA). The results of these comparisons are briefly described below.

2. DESIGN OBJECTIVES FOR ANALYSES AND ANALYTICAL APPROACH IN NUREG-1640

The establishment of design objectives for the dose assessment analysis were defined at the beginning of the process, provided the basis for numerous decisions in structuring calculations and the means for narrowing down the scope of evaluations in selecting appropriate input parameters.

2.1 Design Objectives

The design objectives of estimating potential doses to individuals arising from the release of materials included independent assessments of U.S. industry practices in a realistic, i.e., non-conservative, approach, that takes into account, to the extent practicable, variations in industrial practices. The results of such assessments could be used as part of a technical basis in a rulemaking on controlling the disposition of solid materials, taking into account public comments received on earlier proposed regulations. Regarding implementation, results for both mass-based and surface-based release levels were considered in the overall objective. Moreover, comparisons with existing U.S. regulations, guidance, and practices, along with international clearance guidance, were considered in the design objective in calculating radionuclide concentrations using ICRP 30 (ICRP 1979) and ICRP 60 (ICRP 1991) based dosimetry (ICRP 1975, 1979, 1990, 1994). Overriding design objectives were to identify the critical group for generic release levels and to quantify that group's mean potential dose on a normalized unit concentration basis. Because materials released from a nuclear facility may be characterized by a wide spectrum of radionuclides, the assessments consider exposures from direct radiation, inhalation, and ingestion to adults making up the critical group for each scenario. Thus, it was not a design objective to assess doses to infants and children or to the skin.

Another design objective was to build into the structure of the analyses breadth of scenarios, robustness, and adaptability, so that the licensees could use the generic analyses to support case-specific analyses.

2.2 Analytical Approaches

In general the analytical approaches were guided by the design objectives. Key approaches that characterize these assessments are described below.

2.2.1 Probabilistic analysis

A probabilistic analysis approach was adopted for several reasons. It enables one to take into account variations in input parameters encountered in real situations from which mean values and uncertainties can be estimated. The mean values were considered the most appropriate estimators of normalized dose to an individual for each scenario. The means were ranked to identify the critical groups on a radionuclide-by-radionuclide basis. Ferrous metals, copper, aluminum, and concrete were specifically analyzed because these materials were judged to comprise the great majority of mass likely to be candidate materials for release.

For the various possible pathways considered, realistic choices for their parameters were evaluated using a Monte Carlo statistical averaging technique. The results provide estimates of the collective dose average values and associated uncertainties. Distributions of variable parameters were established based on the quality of the data using literature research for the identified variables (EPA 1994). The ranges of parameters were kept realistic, and were often found to be as uniform, triangular, or beta distributions. The estimation of doses, radionuclide concentrations, or other intermediate parameters involved between 5,800 and 10,000 realizations or calculations, with each set of results forming a probability distribution. The mean values and the 5^{th}, 50^{th}, 90^{th}, and 95^{th} percentile values of each distribution are listed in NUREG-1640 (NRC 2003d). In all cases where an intermediate parameter is calculated using Monte Carlo sampling methods, each of the calculated values is used as input to the next step in the calculation. For example, in using 10,000 realizations to estimate a dose, each realization uses each of 10,000 radionuclide concentrations in succession. Calculations were performed with spreadsheets using commercially available software.

2.2.2 Radionuclides

A total of 115 radionuclides were included in the analysis based on an evaluation of the nuclear industry. In general, the radionuclides correspond to those reported in low-level radioactive waste from a broad variety of facilities, in studies of radionuclide inventories found at nuclear power reactors, neutron activation products, radioactive decay progenies, and those listed in the EC publication Radiation Protection 89 (RP 89) (European Commission 2000a).

2.2.3 Chemical forms and particle sizes

In order to meet the design objective of realistic dose assessments, each scenario was analyzed to determine the most likely chemical form and particle size distributions in the medium of concern and scenario. The appropriate corresponding dose conversion factors or dose coefficients were then used for that calculation.

2.2.4 Assessment of radionuclides on the surface

The critical parameter for assessing the potential doses from radionuclides on the surface of released materials is the mass-to-surface ratio, which is defined as the mass of the component divided by the exposed surface area of that component. Mathematical distributions of mass-to-surface ratios were developed from data derived from site visits and from reports on metal scraps likely to be released from commercial nuclear power plants undergoing dismantlement. Rebar, structural steel, and pipe hangers account for most of the mass of ferrous metals likely to be a candidate for release. Similar distributions were developed for copper and aluminum. For concrete, distributions were developed similarly, however, due to the considerable wall thicknesses found at nuclear facilities - especially nuclear power plants - the mean ratio is significantly higher, namely, 280 g/cm^2 compared to 5 g/cm^2 for ferrous metals. Values from the appropriate mass-to-surface ratio distribution were selected at random during the Monte Carlo analysis and divided into the mass-based normalized dose factor to yield the surficial normalized dose. The distributions of the radionuclides were considered to be uniform over all surfaces. In many cases, this assumption leads to an unrealistic overestimate; however, the situations vary so greatly that a generic analysis was judged not feasible. Therefore, if a less conservative assessment were desired, case-specific factors would have to be taken into account.

2.2.5 Scenario selection

Scenarios were generally selected as realistic candidates to identify the critical group. Some scenarios were selected for analysis because there had been questions raised in public meetings concerning the potential exposures associated with them - especially for consumer products. A third category of scenarios was developed to assess bounding cases where scrap in a single melt was entirely composed of released metal scraps. A significant amount of research was conducted to ensure that the models reflected current U.S. practices for handling scrap metals and concrete for reuse. Because metal refining processes can cause radionuclides to partition to by-products, scenarios covered not only scrap, but also refined metal, slag or dross, dust, airborne emissions, and drinking water downstream from a landfill, among others. In all, eighty-six scenarios were analyzed among the four materials.

2.2.6 Partitioning of radionuclides in refining processes

The distribution of impurities during melting and refining of ferrous metals can be influenced by numerous physical and chemical factors. The partitioning of radionuclides was determined by a combination of considerations. Generally, thermodynamic calculations were used to determine whether an element was likely to partition to the slag or to the melt. Vapor pressures of the more volatile elements and their oxides were used to predict concentration in the dust. These theoretical considerations were supplemented with a review of the literature to obtain realistic data. The convention was adopted that, if an element tends to remain in the melt, 1% is assumed to be physically entrained and transported to the dust due to the turbulence of the melting and refining processes. Similarly, if an element tends to partition to the slag, 5% is assumed to be transported to the dust. Detailed discussions and references are presented in the appendices to NUREG-1640.

3. RESULTS AND COMPARISONS

Detailed probabilistic results are presented in NUREG-1640 for each scenario and each material. In the discussions that follow, the means of the effective dose realizations were used to determine the critical group and for comparison with EC and IAEA guidance. It should be noted that these comparisons address normalized dose factors to individuals within critical population groups, and should not be confused with collective dose, which is the focus of Chapter 3 of the Draft GEIS. Collective doses to a population are used to compare the relative impacts of alternatives.

3.1 Results

For ferrous metals, most critical groups are workers, for example processing either scrap metals or melt products. The use of consumer products containing ferrous metals does not rise to a threshold at which exposures to a specific critical group might be limiting. Other critical groups are controlling for a very few radionuclides associated with exposures from atmospheric releases or drinking water. The scenarios and doses of scrap metal handlers and processors cover the majority of radionuclides and are controlling in defining release levels.

The overall critical groups, on a radionuclide basis, were defined by scenarios for the release of ferrous metals and concrete. These scenarios were almost all from workplace exposures. Thus, controlling hypothetical doses to workers would also control the hypothetical doses to consumers, and would result in lower doses to consumers. Figure E-1 shows the critical group scenarios for ferrous metals and the number of radionuclides for which that scenario defines the critical group. Electric arc furnace is abbreviated as EAF in the scenario descriptions.

Figure E-2 shows the critical group scenarios for concrete. In the scenario description, a municipal solid waste (MSW) landfill with leachates refers to drinking water from a well down-gradient or an industrial landfill where the leachates have reached ground water. One-thousand years after disposal was arbitrarily selected as a time interval when considering ingestion of ground water.

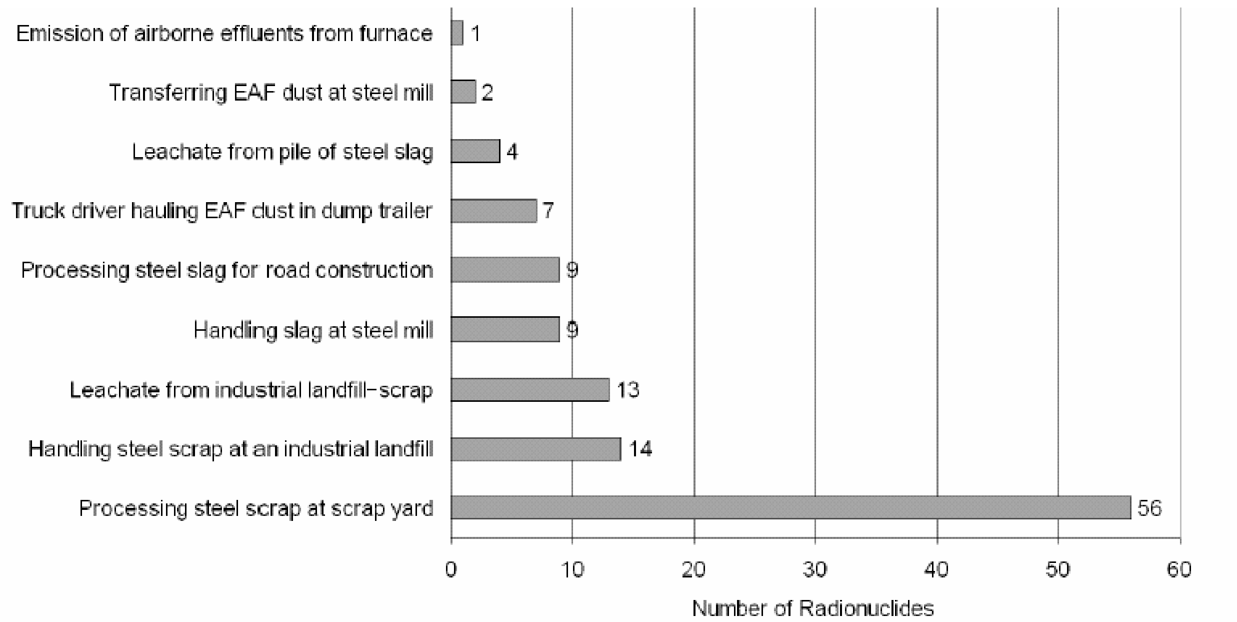

Figure E-1 Critical Group Exposure Scenarios and Defining Number of Radionuclides for the Release of Ferrous Metals

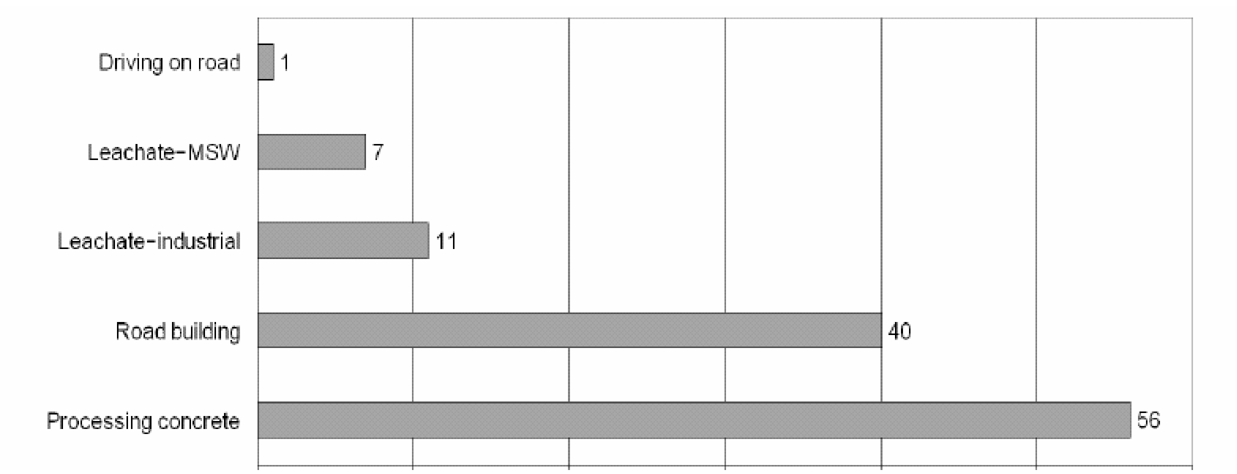

Figure E-2 Critical Group Exposure Scenarios and Defining Number of Radionuclides for the Release of Concrete

3.2 Comparisons

Figure E-3 presents a comparative scatter-plot of effective dose factors from NUREG-1640 on a 10 µSv (1 mrem) in a year basis using the values from EC Radiation Protection 122 (RP 122) (European Commission 2000b). The results are presented in order of increasing radionuclide atomic weight, from tritium to Cf-252. On a radionuclide-by-radionuclide basis, the NUREG-1640 most restrictive (overall critical group) results were divided by the RP 122 values. Thus, when the ratios are greater than one, the NUREG-1640 values are less restrictive than the RP 122 values. Most of the calculations comparing NUREG-1640 with the EC's RP 122 are within a factor of ten of one another.

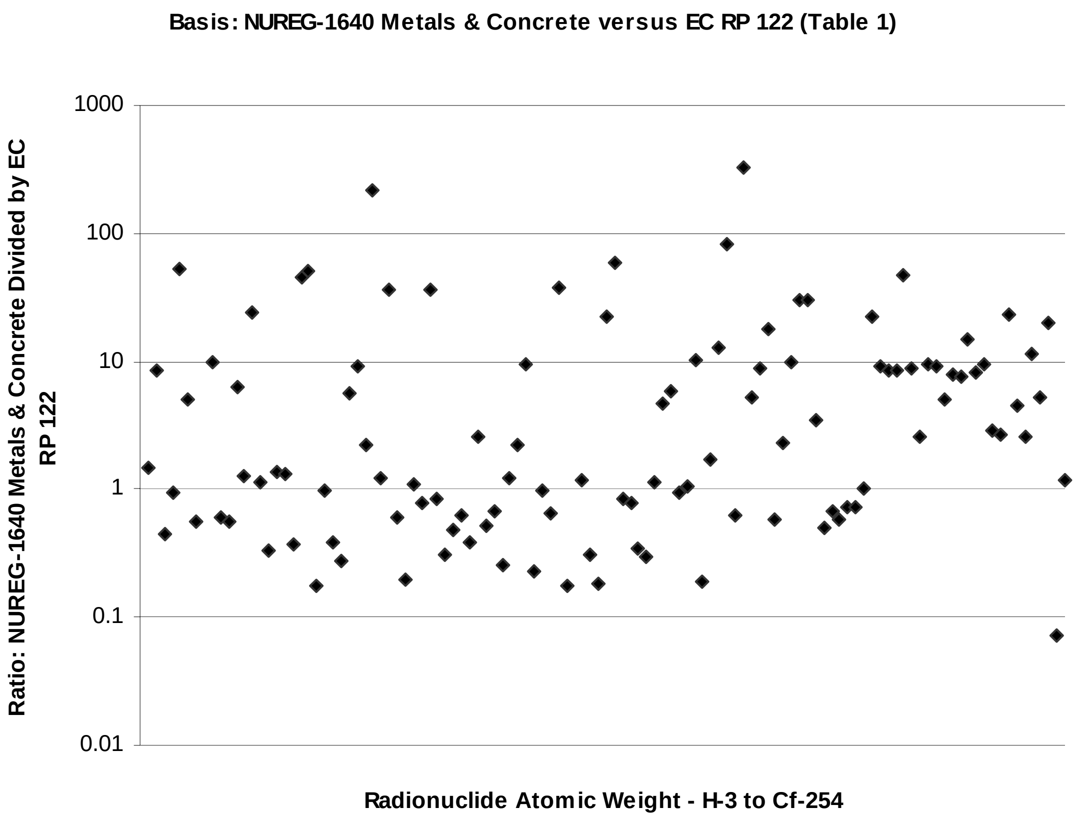

Figure E-3 Radionuclide-by-Radionuclide Comparisons of Values from NUREG-1640 to EC RP 122.

Figure E-4 illustrates a similar comparison with the guidance in the EC's RP 89, which is limited to the recycling of metals from the dismantling of nuclear installations (European Commission 2000a). For this comparison, the NUREG-1640 results for concrete were not included, and the effective dose calculations were used to have a consistent dosimetry system. Most of the results are within a factor of three on a radionuclide-by-radionuclide basis. Only four of the results from EC RP 89 are more restrictive by a factor greater than ten. The differences in the results would require a more detailed evaluation and comparison of the models and assumptions, and could partially reflect a different characterization of industrial practices.

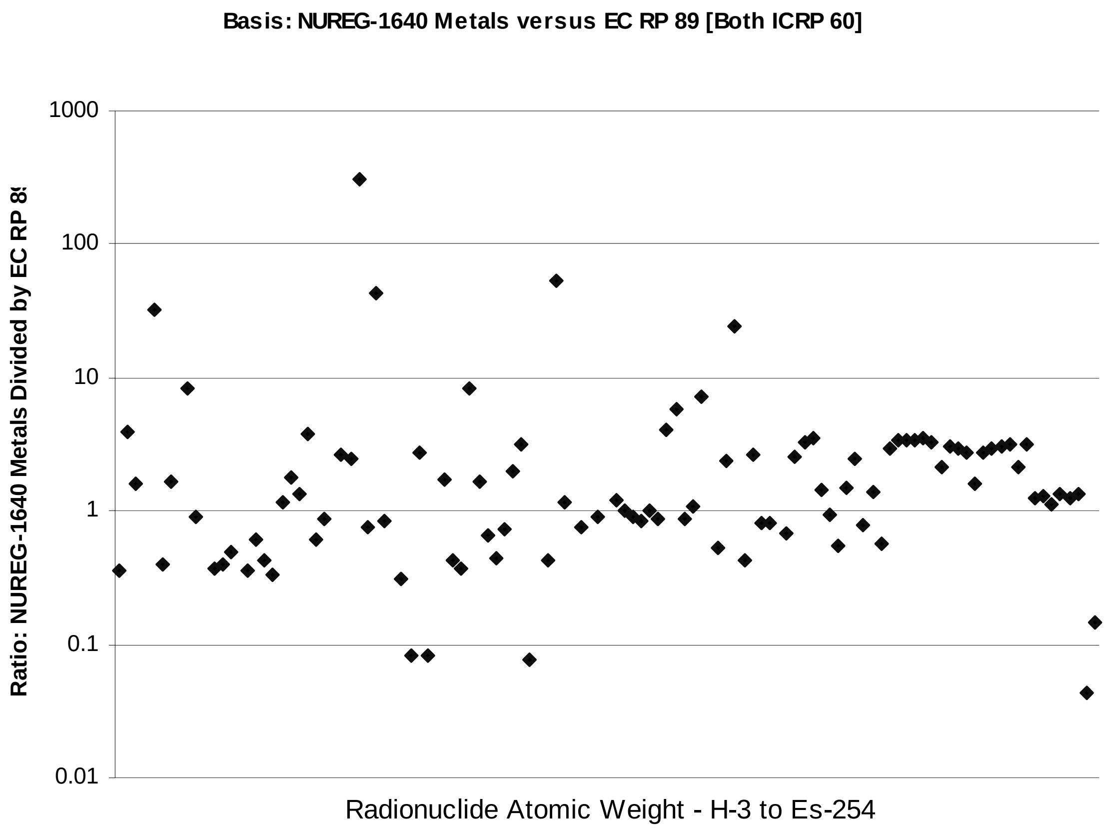

Figure E-4 Radionuclide-by-Radionuclide Comparisons of Values from NUREG-1640 to EC RP 89

Figure E-5 presents a comparative display of the results between NUREG-1640 and IAEA Radiation Safety Guide No. RS-G-1.7 clearance levels (IAEA 2004). The IAEA clearance levels are based on a 10 µSv in a year dose limit. For NUREG-1640, values used in the comparison are based on the most restrictive (overall critical group). The NUREG-1640 results were divided by the corresponding IAEA radionuclide values. As before, when ratios are greater than one, the NUREG-1640 values are less restrictive than the IAEA values. Most of the ratios between NUREG-1640 and IAEA are within a factor of ten of one another.

Most of the calculations comparing NUREG-1640 with the EC's RP 122 or IAEA's RS-G-1.7 guidance are within a factor of ten of one another. For those radionuclides where ratios are greater than one, RP-122 or RS-G-1.7 is more restrictive than NUREG-1640. Generally, ratios less than ten are considered good agreement by modelers because of the uncertainties in making such estimates taking into account, to the extent practicable, variations in modelling complex industrial processes. In part, the variability is attributed to differences in code models; scenarios and exposure pathways describing industrial practices; assumptions and parameters; incorporation of radon and its decay products; adjustments of EC and IAEA clearance values with that of other exemptions to ensure compatibility; and process used in rounding of RP 122 and IAEA values to the nearest power of ten.

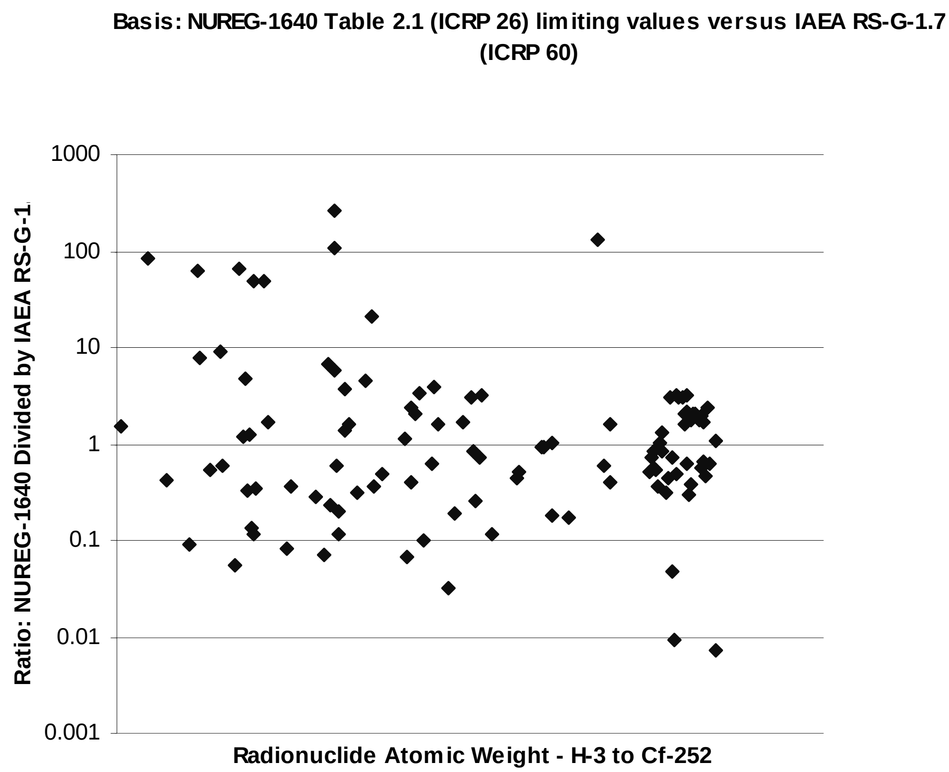

Figure E-5 Radionuclide-by-Radionuclide Comparisons of Values from NUREG-1640 to IAEA RS-G-1.7

The consequence of erring by a factor of ten, with a release criterion based on a 10 µSv (1 mrem) per year dose limit, could mean that a hypothetical individual might receive a dose of 100 µSv (10 mrem) in a year, which is a small fraction of the 1,000 µSv (100 mrem) per year dose limit that is considered protective of public health and safety (see 10 CFR Part 20, Subpart D - Radiation Dose Limits for Individual Members of the Public).

The above discussions addressed comparisons of individual radionuclides, but in implementation, two or more radionuclides may be present in materials that may be released. In such instances, the dose contribution of each radionuclide must be accounted for such that the total dose due to all radionuclides does not exceed the release criteria. This consideration is a requirement of NRC regulations in applying the sum-of-the-ratio. The sum of the ratios of each radionuclide present in materials cannot exceed unity when summed up over all radionuclides, i.e., unity rule. The ratio for a radionuclide is expressed as the concentration of that radionuclide divided by its limit. An example is used to compare differences between NUREG-1640 and RS-G-1.7 release levels when multiple radionuclides are present. The example considers radionuclides and their relative fractions for those radionuclides commonly found in materials generated by nuclear power plants. Typically, 17 radionuclides make up most of the residual activity expected to be found in materials subjected to release, with Fe-55, Co-60, and Cs-137 comprising nearly 80% of the total activity. The following tabulation presents the results of the comparison using the unity rule for all 17 radionuclides.

Case	Concrete	Ferrous Metals
RS-G-1.7 residual gross activity concentration, Bq/g (pCi/g)	0.14 (3.8)	0.14 (3.8)
NUREG-1640 residual gross activity concentration, Bq/g (pCi/g)	0.063 (1.7)	0.34 (9.1)
Ratio of residual concentrations (RS-G-1.7 ÷ NUREG-1640)	2.3	0.4
Restrictive case	NUREG-1640	RS-G-1.7

The results reveal that NUREG-1640 and RS-G-1.7 are alternatively more limiting depending on the type of material. For concrete, the results indicate that RS-G-1.7 yields a less restrictive gross activity concentration (0.14 Bq/g or 3.8 pCi/g), while NUREG-1640 is more permissive for metals (0.34 Bq/g or 9.1 pCi/g). In either case, the differences are less than about a factor of two, which is in very close agreement, especially at these low dose levels. This example illustrates that the differences identified earlier on a radionuclide-by-radionuclide basis are expected to be even less pronounced in implementation or actual practice.

Regarding the possibility of imports, it is estimated that should the IAEA's RS-G-1.7 become an international standard, resulting industry practices might result in annual doses also on the order of 10 μSv, other things being equal. It should be noted that the types and amounts of materials that may be imported is uncertain, but they primarily consist of equipment, parts, and tools used by the nuclear industry. For example, companies involved in servicing power reactors and fuel fabrication facilities ship materials between service centers and power reactors or fabrication plants. As a result, the shipments involve the transfer of materials only between industrial facilities, and exposures to members of the public are very unlikely given that there is no subsequent applications of such materials within the public sector. Moreover, it is not realistic to expect that the nuclear industry would import materials and equipment specifically for disposal in U.S. landfills as the costs of doing so would be prohibitive. Consequently, doses to the public are expected to be a very small fraction of the limit being considered by this rulemaking, i.e., 10 μSv (1 mrem) per year.

3.3 Reuse and Trash

Additional assessments of normalized doses are addressed as supplemental reports to NUREG-1640 (NRC 2005c,d). Specific analyses of the reuse of various kinds of equipment range from small tools (e.g., hand tools) to large industrial equipment with operators assumed to be exposed in an enclosed environment, e.g., in the cab of a truck. Regarding trash, the amounts expected to be shipped for disposal in landfills is expected to be a very small fraction of that estimated for ferrous metals and concrete. Considering the practices of the nuclear industry, it is not realistic to expect that U.S. or European licensees would ship trash and other non-salvageable materials across international borders just for disposal. This is deemed impractical because of costs and regulatory constraints. Because of the reuse of tools and equipment or release of trash for disposal in landfills results in little or no residual radioactivity originating from licensed nuclear facilities, these scenarios are not included in comparisons with international guidance.

E-II SOURCES AND TYPICAL ANNUAL DOSES FROM BACKGROUND RADIATION

1. INTRODUCTION

Background is comprised of various sources of ionizing radiation. These sources collectively produce an average total effective dose equivalent of about 3 mSv/yr (300 mrem/yr) to a U.S. resident. For comparison, the estimate of the average U.S. radiological dose from background is similar to the world average estimate of 2.4 mSv/yr (240 mrem/yr). NUREG-1501 (NRC 1994a) contains a detailed discussion of sources, levels, and variability of background; the following discussion summarizes Section 2 of NUREG-1501. Additional information can be found in two reports issued by the National Council on Radiation Protection and Measurements (NCRP 1987a, b).

2. SOURCES OF EXTERNAL RADIATION

Radiological doses from background typically range between 1 mSv/yr (100 mrem/yr) and 10 mSv/yr (1,000 mrem/yr) in the United States. Although greater radiological doses are possible for people living in houses with very high radon concentrations, 10 mSv/yr could be taken as a practical maximum, with a few rare exceptions. Table E-1 provides a breakdown of the sources of natural background. In addition to the amounts in Table E-1, relatively minor contributors to the dose from background (less than 1 percent each) are cosmogenic radionuclides, created by the interaction of cosmic rays with otherwise stable elements present on earth, and man-made fallout radionuclides from nuclear weapons testing. Cosmogenic radionuclides include H-3, C-14, Ar-41, etc. (NCRP 1987a). Radionuclides from weapons fallout include H-3, C-14, Sr-90, Cs-137, Pu-239, etc. (NCRP 1987a).

Table E-1 Comparison of the Principal Components of Background Between Estimated Populations of the United States and the World

	Annual Effective Dose Equivalent (mSv)		
Component	**U.S. Mean[1]**	**World Mean[2]**	**World Range[2]**
Cosmic	0.27	0.36	0.3 – 2.0
Indoor radon and progeny	2.0	1.1	0.3 – 5.0
Internal (other inhaled, ingested)	0.4	0.5	0.2 – 1.0
Terrestrial gamma	0.28	0.41	0.2 – 1.0
Totals (rounded)	**3.0**	**2.4**	**1.5 – 6.0**

1. NCRP 1987a.
2. UNSCEAR 1988.
1 mSv = 100 mrem

Background produces radiological doses to the U.S. population that are highly variable between locations (spatial) and also over time at the same place (temporal). For example, cosmic radiation is modulated by the 11-year solar cycle and typically varies about 10 percent at the same location, but at different times. Temporal variability of background is also tied to atmospheric circulation and precipitation patterns that affect the distribution of cosmogenic and fallout radionuclides. Short-term changes in external gamma exposure arise from redistribution of radon decay products in the atmosphere and washout with precipitation, resulting in changes ranging from a few percent to more than 200 percent over the course of a day or season. Even larger variations in indoor radon concentrations can occur because of differential air pressures in buildings and resulting changes in ventilation rates. Indoor levels of gamma radiation typically vary by about 50 percent due to the use of different construction materials. Outdoors, changes in soil moisture and snow cover cause external gamma radiation levels to vary seasonally by 10 to 50 percent at the same location. The concentration of radionuclides that produce internal doses, such as Pb-210 in body tissues, has been observed to vary by about a factor of three throughout the United States. Spatial variability of cosmic radiation is observed to be as much as 200 percent, depending greatly on altitude and to a lesser extent on latitude.

3. SOURCES OF NATURAL RADIOACTIVITY IN MATERIALS

Nearly all materials contain naturally occurring radioactivity due to the presence of terrestrial radionuclides, such as K-40, Rb-87, Th-232, and U-238, and cosmogenic radionuclides, such as C-14, H-3, Be-7, and Na-22. The concentration of these radionuclides in soil, water, air, and living matter can vary widely throughout the country because of geological processes, climatic changes, weather, and human activities. For example, concentrations of uranium and thorium in the soil range from as little as one-tenth to as much as four times the average value. Data contained in Table E-2 illustrate a typical range of natural radionuclide concentrations in soil throughout the United States and the world.

Table E-2 Typical Ranges in Average Concentration of Background Radionuclides (Bq per kg)

Material	Uranium-238	Thorium-232	Potassium-40	Reference
Bauxite ore	250	200	n/a	UNSCEAR 1988
Coal, U.S.	18 (1–540)	21 (2–320)	52 (1–710)	Beck et al 1980a,b
Copper ore	30–80	23–110	n/a	UNSCEAR 1988
Crustal rock, U.S.	36	44	850	NCRP 1987a
Oil shale	56 (37–74)	24 (19–37)	481 (185–962)	Gogolak 1982
Phosphate fertilizer, U.S.	9200	n/a	n/a	UNSCEAR 1988
Soil, worldwide	25 (10–50)	25 (7–50)	370 (100–700)	UNSCEAR 1988
Soil, U.S.	37 (4–141)	36 (4–126)	n/a	Myrick 1983

1 Bq = 27.027 pCi

The concentration of the principal gamma-emitting radionuclides in soil is directly related to the external gamma radiation levels in a locale. On a nationwide scale, the concentrations of terrestrial radionuclides vary widely, which is reflected in the grouping of external gamma radiation levels into three regions:

- The Atlantic and Gulf coastal plains, which average about half of the level seen for Middle America (0.23 mGy/yr or 23 mrad/yr);

- Middle America, which has an average level of 0.46 mGy/yr (46 mrad/yr); and

- The Denver, Colorado area, which has an average level about twice that of Middle America (0.9 mGy/yr or 90 mrad/yr).

Throughout the United States, concentrations of naturally occurring radionuclides in ground water can also vary widely. In certain areas of the midwest, for example, the concentration of uranium in water (13 mBq/l or 0.35 pCi/l) is 35 times greater than that found in some eastern States (0.37 mBq/l or 0.01 pCi/l), but even greater concentrations are reported in western areas of the country, where natural uranium concentrations in ground water (130 mBq/l or 3.5 pCi/l) are 350 times that of eastern ground water.

On a smaller scale, such as within an individual State, background radioactivity levels can vary even more. For example, in a particular location in northwestern New Jersey, external gamma radiation levels triple across a small field and, at a nearby rock outcropping, the average soil concentration of naturally occurring radionuclides increases one-hundred-fold, yet 99 km (62 miles) away from this location, gamma radiation levels fall to less than 10 percent of the regional average due to the presence of sandy beaches.

4. MAN-MADE SOURCES OF RADIOACTIVITY

Spatial variability in the concentration of background radionuclides can also be caused by human activities. Fallout from a nuclear weapon test can change background abruptly and require a few months to a few decades to decay. Such testing has correspondingly increased the spatial variability of background because the distribution of fallout radionuclides in the United States is not homogeneous. The deposition of weapons fallout is dependent on meteorological conditions. Mining and milling have also increased the spatial variability of background by redistributing the preexisting concentrations of naturally occurring radionuclides in a locale. Another human activity that affects the spatial distribution of background is the combustion of fossil fuels which produces ash that redistributes natural radioactivity from the ground to the air.

In addition to naturally occurring sources of radiation, nuclear technology has led to the creation of man-made radionuclides that contribute to the background radiological dose. Man-made sources of ionizing radiation exposure account for 18 percent of the total radiological dose to the U.S. population. Of the man-made sources, medical x-ray examinations are the largest source of exposure, producing 11 percent of the total dose (0.39 mSv/yr or 39 mrem/yr). Nuclear medicine procedures account for 4 percent of the total population dose, followed by consumer products (3 percent), weapons test fallout (less than 1 percent) and occupational exposures (less than 1 percent). On average, however, 82 percent of the total dose to the U.S. population comes from naturally occurring radiation sources. The magnitude and variability of radiation doses is directly proportional to the background level that individuals are exposed to and the activities in which they are engaged. Because of their widely varying and ubiquitous characteristics, radiation doses to U.S. residents from background, in turn, vary widely, as well.

E-III POPULATION COLLECTIVE DOSE DUE TO BACKGROUND RADIATION

As was noted earlier, individual doses from background radiation typically range between 1 mSv/yr (100 mrem/yr) and 10 mSv/yr (1,000 mrem/yr) in the United States. It is sometime necessary to assess radiation exposures to an entire population, as compared to just one individual member (NCRP 1995). In simple terms, the collective dose of a population is the sum of the dose received by each individual within that population group. An important distinction in the concept of collective dose is that it addresses members of population groups and not members of the critical group as is defined in the context of regulatory dose limits. Collective dose is derived as:

$$S = \sum H_i P_i$$

where:

S = collective to the population
H_i = dose to each individual in group i
P_i = population group i

Collective dose is expressed in person-rem or person-sievert. For example, lets assume that the annual doses to members of two groups of individuals are 0.8 and 1.2 mSv each, with a population of 1,250 and 800 persons in each group, respectively. For this example, the collective dose of each group is estimated as:

0.8 mSv x 1,250 persons = 1,000 person-mSv
1.2 mSv x 800 persons = 960 person-mSv

The results indicate that although doses and population sizes are different, the resulting collective doses are essentially identical. This example also illustrates the competing effects of individual doses and sizes of populations on the collective dose. In this example, the differences in doses and sizes of the populations nearly cancel one another out.

It can be seen that collective dose may be a useful index in differentiating dose impacts when population sizes and doses vary. However, a number of inherent limitations have been identified in the application of collective dose (NCRP 1995). Of specific interest, is whether there is a justification for excluding negligible individual doses from collective dose calculations. The NCRP notes that all doses should be included in assessing collective doses and “there is no conceptual basis for excluding any individual doses, however small.” However, the NCRP recognizes that there may be legitimate practical limitations for doing so. Another issue addresses itself to uncertainties in the types of exposed populations, size of the exposed populations, and exposure pathways, among others. Regarding uncertainties in the underlying components on which collective doses are based, the NCRP states that collective doses should not be used when the uncertainty in the number of individuals summed in the population component of the dose is large, i.e., greater than one order of magnitude. Similar care should be considered in evaluating the other components used in calculating collective doses. Finally, there may be a justification in identifying a collective dose threshold below which it should be recognized that there may be no significant impacts, nor risks. The NCRP recommends a threshold based on 10 percent of the reciprocal of the risk coefficient. Using the NCRP approach, the collective dose threshold for a risk coefficient of 4×10^{-2} per Sv (4×10^{-4} per rem) would be 2.5 person-sievert (250 person-rem), used here only as an illustrative example. Chapter 3 of the GEIS addresses collective doses in the context of the alternatives.

The collective dose to the U.S. population associated with background radiation has been estimated using typical sources of radioactivity and resulting radiation doses. The annual collective dose from background radiation in the United States is estimated to be about 840,000 person-Sv (84 million person-rem), assuming an annual average effective dose equivalent of 3 mSv (300 mrem) and a population of about 280 million (NCRP 1987b, 1995).

E-IV EXPOSURES FROM MULTIPLE SOURCES DERIVED FROM THE RELEASE OF MATERIALS FROM LICENSEES

1. INTRODUCTION

Assessment of the potential doses to an individual that could arise from the release of materials from a licensed facility were performed according to particular activities, called scenarios. The scenarios involved the transport, processing, refining, consumer use, and disposal of these materials. Conceptually, multiple scenarios could apply to the same individual, and this potential raises the question of what would be the exposure and the probability of such an occurrence. That is, what would be the consequence and the frequency of multiple scenarios affecting the same individual–the risk. The possibility of multiple scenarios concurrently applying to an individual implies that the individual would be exposed to very low levels of radioactivity from more than one source, for example from a vehicle's engine block and recycled concrete in a roadbed. The range of potential doses from multiple exposures, should they occur, and the potential for their occurrence are assessed below.

Many exposure scenarios were assessed for each radionuclide and each material to evaluate those circumstances that could lead to the greatest exposures following the release of materials [see NUREG-1640 (NRC 2003d)]. These scenarios are the critical group scenarios for that material. The scenario that yielded the greatest exposure to an individual in a year, regardless of the material, was identified for each radionuclide on a per unit of radioactivity basis. This scenario is not only the critical group scenario for that material and radionuclide, but also the overall critical group scenario for that radionuclide. For example, road building with recycled concrete is the scenario that potentially gives the greatest exposure for Co-60 for each Bq per gram. Other scenarios involving the processing, refining, consumer use, and disposal of iron, steel, copper, and aluminum gave less potential exposure from Co-60 for each Bq/g.

2. MULTIPLE POTENTIAL EXPOSURES

Several hypothetical situations could arise where an individual could be exposed from the release of several different types of materials, products made from them, disposals in landfills, or reuse of equipment once released. There could be multiple radionuclides involved, or multiple kinds of materials released, or multiple concurrent scenarios. Such scenarios might include multiple facilities releasing materials, processing released materials while using consumer products made from released materials, reuse of tools and equipment, or disposal of materials from multiple licensees in one landfill. The potential exposures from these hypothetical situations are examined below.

2.1 Multiple Radionuclides and the Sum of the Fractions Rule

The standard regulatory approach for implementing limits involving multiple radionuclides requires that the sum of the fractional concentrations, the nuclide concentration divided by the concentration limit for each respective nuclide, be kept less than one. This is often known as the "sum-of-the-ratios rule," and is described in footnote 4 to App. B of 10 CFR Part 20. Use of this rule limits the contribution to the overall exposure of an individual from any one radionuclide to a fraction of the overall allowed level when more than one radionuclide is present.

2.2 Multiple Materials - Implementation Based on the Overall Critical Group Scenario for Each Radionuclide

Implementation of a regulation for the release of solid materials would likely be dose-based. Thus, to ensure that individuals would be protected regardless of the material being released, the release criteria of a particular radionuclide, for example, Co-60, would be based on the most restrictive scenario for that radionuclide and critical group scenario. Then, that concentration would be applied to all materials. In this case, the same concentration that could give a certain dose, say 10 μSv (1 mrem) in a year, for road building with recycled concrete, would also be applied to the release of iron, steel, copper, and aluminum with associated Co-60. That concentration would give less than 10 μSv in a year for any of these other materials, even in the most restrictive scenario for other materials. For every other scenario, the potential dose actually would be less than 10 μSv in a year because the release criteria would be a lower concentration than could result in 10 μSv in a year. The effects of these small doses are bounded and addressed in the following discussions. The most restrictive scenarios of all materials do not include any scenario from the assessments of copper or aluminum, because their contributions are much smaller when compared to the most restrictive ones listed in Table E-3. For materials with radionuclides only on the surface (surface concentrations as compared to the previous discussion on volume concentrations), the overall critical group scenarios are limited to steel and copper. Concrete scenarios disappear from this latter list due to the mixing of the surficial radionuclides in rubble. That is, there is usually a greater relative thickness of concrete - mass to surface ratios - in buildings and structures.

Table E-3 Overall Critical Group Scenarios Bq/g Basis

Iron & Steel	
	SCENARIO
	Processing steel at scrap yard
	Leachate from steel slag
	Handling slag at steel mill
	Processing steel slag for road construction
	Emission of airborne effluents from furnace
Concrete	
	SCENARIO
	Processing concrete
	Road building
	Leachate–industrial
	Leachate–Municipal solid waste
	Truck driver

2.3 Multiple Concurrent Scenarios

Hypothetically, it is possible that an individual could be exposed through multiple concurrent scenarios. A hypothetical example is given to illustrate this possibility. The approach that is used to illustrate this hypothetical example is to add a number of scenarios to maximize the potential dose to an individual. For reasons described later, the likelihood of such multiple concurrent exposures becomes vanishingly small as the number of potential concurrent scenarios increases.

Some combinations of scenarios can be ruled out, because they are impossible or very highly unlikely. For example, it is impossible to be in two places at once, there are only twenty-four hours a day, some scenarios take place in different years after release, and there is a very low percentage of the population who are fully employed concurrently in two or more jobs covered by these scenarios. For example, it is reasonable to assume that it is very highly unlikely that the same individual would be employed at the same time during an entire year as full-time road builder using processed concrete and also as a full-time slag handler at a copper refinery where both facilities are processing released materials during that year.

However, other combinations of scenarios are possible and these merit analysis. From Table E-3, a hypothetical set of concurrent scenarios that are also credible can be assembled with only two scenarios. A full-time job and residing downwind from a refinery could occur concurrently. Hypothetically, the expected exposure (from two scenarios) could be up to 20 μSv (2 mrem) in a year, if the limit for release were based on 10 μSv (1 mrem) in a year. More credible conjunction of concurrent scenarios can be hypothesized if the less-than-overall-critical group scenarios are added. However, the hypothetical exposures from each of the other scenarios would be expected to add less than the dose upon which release would be based, e.g., less than 10 μSv in a year.

A hypothetical road builder using processed concrete material with associated cobalt-60 could drive to work over a roadbed made from aggregate with associated thorium-232. He could live within the area that is in the effluent pathway of a refining furnace. Furthermore, he could drive a truck with an aluminum engine block, and use aluminum cookware and jewelry made from recycled metals. Hypothetically, if a release regulation were to limit the mean individual dose to the critical group to, for the purposes of clarity and illustration, 10 μSv in a year from release, and if the implementation of the regulation takes into account the practices described above, as shown in Table E-4, the dose to the hypothetical individual, calculated from the results in NUREG-1640 (NRC 2003d), would be approximately 30 μSv (3 mrem) in a year or three percent of the public dose limit, which is 1,000 μSv (100 mrem) in a year (see Subpart D to 10 CFR Part 20).

As shown in Table E-4, even when, for illustrative purposes, an extremely conservative and highly implausible situation is considered for estimating individual dose, where six hypothetical exposures occur concurrently, the resulting dose is only 30 μSv in a year. The underlying assumption for making the above dose estimate assumed that several different licensed facilities that use different radionuclides come together to make this situation possible and all these

Table E-4. Hypothetical Multiple Concurrent Scenarios

Scenario	Nuclide	Material	Dose[1] (μSv in a year)
Road builder	Cobalt-60	Concrete	10
Driving on road	Thorium-232	Concrete	10
Air borne emissions	Iodine-125	Steel	10
Aluminum engine block	Cobalt-60	Aluminum	0.009
Aluminum cookware	Protactinium-231	Aluminum	0.008
Copper object on body	Silver-108m	Copper	0
			Total 30.017

[1]NUREG-1640, mass based mean effective dose.

facilities released materials at the maximum release concentration levels. A more realistic estimate of the dose to this hypothetical individual would be significantly less than 10 μSv in a year from each of the six scenarios, and a more realistic cumulative total dose would be less than 30 μSv in a year. This is much more than adequate protection of the public because, for adequate protection of the public, NRC requires that each licensee conduct operations so that the total effective dose equivalent to individual members of the public from the licensed operation does not exceed 1,000 μSv in a year.

2.4 Potential for Occurrence of Multiple Concurrent Scenarios

The potential for the same individual to be involved in concurrent scenarios is physically constrained by the relatively limited amount of materials that could be released from licensed facilities. Geographical distances between licensees and the different locations where the scenarios could occur also decrease the potential for concurrent scenarios to affect a single individual. From the above lists of scenarios that could result in the highest doses, it can be seen that many involve specialized industrial processing. There are not many of these processors in the country, and thus, only a limited number of individuals could be affected by those scenarios. Such individuals would likely be affected by only one processing scenario. The more likely scenarios that could affect these processors would involve consumer products or use of public roads. The potential that a particular consumer product made from released materials is used by the same hypothetical individual depends on the number of such products made, the total number of these products made from released materials and the fraction of those made that are in use.

The potential for a processor to be affected by additional scenarios is the serial multiplication of each additional scenario. While it is difficult to estimate the actual probability of a particular scenario[1], an example can illustrate that with each additional scenario, the potential for all the

[1] Data are usually not available to calculate the probability, however, an example of an approach to make such an estimate illustrates that the probabilities of these scenarios is usually small. Consider the probability of an auto with a cast-iron engine block containing radionuclides that were released in steel. From NUREG-1640, the fraction of iron castings that are used for the auto and truck industry is 0.5. The (continued...)

scenarios occurring together becomes smaller. Even with only a few scenarios, this potential is very small. For example, in the illustrative case above, six scenarios were hypothetically aggregated. A relatively large estimate of the likelihood that any of the additional scenarios would affect the hypothetical road builder above would be one-in-a-hundred, or 0.01. If only one additional scenario affected the hypothetical road builder, then there would be an estimated one-in-a-hundred chance that this individual would be exposed to as much as 20 μSv in a year. The potential for two additional scenarios would be estimated as 0.01 x 0.01 = 0.0001 or one-in-ten-thousand in a year to be exposed to something less than 30 μSv in a year. Repeating this process for each additional scenario in our hypothetical example above gives an estimate of one-in-ten-thousand million that this hypothetical individual would be exposed to less than 30 μSv in a year. Considering that the population of the U.S. is approximately 280 million, this is a very small potential as the probability indicates that no one individual in the entire U.S. is likely to be affected by six concurrent scenarios.

2.5 Landfill Disposal

Materials released from licensed facilities may be disposed of in regulated landfills. The types of disposal facilities include municipal solid waste (MSW) landfills, industrial landfills (IL), and construction and demolition (C&D) landfills. Collectively, these facilities are referred to as Subtitle D landfills under EPA regulations. Municipal solid waste landfills are regulated under 40 CFR Part 258, and industrial landfills and construction and demolition landfills are regulated under 40 CFR Part 257. In addition, State and local agencies regulate landfill siting, design and construction, operation, surface and ground water monitoring and corrective action, closure and post-closure care, and financial assurance. Municipal solid waste landfills are required to install a cap upon closing each disposal cell, and a composite bottom liner and a leachate collection system. Performance standards include requirements to limit the amounts of leachate accumulations at the bottom of disposal cells, specifications on leachate release rates out of landfills, and chemical concentration limits in ground water. Industrial landfills are not required to have bottom liners and leachate collection systems. However, all landfills are required to operate in a manner that will not cause discharges of pollutants into surface water or ground water in violation of the requirements of the Clean Water Act and Safe Drinking Water Act.

Such requirements are expected to mitigate exposures and doses to both landfill workers and nearby members of the public. For example, MSW landfills are required to place a daily soil cover over wastes. The presence of a soil cover is expected to reduce worker exposures from external radiation, dust inhalation, and incidental ingestion of materials. The cover is also

[1] (...continued)
fraction of all scrap that is used for casting is 0.2. If all the scrap that could potentially be released from the nuclear industry were to be used in one year, it would be one-thousandth of all the scrap used that year. Thus, the fractional mass of released metal in new engine blocks would be one-ten-thousandth. This fraction can be used as an estimate of the probability of getting a new engine block with released metal. That probability is then multiplied by the probability that the hypothetical individual is driving a new auto. Therefore, an estimate for the probability of a single scenario occurring of one-in-one-hundred is likely an overestimate, but it is useful to illustrate a conservative upper bound of the probability.

expected to reduce fugitive dust emissions and airborne materials at downwind locations, thereby reducing inhalation exposures to nearby residents. The control of leachate discharges, landfill closure, and the post-closure care and monitoring periods are part of the process required to mitigate impacts on surface and ground water. These requirements are designed to minimize discharges from closed disposal cells and reduce or eliminate impacts on nearby usable surface and ground water resources.

In considering the disposal of materials from multiple licensees, although possible, the dumping of released materials is expected to be governed by several factors. First, the disposal of materials is driven by the availability of nearby landfills, disposal capacity of each landfill, and restrictions placed by each landfill on the types of wastes it may accept. As a result, it is expected that in some cases, disposals will be shared by two or more landfills, and in other instances, disposals may be confined to a regional, and possibly larger, landfill. Second, the sequence in which shipments of released materials are sent for burial can be considered as independent events, with shipments occurring on a schedule driven by the need of each licensee. The likelihood that two licensees might ship materials at the same time and arrive at the landfill for disposal also at the same time is very unlikely. Third, the disposal process at landfills is often organized by disposal cells, where burials are segregated by types of wastes and volumes. In such instances, materials sent by two licensees would most likely be dumped in separate disposal cells, and processed by different work crews. Together, these factors are anticipated to minimize exposures to both workers and members of the public.

In light of regulatory requirements imposed on the operation and closure of landfills, and post-closure monitoring, doses to both landfill workers and nearby residents are expected to be well below the release limit. Other factors that are expected to contribute to still lower doses include the remote possibility of multiple disposals occurring at every single landfill, the segregation of materials by disposal cells, and disposal activities being conducted by different work crews. Finally, the application of the most limiting unrestricted release scenario and its corresponding radionuclide concentrations as release criteria would tend to result in doses that are less than 10 uSv (1 mrem) per year, even when considering multiple disposal events at a single landfill.

2.6 Equipment Reuse

The type of equipment that could be released from nuclear facilities for reuse in an environment free of radiological controls ranges from small items, such as hand tools, to very large ones, such as mechanized equipment and industrial vehicles. The release of equipment is a dynamic process involving different types of facilities and activities, such as routine operations, research and development, and plant outages, refurbishment, and decommissioning. In addition, this process is taking place simultaneously at thousands of facilities across the nation and being conducted every day. As a result, it is not readily possible to define what types of items and how many are routinely used in radiologically controlled areas, what fraction is surveyed and released for reuse versus those that are discarded as low-level radioactive waste, and assign representative residual radioactivity levels by radionuclides and relative mix for all licensees.

Doses to workers using tools and equipment that have been released depend on several factors. For example, the dose is directly proportional to the number of hours that a worker is assumed to handle reused items. Time spent on other activities that do not require the use of any equipment that was released would result in lower doses. Another consideration is whether other equipment and tools may be available that are not a product of release, i.e., equipment of other origins that were never introduced in radiologically controlled areas. For equipment that have been released, the duration of exposure to workers is confined to its useful life-cycle. The useful life of equipment is driven by operational conditions and economic considerations, taking into account replacement and repair costs. These factors are expected to be different among facilities. For large equipment (e.g., trucks), the useful life is typically much longer than that of small equipment, such as hand tools. The useful life of small equipment is much shorter as these items are discarded given that replacement costs are usually less than repair costs. Also, the dose is directly proportional to the total number of items being used by a worker at any one time. For large equipment, such as mechanized equipment, a worker can only operate one piece of equipment at a time. However, for small equipment, such as hand tools, it is conceivable that a worker could use a number of items or at least be surrounded by several such small tools while working. Other mitigative measures are associated with different practices among licensees, such as whether equipment and tools are protected (by wrapping in plastic) before being introduced in controlled areas; the types of administrative controls used for releasing equipment; conditions on the types of equipment that may be released *versus* those that are discarded as radioactive waste; and the application of constraints on how equipment may be used after having being released.

In practice, licensees control equipment and tools that are introduced in radiologically controlled areas. In some instances, licensees supply all equipment and tools for use in controlled areas, thereby minimizing the constant flux of equipment being processed in and out of such areas. Also, equipment and tools are surveyed before being taken out of radiologically controlled areas. Such surveys consist of conducting scans with a radiation survey meter and taking wipes to assess the presence of removable surface activity. The presence of radioactivity on wipes is evaluated using separate instrumentation. Some survey methods involve the introduction of the item into an instrument that measures radioactivity from all external and internal surfaces. Depending on the results of the survey, the items are either cleaned to meet release criteria, not taken out of the controlled area and set aside for later use in the same work area, or simply discarded as low-level radioactive waste. Moreover, experience has shown that cleaning efforts involve a process in which residual radioactivity levels are removed to non-detectable levels, as opposed to cleaning to a level that just meets release criteria. In recognition of operational practices and application of ALARA by licensees, it is expected that the presence of residual radioactivity on released equipment would be well below release criteria and should result in doses that are less than 10 uSv (1 mrem) per year, even when considering the use of multiple small items.

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APPENDIX F
CHARACTERIZATION OF SOLID MATERIALS

Introduction

This appendix provides supporting information for Chapter 3 on the types of NRC licensed facilities and inventory estimates for materials released for each alternative.

Table F-1 lists commonly reported radionuclides for all licensees. For nuclear power plants, the radionuclide profile and relative fraction of each radionuclide are based on site characterization results and some low-level waste data. A single inventory was derived for all reactors, both operating and shutdown. The radioactivity profile assumed the presence of 17 radionuclides, as beta and gamma emitters, and transuranics. The most predominant radionuclides, comprising about 96% of expected residual radioactivity levels, are Mn-54, Co-58, Co-60, Ni-63, Fe-55, Cs-134, and Cs-137. For all other licensees, the listing is meant only to be illustrative of some of the most common radionuclides, while recognizing that radioactivity profiles in materials designated for release are expected to vary. It should be noted that the types and amounts of radioactive materials authorized under a license are not always reliable predictors of radionuclide distributions that might be found in potentially clearable material. The uncertainty about the presence of radionuclides and their relative fractions in any material is dependent on the license specifying types of radionuclides and their chemical and physical properties, processes or events leading to the release of materials, use of material control measures, and radioactive decay.

This Draft GEIS is focused on controlling the disposition of solid materials that are present in areas in NRC-licensed facilities where radioactive materials are used or stored. These areas are generally referred to as either restricted or impacted[1] areas. Despite its location in these restricted or impacted areas, much of this solid material has no, or very little, radioactivity resulting from licensed operations because (1) the material was not exposed to radiation, or (2) the material was exposed to radioactivity only minimally, or (3) it has been decontaminated. In this Draft GEIS, these solid materials are referred to as "potentially clearable" materials. These solid materials can include furniture and ventilation ducts in buildings; metal equipment and ferrous metals and copper pipes; wood, paper and glass; laboratory materials (gloves, beakers, etc); routine trash; site fences; concrete; soil; or other similar materials.

Other solid materials in these restricted or impacted areas can contain more appreciable levels of radioactivity. However, these are separated from those materials with no, or very small amounts of radioactivity at the licensed facility and are required to be disposed at licensed low-level waste (LLW) disposal sites under NRC's existing regulations in 10 CFR Part 61. Solid materials containing appreciable levels of radioactivity are not the subject of the Proposed Action. These materials are referred to as "activated" or "contaminated."

[1] A restricted area is defined in the NRC regulations at 10 CFR 20.1003 as an area to which access is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. An impacted area is defined in 10 CFR 50.2 as an area with some reasonable potential for residual radioactivity in excess of natural background or fallout levels.

Table F-1 Radionuclides Expected in Potentially Clearable Materials

Radiouclide	Power Reactors & ISFSIs	Research Reactors	Fuel Cycle Facilities & U-Mills	All Material Licensees	Complex Sites
H-3	x	x		x	
C-14	x	x		x	
P-32, P-33				x	
S-35				x	
Mn-54	x	x		x	
Cr-51				x	
Fe-55, Fe-59	x	x		x	
Co-57, Co-58, Co-60	x	x		x	
Ni-63	x	x		x	
Zn-65	x	x			
Ga-67				x	
Sr-89, Sr-90	x	x		x	
Tc-99	x	x	x	x	
Tc-99m				x	
Ru-106	x	x			
Ag-110m	x	x			
In-111				x	
Sb-125	x	x		x	
I-123, I-125, I-129, I-131	x	x		x	
Cs-134, Cs-137	x	x		x	
Ce-144	x	x			
Eu-152, Eu-154, Eu-155	x	x			
Ir-192				x	
Tl-201				x	
Ra-226, Po-210				x	x
U-238, U-234, U-235			x	x	x
Pu-238, Pu-239, Pu-240, Pu-241	x	x	x	x	
Am-241	x	x	x	x	
Cm-243, Cm-244	x	x	x		
Natural-U			x	x	x
Natural-Th			x	x	x
Enriched-U and Depleted -U			x	x	

Note: All “material licensees” include manufacturers of sealed sources and radio-labeled compounds, nuclear pharmacies, R&D facilities, academic institutions, medical centers, nuclear laundries, government laboratories, decontamination services, and commercial service organizations supporting licensees.

Solid materials not located in restricted or impacted areas, and considered to be free of radioactivity resulting from licensed operations, are not currently required to be part of a disposition radiological survey program. Such materials can include furniture, glass bottles, paper, equipment, or trash in administrative buildings or office areas. This rulemaking does not propose to alter this approach and, therefore, these materials also are not the subject of the Proposed Action. In this Draft GEIS, these materials are referred to as "clean."

Contamination is characterized by a large mass of potentially clearable material and a large mass of materials with very high contamination levels (SC&A 2003). Little material is expected to have intermediate contamination levels. The high end contamination is typically associated with areas where contamination is inevitable (e.g., areas with equipment used to process nuclear materials).

Description of NRC-Licensed Facilities

The facilities that generate the solid materials and are the subject of this Draft GEIS are all licensed facilities (about 21,000 sites/facilities) and include the following:

- Commercial Nuclear Power Reactors
  - Currently licensed (104)
  - Formerly licensed, excluding reactors which have largely completed DECON[2] (17)
- Non-Power Licensed Reactors (36)
- Fuel Cycle Facilities
  - Uranium mills and *in situ* leach facilities (16)
  - Conversion/enrichment plants (4)
  - Fuel fabrication plants (7)
  - Independent spent fuel storage installations (28)
- Material Licensees (21,000)
- Complex Materials Decommissioning Sites (43[3])

The number of licensed facilities is constantly changing because every year new facilities receive operating licenses and some licenses are terminated. This listing of facilities is based primarily on data compiled by the NRC in its *2002 Information Digest* (NRC 2002c) and as such represents a snapshot at that instant in time.

[2] DECON is an NRC Classification for nuclear facilities in which "the equipment, structures, and portions of a facility and site that contain radioactive contaminants are removed or decontaminated to a level that permits termination of the license after cessation of operations."

[3] Formerly known as SDMP sites. The number of sites indicated does not include reactor sites. The NRC has eliminated the designations of the "Site Decommissioning Management Plan (SDMP)," "SDMP Program," or "SDMP sites." (Federal Register, June 17, 2004, Vol. 69, No. 116, p. 33946). Such sites are now referred to as "complex decommissioning sites."

1. Commercial Nuclear Power Reactors

Commercial nuclear power reactors include boiling water reactors (BWRs) and pressurized water reactors (PWRs). In order to characterize the solid materials that could be released from commercial nuclear power reactors, reference facilities were developed for both BWRs and PWRs and the results were scaled to cover all the reactors (SC&A 2003).

Reference Boiling Water Reactor

The reference BWR consists of three principal buildings where radioactive contamination may be present: the Reactor Building, the Turbine Generator Building, and the Radwaste and Control Building.

The Reactor Building contains the nuclear steam supply system and its supporting systems. It is constructed of reinforced concrete capped by metal siding and roofing supported by structural ferrous metals. The building surrounds the primary containment vessel, which is a free-standing ferrous metals structure. The exterior dimensions of the Reactor Building are approximately 42 m by 53 m in plan, with 70 m above grade and 10.6 m below grade to the bottom of the foundation.

The Turbine Generator Building, which contains the power conversion system equipment and supporting systems, is constructed of reinforced concrete capped by ferrous metals-supported metal siding and roofing. This structure is approximately 60 m by 90 m in plan and 42.5 m high.

The Radwaste and Control Building houses, among other systems, the condenser offgas treatment system, the radioactive liquid and solid waste systems, the condensate demineralizer system, the reactor water cleanup demineralizer system, and the fuel-pool cooling and cleanup demineralizer system. The building is constructed of reinforced concrete and structural ferrous metals and has metal siding and roofing. This structure is approximately 64 m by 49 m in plan and 32 m in overall height.

Several additional buildings make up the reference BWR complex. These include the Diesel Generator Building, Service Building, Circulating Water Pump House, Spray Pond Complex, Makeup Water Pump House, the yard, and other buildings (i.e., Office Building, Warehouse, Guard House, and Gas Bottle Storage Building). These buildings are assumed not to be radioactively contaminated. They would generally fall into the clean category in the MARSSIM definition of a non-impacted area.

Reference Pressurized Water Reactor

The principal structures at the reference PWR power station are the Reactor Building, Fuel Building, Auxiliary Building, Control Building, and Turbine Building.

The Reactor Building houses the nuclear steam supply system. Since its primary purpose is to provide a leak-tight enclosure for normal as well as accident conditions, it is frequently referred to as the containment building. Major interior structures include the biological shield, pressurizer cubicles, and a ferrous metals-lined refueling cavity. Supports for equipment, operating decks, access stairways, grates, and platforms are also part of the containment structure internals. The Reactor Building is in the shape of a right circular cylinder approximately 64 m tall and 22.5 m in diameter. It has a hemispherical dome, a flat base slab with a central cavity, and an instrumentation tunnel.

The Fuel Building, approximately 27 m tall and 19 m long by 54 m wide, is a ferrous metals-reinforced concrete structure with four floors. This building contains the spent-fuel storage pool and its cooling system, much of the chemical and volume control system, and the solid radioactive waste handling equipment. Major ferrous metals structural components include fuel storage racks and liners, support structures for fuel handling, and components, ducts, and piping associated with air conditioning, heating, cooling, and ventilation.

The Auxiliary Building, approximately 30 m tall with lateral dimensions of 19 m by 35 m, is a ferrous metals and reinforced concrete structure with two floors below grade and four floors above grade. Principal systems contained in the Auxiliary Building include the liquid radioactive waste treatment systems, the filter and ion exchanger vaults, waste gas treatment system, and the ventilation equipment for the Reactor, Fuel, and Auxiliary Buildings.

Other major building structures with substantial inventories of metals include the Control Building and Turbine Building. The principal contents of the Control Building are the reactor control room, as well as process and personnel facilities. The principal systems in the Turbine Building are the turbine generator, condensers, associated power production equipment, steam generator auxiliary pumps, and emergency diesel generator units.

2. Non-Power Reactors

Non-power reactors (NPRs) come in many varieties and forms, with most being either pool-type or tank-type. Many are located at universities and research organizations. Pool-type reactors have a core immersed in an open pool of water. The pools typically provide about 20 ft of water above the core to allow cooling and radiation shielding. At pool-type NPRs, the operating core and fuel can be observed through the pool water. Tank-type reactors have a core in a tank with water, sealed at the top. Non-power reactors are also categorized by fuel type: plate-type fuel, TRIGA (Training, Research, Isotopes, General Atomics), or AGN (Aerojet General Nucleonics). Plate-type fuel consists of several thin plates containing a uranium mixture clad with aluminum formed into an assembly. This geometry promotes efficient heat removal and the ability to provide a high-neutron density. TRIGA fuel is in the shape of rods and consists of a uranium and zirconium hydride mixture. AGNs are compact, self-contained, low-power (<5 watts) tank-type reactors. The 10-in diameter core consists of uranium oxide powder embedded in a polyethylene moderator.

3. Uranium Mills

Nuclear fuel cycle facilities include uranium mills, uranium hexafluoride production facilities, fuel fabrication facilities, and uranium enrichment facilities.

NRC currently licenses 16 uranium recovery facilities[4] under 10 CFR Part 40, including 12 conventional uranium mills and 4 *in situ* leach facilities. In addition, some milling sites are licensed by Agreement States. Most conventional uranium mills have been shut down and are undergoing decommissioning. These mills are not likely to be significantly affected by any future NRC regulations relating to the release of solid materials from regulatory control, since dismantlement will likely be well advanced or completed prior to any rulemaking. One conventional mill is on standby status and two are operating. Based on the likely approach to decommissioning, where there is little or no salvageable equipment and most materials are buried in onsite tailings piles or at other approved sites, the quantities of potentially clearable materials from uranium mills are expected to be small. Some licensees may attempt to sell or transfer larger items such as tanks, and office trailers and construction equipment.

Of the four NRC-licensed *in situ* leach facilities, one has been shut down and is undergoing decommissioning. The shutdown facility is unlikely to be affected by the Proposed Action, since dismantlement is expected to be largely completed prior to issuance of any final rule. Two *in situ* leach facilities are operating, one is decommissioning, and one is not yet built. Some large resin and chemical tanks and pumps may be available for recycle/reuse when these facilities are ultimately decommissioned. Contaminated equipment and plastic piping are likely to be disposed of in tailings piles or at other licensed disposal sites. Disposition of structures and clean equipment could be affected by the Proposed Action.

4. Uranium Hexafluoride Production Facilities

Most nuclear reactors require uranium to be enriched from its natural isotopic composition of approximately 0.7 percent U-235 (most of the rest being U-238) to 3.5-4 percent U-235. To enrich uranium in a diffusion plant, it must first be converted to a gaseous form, and the standard way of achieving this is to convert the uranium oxides to uranium hexafluoride (UF_6). The reference UF_6 production facility consists of a main building, a solvent extraction facility, a warehouse, a cooling tower, retention lagoons, and other storage areas.

The only operating UF_6 conversion facility in the United States is managed by Honeywell in Metropolis, Illinois. The Sequoyah Fuels Corporation facility in Gore, Oklahoma, was shut down in 1993 and is currently awaiting decommissioning. The NRC license for the Honeywell facility expires on June 30, 2005. Closure of that facility at that time would force reliance on foreign sources of conversion capacity. To ensure continued domestic UF_6 production capability, the Honeywell license would need to be renewed, or a new facility would need to be constructed and licensed to operate by June 2005. However, DOE is currently in the construction phase for a UF_6 conversion facility on the site of the existing Portsmouth Gaseous Diffusion Plant (uranium enrichment plant) in Portsmouth, Ohio. It is not yet clear exactly when this facility will be operational.

[4] A uranium mill tailings waste disposal facility in South Clive, Utah, is also licensed under the regulation.

5. Uranium Enrichment Facilities

DOE leases uranium enrichment facilities in Paducah, Kentucky, and Portsmouth, Ohio, to the U.S. Enrichment Corp. These facilities are administered under NRC regulations at 10 CFR Part 76. DOE's K-25 enrichment facility in Oak Ridge, Tennessee, has been shut down and is undergoing decommissioning. The Portsmouth plant was shut down in March 2001 and DOE plans to keep the plant in a cold standby basis permitting rapid reopening. Recently, both Louisiana Energy Services (Lea County, New Mexico) and USEC, Inc. (site of the current Portsmouth Gaseous Diffusion Plant) have submitted license applications to the NRC to construct and operate a gas centrifuge uranium enrichment facility. The gas centrifuge uranium enrichment process uses a large number of rotating cylinders in series to enrich uranium in its U-235 isotope. Since DOE has responsibility for decommissioning and dismantling these plants, they are not considered here.

6. Fuel Fabrication Facilities

Fabrication is the final step in the process used to produce uranium fuel. This process converts enriched UF_6 into a solid form of uranium suitable for use in a nuclear reactor. Fabrication of reactor fuel consists of three basic steps: the chemical conversion of UF_6 to uranium dioxide (UO_2) powder; the ceramic process that converts UO_2 powder to pellets; and the mechanical process that loads the fuel pellets into rods and constructs finished fuel assemblies.

There are six uranium fuel fabrication facilities currently licensed to operate by the NRC, plus one in decommissioning and a mixed oxide (MOX) fuel fabrication facility currently under development. An application has been submitted to NRC for authority to construct a MOX facility. The application is under review by the NRC. The reference uranium fuel fabrication facility is based primarily on the Global Nuclear Fuel facility in Wilmington, North Carolina.

7. Independent Spent Fuel Storage Installations (ISFSI)

An ISFSI is a complex designed and constructed for the interim storage of spent nuclear fuel. As of August 2003, there are 28 licensed facilities. In addition, there are 19 soon-to-be-built or operational facilities and a further four being considered in addition to the proposed Private Fuel Storage facility in Tooele, UT. There is also a single wet storage facility in Morris, Illinois, operated by the General Electric Company.

ISFSIs may be initially licensed for a period of up to 20 years. The license may also be renewed for an additional 20 years. Therefore, it is expected that the materials contained in the above ISFSIs would be available for release 20 or 40 years after the ISFSI start-up dates. However, a recent study has determined that extending the storage period to 100 years would have no adverse impacts (Einziger et al. 1998). Conversely, fuel may be removed from storage prior to the end of the licensed lifetime of the ISFSI, if a high-level waste (HLW) repository becomes available. Spent fuel may be stored in either a wet or dry environment; the various techniques include: Concrete Casks, Horizontal Storage Modules (HSM), Metal Casks, Pool (Wet) Storage, and Modular Vault Dry Storage (MVDS).

8. Materials Licensees

The NRC Information Digest (NRC 2002c) indicates a total of 21,175 medical, academic and industrial materials licensees in the United States. Of these, 23 percent are NRC licensees and 77 percent are licensed by Agreement States.

Profiles were prepared of materials licensees potentially affected by the Proposed Action (SC&A 2003). These profiles do not include those licenses that authorize only possession and use of licensed materials in sealed sources or other non-dispersible forms, such as plated disks and foils because for these licensees, operation and decommissioning would normally entail no decontamination efforts. At decommissioning the licensed source would simply be removed from the facility and disposed of in accordance with NRC regulations. Elimination of these types of licensees resulted in a population of 3,017 non-reactor licenses that are potentially affected by the Proposed Action. Based on this understanding of the universe of potentially affected non-reactor, non-sealed source NRC licensees, this section addresses four broad categories of licensees: large medical centers, research and development laboratories, nuclear pharmacies (including both manufacturers and regional and local distributors), and manufacturers of sources and radio-labeled compounds.

Large Medical Centers

The inventory of materials in the reference room of a large medical center is about 2,300 kg (5,000 lb). The total inventory of materials in large medical centers in the U.S. is about 440,000 metric tons (480,000 tons). Much of this mass would be trash (e.g., plaster board, floor tiles) rather than recyclable materials. Items such as refrigerators and storage cabinets could potentially be released for reuse.

Research and Development Laboratories

In many respects, research and development (R&D) laboratories are similar to the research laboratories at large medical facilities. R&D facilities using radioactive materials cover a broad range of activities, including the use of laboratories or health treatment facilities that use radioisotopes. Both short-lived (^{3}H) and long-lived isotopes (^{14}C) may be used. The reference R&D laboratory facility includes rooms for synthesis of labeled compounds and for preparing radioactive samples, a laboratory, a counting room, and a storage room. In addition to the contaminated structural material, the reference R&D facility also contains furniture and equipment.

Nuclear Pharmacies

The NRC issues commercial nuclear pharmacy licenses pursuant to 10 CFR Part 30 and 10 CFR 32.72, for the possession and use of radioactive materials for the manufacture, preparation, or transfer for commercial distribution of radiopharmaceuticals (radioactive drugs) containing byproduct material for medical use under Part 35. Radiopharmaceuticals produced from NORM or accelerator-produced radionuclides are not within the regulatory authority of the NRC, although they may be subject to State licensing requirements. Preparation includes the making of radiopharmaceuticals from reagent kits and from raw materials. Typically, nuclear pharmacies are also authorized to transfer for commercial distribution (per 10 CFR 31.11) in vitro test kits, radiopharmaceuticals to licensees authorized to possess them for other than human medical use (i.e., veterinary medicine and research licensees), and radiochemicals to those licensees authorized to possess them, pursuant to 10 CFR Part 30. Additionally, nuclear pharmacies are authorized to redistribute (transfer) sealed sources for calibration and medical use initially distributed by a manufacturer licensed pursuant to 10 CFR 32.74. The NRC database identifies 52 nuclear pharmacies.

For nuclear pharmacies, decommissioning for license termination will typically involve the removal of all sealed sources and depleted uranium and maintenance of active radiological control of the facility until the longest half-life material used at the facility have decayed to an acceptable level. A confirmatory survey after the appropriate elapsed time would then complete decommissioning efforts. Nuclear pharmacies are not expected to be significant sources of potentially clearable materials for recycle or reuse.

Manufacturers of Sources and Radio-Labeled Compounds

The sealed source manufacturing process is a hand operation that is carried out in buildings which contain a number of small laboratories, each of which is devoted to a specific process and/or isotope. The reference sealed source manufacturer is a laboratory which processes ^{137}Cs and ^{60}Co. Contaminated facilities associated with the reference sealed source manufacturer include: hot cells, fume hoods, workbenches, sinks, laboratory floor and wall areas, and building areas used for storage of waste drums. The Commission's license tracking system identified 63 sealed source and radio-labeled compound manufacturers licensed by the NRC. As is the case for R&D labs, the individual facilities that make up this category are very diverse. Not all facilities within this category manufacture Co-60 sealed sources. Some facilities manufacture radio-labeled compounds and therefore may have more in common with the hospital and R&D laboratories.

9. Complex Materials Decommissioning Sites

Forty-three complex (not routine) materials decommissioning sites are currently being remediated. At many of these locations, the only issue is soil with elevated levels of radioactivity. In addition, building materials and slags will be released during cleanup operations. Some of the slags may be processed for metals recovery.

Inventories of Solid Materials for the Rulemaking Alternatives

This section summarizes the characteristics of solid materials generated largely from commercial nuclear reactor facilities and considered in the collective dose assessment (SC&A 2003). Material characteristics are provided in terms of the total mass (tons) of each material (ferrous metals, concrete, and trash) released from commercial reactor facilities and the total activity (curies) for each alternative. SC&A 2003 describes the detailed information for these inventory estimates.

1. No Action Alternative

The total mass and activity of material generated from commercial nuclear reactor facilities forms the baseline solid material inventory for all the alternatives. Under the No Action Alternative, for example, a total of 2.06 million tons of ferrous metals generated from commercial nuclear reactor facilities would be released for recycling, out of a total estimated amount of scrap ferrous metals generated of approximately 2.5 million tons. The remaining 0.44 million tons of ferrous metals generated from commercial nuclear reactor facilities but not released for recycling would be disposed of as LLW in a licensed disposal facility. Similar calculations apply to the other materials (concrete and trash).

Table F-2 provides an estimate of the total mass and total activity of solid material released from commercial reactor facilities under the No Action Alternative. For the No Action Alternative, the mass of material released is dominated by concrete, which represents approximately 90 percent of the total mass. However, the total activity of the material is represented primarily by the ferrous metals and trash, which represent almost 94 percent of the total activity.

Table F-2 Total Activity and Total Mass of Material Released from Commercial Nuclear Reactor Facilities: No Action Alternative

No Action Alternative	Activity (Ci)	Mass (million tons)
Ferrous metals	1.76	2.06
Concrete	0.24	16.20
Trash	2.32	0.02
Aluminum	0.0008	0.000173
Copper	0.043	0.005326
Total for All Materials	4.36	18.29

Source: SC&A 2003, Tables 5.8, 10.3, 10.4, and 10.7.

2. Unrestricted Release Alternative

Tables F-3 and F-4 provide estimates of the total mass and total activity of solid material released from commercial reactor facilities under the Unrestricted Release Alternative. The values in these tables are based on summations from statistical sampling and mean (average) values are used. Mass and activity values are reported for both material-specific and material-independent cases. The material-specific case applies different radionuclide concentration limits to the different materials for each radionuclide, while the material-independent case applies the same radionuclide concentration limit to all of the materials for each radionuclide.

The material-specific case employs NUREG-1640 (NRC 2003d) normalized doses that are specific to each type of material (i.e., ferrous metals, concrete, and trash) and each radionuclide. This approach derives the maximum radionuclide concentration in each material. For example, the radionuclide concentration for Co-60 for the 1 mrem/yr dose option differs for ferrous metals, concrete, and trash; i.e., the allowable radionuclide concentration at which material could be released for unrestricted release differs depending on the material.

Table F-3 Total Mass (million tons) of Material Released from Commercial Nuclear Reactor Facilities: Unrestricted Release Alternative

	Dose Option				
	0.03 mrem/yr	**0.1 mrem/yr**	**1 mrem/yr**	**10 mrem/yr**	**RS-G-1.7[1]**
Ferrous metals					
Unrestricted/Material-Specific	0.970	1.490	2.20	2.45	
Unrestricted/Material-Independent	0.441	0.786	1.74	2.30	1.74
Concrete					
Unrestricted/Material-Specific	15.0	17.6	19.6	19.8	
Unrestricted/Material-Independent	15.0	17.6	19.6	19.8	19.6
Trash					
Unrestricted/Material-Specific	0.014	0.021	0.041	0.066	
Unrestricted/Material-Independent	0.0002	0.0004	0.002	0.006	0.002
Total for All Materials					
Unrestricted/Material-Specific	16	19.1	21.9	22.3	
Unrestricted/Material-Independent	15.5	18.4	21.4	22.1	21.4

[1] Based on calculations by NRC, the mass of material for the RS-G-1.7 dose option is assumed to be the same as for the 1 mrem/yr dose option.

Source: SC&A 2003, Tables 10.3 and 10.7.

Table F-4 Total Activity (Curies) Released from Commercial Nuclear Reactor Facilities: Unrestricted Release Alternative

	Dose Option				
	0.03 mrem/yr	**0.1 mrem/yr**	**1 mrem/yr**	**10 mrem/yr**	**RS-G-1.7[1]**
Ferrous metals					
Unrestricted/Material-Specific	0.092	0.395	2.86	12.74	
Unrestricted/Material-Independent	0.008	0.048	0.745	4.33	1.49
Concrete					
Unrestricted/Material-Specific	0.168	0.401	1.49	1.73	
Unrestricted/Material-Independent	0.168	0.401	1.49	1.73	2.98
Trash					
Unrestricted/Material-Specific	0.588	2.56	36.79	523.81	
Unrestricted/Material-Independent	0.00001	0.00005	0.0015	0.043	0.003
Total for All Materials					
Unrestricted/Material-Specific	0.865	3.40	41.32	538.60	
Unrestricted/Material-Independent	0.194	0.497	2.43	6.42	4.86

[1] Based on calculations by NRC, the total activity release for the RS-G-1.7 material-independent scenario is assumed to be two times that of the total activity released for the 1 mrem/yr dose option.

Source: SC&A 2003, Tables 5.8 and 10.7.

For the material-independent case, the most limiting normalized doses in NUREG-1640 are used to define the radionuclide concentration level and, as a result, the levels that correspond to a given radionuclide are the same for all materials. For example, the presence of Co-60 in concrete (used in road building) results in the most limiting dose factor as compared to the presence of Co-60 in ferrous metals, copper, or aluminum. The material-independent case is thus more restrictive than the material-specific case and the quantity of material and the collective radiation doses to the members of the public are lower for the material-independent case. More details can be found in Appendix D for both cases - material-specific results (Case A) and material-independent results (Case B) (see Tables D-1 to D-3).

For the Unrestricted Release Alternative using a material-specific case, as for the No Action Alternative, the mass of material released is dominated by concrete, which represents approximately 90 percent of the total mass. The total activity of the material is represented primarily by the ferrous metals and trash, which represent approximately 95 percent of the total activity, for the 1 mrem/year dose option.

Using a material-independent case, concrete is the limiting material for radionuclide concentrations and the total mass of ferrous metals and the total mass and activity of trash released are lower than amounts that would be released under material-specific conditions. Using a material-independent case, the ferrous metals and concrete released represent greater than 99 percent of the activity, and trash represents less than 0.1 percent of the activity.

3. EPA/State-Regulated Disposal Alternative

Tables F-5 and F-6 provide estimates of the total mass and total curies of solid material released from commercial nuclear reactor facilities under the EPA/State-Regulated Disposal Alternative. The values in these tables are based on summations from statistical sampling and mean (average) values are used. For the EPA/State-Regulated Disposal Alternative without trash incineration, as for the No Action Alternative and Unrestricted Release Alternative, the mass of material released is dominated by concrete, which represents 93 percent of the total mass. The total activity of the material released is represented primarily by the ferrous metals and trash, which represent almost 95 percent of the total activity, for the 1 mrem/year dose option. The mass and activity released for the EPA/State-Regulated Disposal Alternative with and without trash incineration are assumed to be the same.

4. Low-Level Waste (LLW) Disposal Alternative

Under the LLW Disposal Alternative, none of the potentially clearable solid material would be released for either unrestricted use or EPA/State-regulated disposal. All of the material would be classified as LLW and would be transported to and disposed of in a LLW disposal facility. The total mass and activity of material that would be disposed of in LLW disposal facilities under this Alternative is summarized in Table F-7.

Table F-5 Total Activity (Curies) Released from Commercial Nuclear Reactor Facilities: EPA/State-Regulated Disposal Alternative

	Dose Option				
	0.03 mrem/yr	0.1 mrem/yr	1 mrem/yr	10 mrem/yr	RS-G-1.7[1]
Ferrous metals	0.484	1.46	7.09	23.81	14.18
Concrete	0.201	0.460	1.67	1.73	3.34
Trash	0.588	2.56	36.79	523.81	73.58
Total for All Materials	1.29	4.53	45.74	549.67	91.48

[1] Based on calculations by NRC, the total activity release for the RS-G-1.7 material-independent scenario is assumed to be two times that of the total activity released for the 1 mrem/yr dose option.

Source: SC&A 2003, Tables 5.8 and 10.4.

Table F-6 Total Mass (million tons) of Material Released from Commercial Nuclear Reactor Facilities: EPA/State-Regulated Disposal Alternative

	Dose Option				
	0.03 mrem/yr	0.1 mrem/yr	1 mrem/yr	10 mrem/yr	RS-G-1.7[1]
Ferrous metals	1.57	2.00	2.38	2.48	2.38
Concrete	15.6	17.9	19.7	19.8	19.7
Trash	0.014	0.021	0.041	0.066	0.041
Total for All Materials	17.2	19.9	21.2	22.3	21.2

[1] Based on calculations by NRC, the mass of material for the RS-G-1.7 dose option is assumed to be the same as for the 1 mrem/yr dose option.

Source: SC&A 2003, Tables 10.3 and 10.7.

Table F-7 Mass and Radioactivity of Materials Released from Commercial Nuclear Reactor Facilities: LLW Disposal Alternative

Material	Total Mass (tons)	Contained Radioactivity (Ci)
D&D Ferrous metals	2,117,906	11
D&D Ferrous metals (Decon)	285,212	284
Operating Ferrous metals	95,793	95.3
Total Ferrous metals	2,498,911	390.3
D&D Concrete	19,877,341	1.74
Trash	323,023	2,560
Aluminum	212	0.006
Copper	6,584	0.31
Total	22,706,071	2,951

Source: SC&A 2003, Tables 5.8, 8.6, and 10.3.

5. Limited Dispositions Alternative

The mass and activity of concrete recycled under the Limited Dispositions Alternative would be the same as for the Unrestricted Release Alternative. The mass and activity of other disposed materials would be the same as for the EPA/State-Regulated Disposal Alternative.

Characterization of Solid Materials Generated from Licensed Facilities Other than Commercial Reactors

The mass and activity values described above and the collective dose results are based on material generated only from commercial nuclear reactor facilities. This is because smaller amounts of solid materials would be generated from licensed facilities other than commercial nuclear reactor facilities and released for either recycling or disposal. Trash is the significant material for these other licensed facilities and, therefore, ferrous metals and concrete are not included here. Table F-8 provides a summary of the total estimated mass and activity of trash generated from licensed facilities other than commercial nuclear reactor facilities for the No Action and Unrestricted Release Alternatives.

Table F-8 Comparison of Mass and Activity of Trash Released from Commercial Nuclear Reactor Facilities with Trash Generated from Other Licensed Facilities

Alternative and Dose Option	Total Activity Released (Ci)			Total Mass Released (million t)		
	Nuclear reactors	Other licensees	Total	Nuclear reactors	Other licensees	Total
No Action	2.32	0.976	3.296	0.02	0.273	0.293
Unrestricted Release						
RS-G-1.7	73.6	30.8	104.4	0.041	0.549	0.59
10 mrem/yr	524	220	744	0.066	0.886	0.952
1 mrem/yr	36.8	15.4	52.2	0.041	0.549	0.59
0.1 mrem/yr	2.56	1.08	3.64	0.021	0.282	0.303
0.03 mrem/yr	0.588	0.247	0.835	0.014	0.183	0.197

Source: SC&A 2003, Table 5.6.

APPENDIX G
HUMAN HEALTH AND SAFETY - SUPPLEMENTAL INFORMATION CHARACTERIZING GENERAL PUBLIC AND FACILITY WORKER GROUPS

Introduction

This Appendix describes the affected General Public and Non-Licensed Facility Worker groups and the radiological impact assessment methodology used for the collective dose assessment for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Disposition Alternatives. This includes a description of the characteristics of each affected group and the assumed dispositions of each solid material under each Alternative upon which the collective dose assessment for each Alternative and solid material is based.

1. No Action, Unrestricted Release, and Limited Dispositions Alternatives

General Public

<u>Concrete</u>

The only end use of recycled concrete that is analyzed in this Draft GEIS is its use for road construction. The affected General Public groups for the No Action, Unrestricted Release, and Limited Dispositions Alternatives were identified for this end use and potential collective dose was estimated based on driving on roads containing recycled material. Road bed construction was selected as the single end use based on research conducted into the disposition of recycled concrete in commerce. Approximately 85 percent of recycled concrete rubble is used in road construction. The use of concrete rubble is limited because reclaimed concrete is not pure Portland concrete, but rather a mixture of concrete, soil, some amounts of bituminous concrete, and other small debris generated during demolition. The use of concrete with more than 15 percent reclaimed concrete has lead to problems in meeting quality specifications, resulting in its difficult use and workability. Besides road construction, reclaimed concrete is being used in bulk fill applications on land and water, as riprap for shoreline protection, as trench backfill, as a mix in asphaltic concrete, and in revetments for fieldwork and mining. It is expected that such uses would result in much lower exposures and collective doses as compared to the construction and use of road bed made with reclaimed concrete. No general usage of this recycled material as an aggregate for concrete used in building construction was identified in the course of the research conducted for the Draft GEIS.

The selection of road bed construction as the single end use for recycled concrete analyzed in the Draft GEIS is based on research conducted into the disposition of recycled concrete in commerce. USGS reported that in 1997 68 percent of concrete rubble that is recycled was used directly for road base construction, and reported that recycled concrete rubble is also used in new concrete mixes (6 percent), general fill and related “low value” applications (7 percent), asphalt hot mixes (9 percent), “high value” rip rap aggregate (3 percent) and other unclassified applications (7 percent) [USGS 2000a; USGS 1998a]. USGS allocated these applications into three general categories for the purposes of developing a material flow analysis: road base and other related applications; bituminous concrete; and cement concrete.

While recycled concrete is used to a limited extent as an aggregate in portland cement concrete for highway construction, no general usage of this recycled material as an aggregate for concrete used in building construction was identified. A representative of Southern Crushed Concrete Inc.—a company that recycles concrete—knew of no use of recycled concrete as aggregate in new concrete mixes for buildings. He believed that recycled aggregate was not used in buildings because of structural concerns as compared to concrete with virgin aggregate. The company had been involved in a highway project in Texas, where 30 percent of the virgin aggregate was replaced with aggregate from recycled concrete (Miller 2001). The view that reclaimed concrete was not used as an aggregate in concrete used to construct buildings was confirmed by an official of the Construction Materials Recycling Association (Turley 2002). Therefore analysis of recycling of concrete to make building material is not included in the Draft GEIS.

General Public exposure pathways for use of the concrete rubble for road construction include direct radiation exposure to drivers on roads built using recycled concrete and exposure to surface water/drinking water affected by leachate from landfill disposal of concrete dust generated by concrete recycling activities. Drivers on roads built using recycled concrete would be exposed to direct radiation from the radionuclide content of the material, but would not be exposed through inhalation or ingestion. Persons in the vicinity of landfills where concrete dust generated by concrete recycling activities was disposed of would be exposed through ingestion of surface water or drinking water affected by leachate from landfill concrete dust disposal, however, these exposure pathways are not included in the collective dose assessment because it is assumed that 100 percent of the activity in the released concrete is contained in the recycled material used for road bed, and this single exposure pathway would result in a higher collective dose than dividing the activity among multiple pathways. General Public exposure parameters for the No Action Alternative, Unrestricted Release Alternative, and Limited Dispositions Alternative for concrete are listed in Table G-1.

Table G-1 Concrete End Use General Public Exposure Parameters

No Action Alternative, Unrestricted Use Alternative, and Limited Dispositions Alternative	Product mass (t)	Mass of material (t)	Fraction of material (%)	Occupancy	Exposure Duration (person-h/y)	
					Individual	Integrated
Driving on road made from RCM[a]	—	385	38.5	—	—	2,154

a - Recycled concrete material
Source: NUREG-1640 (NRC 2003d).

Ferrous Metal

The affected General Public groups for the No Action and Unrestricted Release Alternatives for ferrous metal are based on the anticipated end uses for recycled ferrous metal. General Public exposure pathways for the collective dose assessment are limited to direct radiation exposure from use of end use products containing recycled ferrous metal and use of byproducts (e.g., furnace slag cement) generated by recycling processes. Recycling of scrap ferrous metal could also result in General Public radionuclide exposure through air emissions and surface water and groundwater discharges from generation and handling of scrap ferrous metal at the licensed facility site, recycling of the scrap ferrous metal into finished recycled ferrous metal, processing of the finished ferrous metal into end use products (e.g., automobiles, home appliances, building materials), and processing and landfill disposal of wastes (e.g., EAF baghouse dust) generated by ferrous metal recycling processes. General Public exposure parameters are listed in Table G-2. The affected General Public groups for disposal of ferrous metal under the Limited Dispositions Alternative are discussed under the EPA/State-Regulated Disposal Alternative.

Table G-2 Ferrous Metal End Uses and General Public Exposure Parameters

No Action Alternative and Unrestricted Release Alternative	Product mass (t)	Mass of material (t)	Fraction of material (%)	Occupancy	Exposure Duration (person-h/y)	
					Individual	Integrated
Driving on slag road	—	35.8	30.6	—	—	125
Slag cement basement	61.2	4.5	3.0	1.78	4,200	430
Occupying automobile	0.927	253	28.1	1.59	351	153,000
Office building	7.18	427	47.4	16	2,000	1,900,000
Office furniture	0.544	9	1.0	3	2,000	99,200
Home appliances	0.288	93.6	10.4	1.78	633	464,000
Sleeping on bed	0.037	11.4	0.8	1.78	3,180	1,100,000
Sailor—operations	17,900	9	0.6	447	—	—
Sailor—deck duty	17,900	9	0.6	200	—	—

Source: NUREG-1640 (NRC 2003d)

The selection of specific end uses of recycled ferrous metal for analysis in the Draft GEIS is based on research into the disposition of recycled ferrous metal in commerce. The dose assessment calculations are based on the percentages of finished recycled ferrous metal that is used in various end uses. The total mass and activity of recycled ferrous metal generated from licensed facilities under the No Action and Unrestricted Release Alternatives is distributed amongst the various end uses for the purposes of the dose assessment. The percentages of finished ferrous metal used in various end uses is based on analysis of data on steel end-use markets obtained from the 2001 American Iron and Steel Institute (AISI) report AIS 16, “Shipments of Steel Products by Market Classification” (AISI, 2001). The AIS 16 report data, as reported and applied for the purposes of the collective dose assessment, are summarized in Table G-3.

The AIS 16 report provides a breakdown of the categories and subcategories of end use products and applications in which finished steel was used in 2001. The AIS 16 report data indicate that the construction and automotive sectors are responsible for over two-thirds of total domestic steel consumption. The subcategory data for the automotive category indicate that the majority of the steel is used in “vehicles, parts and accessories,” therefore “Automobile Users” was selected as the representative “affected environment” for this end use category. The Automobile User end use encompasses the Shipbuilding and Aircraft categories and the “passenger car” Rail Transportation sub-categories, as these are also transportation-related categories. This resulted in the steel consumption percentage for the Automobile User end use increasing from 14.2 percent to 28.1 percent, as shown in Table G-3.

Table G-3 Steel Mass/Activity Distribution

Category		AIS 16 Data	Adjusted Percentage	End Use
1	Steel for converting and processing	10.4%	—	—
2	Forgings (NEC)	0.7%	—	—
3	Industrial fasteners	0.4%	0.7%	Building
4	Steel service centers & distributors	27.4%	—	—
5	Construction & contractors' products	21.8%	43.1%	Building
7[a]	Automotive	14.2%	28.1%	Automobile
8	Rail transportation	1.0%	2.0%	Rails, Freight Railcars[b,d]
9	Shipbuilding and marine equipment	0.3%	0.6%	Automobile
10	Aircraft & aerospace	0.0%	0.0%	Automobile
11	Oil & gas industry	3.0%	5.9%	Equipment [d]
12	Mining, quarrying, and lumbering	0.2%	0.3%	Equipment [d]
13	Agriculture	0.7%	1.3%	Building
14	Machinery, industrial equipment & tools	1.5%	2.9%	Building
15	Electrical equipment	1.7%	3.4%	Equipment [d]
16	Appliances, utensils, & cutlery	1.8%	3.6%	Miscellaneous
17	Other domestic and commercial equipment	0.7%	1.5%	Miscellaneous
18	Containers, packaging and shipping equipment	3.3%	6.5%	Miscellaneous[c]
19	Ordnance & other military	0.0%	0.1%	Equipment [d]
20	Export	2.6%	—	—
	Non-classified Shipments	8.4%	—	—
	Total	100.0%	100.0%	—

[a] AIS 16 does not contain a category 6.
[b] Except for the "Passenger Rail Car" subcategory, which is allocated to the "Automobile" Category
[c] Except for the "Compressed Gas Cylinders" subcategory, which is assumed to have No General Public Dose
[d] There is No General Public Dose associated with equipment

Source: AISI 2001.

The subcategory data for the construction category do not specify which subcategories of construction used the majority of steel, only that the steel was used in "general construction." Therefore, "Office Workers" was selected to be the representative "affected environment" for the construction category. Office Workers would typically spend approximately one fourth of their time within the office building. Other general construction projects (e.g., bridges) would have few, if any, people in the vicinity for any length of time. The Office Worker end use encompasses other work place-related categories, including Industrial Fasteners, Agriculture, and Machinery. This resulted in the steel consumption percentage for the Office Worker end use increasing from 43.1 percent to 48.0 percent.

Several categories included in the AIS 16 report data involve utilization of steel in end use locations that are essentially removed from contact with the general public. Examples include “Oil & Gas Industry”, ‘Mining”, ‘Electrical Equipment” (e.g., transmission towers), Rail Transportation (subcategories other than passenger rail cars), and Containers (compressed gas cylinder subcategory). These categories are assumed to have no significant potential for public exposure.

The remaining end use categories in the AIS 16 report are Appliances, Utensils, and Cutlery; Other Domestic and Commercial Equipment; and Containers, Packaging and Shipping Equipment. Three end use scenarios have been selected to represent these three categories. The Appliances, Utensils, and Cutlery category is represented by Home Appliances, specifically use of domestic kitchen ranges, dishwashers, and refrigerators manufactured from recycled steel scrap in a residential kitchen. This end use was selected for analysis because a kitchen range, dishwasher, and refrigerator collectively contain a large amount of steel (as opposed to kitchen utensils, cookware, and cutlery) and the primary exposure pathway from steel is direct radiation exposure, not leaching of radionuclides from the steel article into prepared food (USGS 2000a), and also because persons in a residential location spend a significant amount of their time at home in the kitchen.

The Other Domestic and Commercial Equipment category is represented by two subcategories - Domestic Beds and Office Furniture. The Domestic Beds end use includes a bed frame, box spring, and mattress, manufactured from recycled steel and used in a residential bedroom. This end use was selected for analysis because persons in a residential location would spend approximately one third (8 hours) of their time sleeping. The Office Furniture end use includes office desks and cabinets manufactured from recycled steel scrap and used in a typical office environment. This end use was selected for analysis because typical office workers would spend approximately one-fourth of their time at work, and office furniture contains a significant amount of steel. The percentage of steel utilization from these three AIS 16 report categories (including the amount of steel reported in the Containers, Packaging and Shipping Equipment category, other than the compressed gas cylinder subcategory) was apportioned to the three end uses selected for analysis based upon the actual amount of steel used in bed and office furniture production, as reported in the subcategory data, with the remainder of the steel consumption being allocated to the home appliances end use, which is not reported as a separate subcategory in the AIS 16 report.

The end uses selected for analysis, along with the fraction of activity (i.e., steel) allocated to each end use, are shown in Table G-4. This Draft GEIS has not attempted to categorize every potential end use of recycled ferrous metal, because the number of end uses is too diverse to

Table G-4 Final Ferrous metal Mass/Activity Distribution

End Use	Fraction	Tons (2001)
Building	48.0%	46,290,974
Automobile	28.8%	27,777,647
Miscellaneous	11.4%	10,990,447
Home Appliances	9.6%	9,233,301
Bed Springs	0.8%	754,650
Office Furniture	1.0%	1,002,496
Negligible dose to general public [1]	11.8%	11,345,338
Total	100.0%	96,404,406

facilitate a collective dose analysis. The end uses are intentionally categorized into broad categories that represent the most common uses of recycled scrap ferrous metal and a reasonable estimate of the resultant collective dose exposures associated with those end uses.

Recycling of scrap ferrous metal involves smelting operations and other processes that generate airborne emissions, including particulate emissions from ferrous metal recycling furnace air emissions control equipment. The collective dose assessment includes transport of radionuclides that are not removed from the furnace gas by the air emissions control equipment and that are emitted to the atmosphere. These particulate radionuclides are assumed to deposit on the ground in the vicinity of the steel mill and result in exposure through both inhalation of the particulate and direct radiation from radionuclides deposited on the ground. Deposited radionuclides also result in General Public exposure through uptake of radionuclides from the soil into food, including meat, milk, and vegetables.

Recycling furnace operations also generate Electric Arc Furnace (EAF) baghouse dust and furnace slag waste products. Furnace slag may either be disposed of in landfills or used to make furnace slag cement. Furnace slag cement is typically used in road building and building construction, and drivers on roads built using furnace slag cement and occupants of buildings built using furnace slag cement would be exposed to direct radiation from the radionuclide content of the material. The exposure pathway for drivers on roads built using furnace slag cement is similar to the exposure pathway for drivers on roads built using recycled concrete.

Furnace slag, if not recycled into end use products, is typically disposed of in Subtitle D landfills, while EAF baghouse dust may be disposed of either in Subtitle D landfills or Subtitle C landfills, depending upon whether the EAF baghouse dust is treated prior to disposal. The landfill disposal of furnace slag and EAF baghouse dust generated from ferrous metal recycling processes could contribute radionuclides to leachate generated from the landfills in which those materials are

[1] Does not include disposal.

disposed. Migration of leachate to persons in the vicinity of landfills represents public exposure pathways for ferrous metal recycling.

Transportation of scrap ferrous metal from the points of generation to the ferrous metal recycling facilities, and transportation of finished ferrous metal and associated waste materials from the recycling facilities to the point of end use or disposal has the potential to expose persons along the transportation routes to direct radiation from the radionuclide content of the materials. Transportation of end use products also has the potential to expose persons to direct radiation. General Public exposure to direct radiation along material transportation routes represent public exposure pathways for ferrous metal recycling.

Aluminum

As discussed above, the overall collective dose associated with released aluminum for the No Action and Unrestricted Release Alternatives, including both Non-Licensed Facility Workers and the General Public is evaluated for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives using a screening model, because the collective dose associated with the small amount of aluminum generated would be minimal as compared to the collective dose associated with ferrous metal.

Copper

As discussed above, the overall collective dose associated with released copper, including both Non-Licensed Facility Workers and the General Public is evaluated for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives using a screening model, because the collective dose associated with the small amount of copper generated would be minimal as compared to the collective dose associated with ferrous metal.

Trash

The affected General Public groups for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives for trash are based on the anticipated transportation to and disposal of trash in an EPA/State-regulated Subtitle D landfill. The radionuclide transport and exposure pathways for Subtitle D landfill disposal of trash are the same as for Subtitle D landfill disposal of concrete, ferrous metal, aluminum, and copper, described above, and include surface water and groundwater transport pathways. The collective dose from the incineration of trash is not assessed under the No Action Alternative, Unrestricted Release Alternative, and Limited Dispositions Alternative, but is assessed under the EPA/State-Regulated Disposal Alternative discussed below.

Non-Licensed Facility Workers

These workers are members of the public who may experience work-related exposure while handling or otherwise encountering released material at their place of employment. Examples of these individuals include workers in scrap yards, iron and steel mills, EPA/State-regulated landfills, and EPA/State-regulated incinerators; truck drivers transporting released material; and building and road construction workers utilizing released material or byproducts of processing released material. Truck drivers transporting LLW to LLW disposal facilities are not workers situated at licensed facilities and are therefore categorized for the purposes of the Draft GEIS as Non-Licensed Facility Workers.

Concrete

Non-Licensed Facility Worker activities and groups of affected workers for the No Action, Unrestricted Release, and Limited Dispositions Alternatives for concrete are based on a single end use for recycled concrete, use as road building material. Non-Licensed Facility Worker activities include processing of the concrete rubble into road building material at satellite facilities, transportation of concrete rubble, and application of the road building material. Disposal of concrete dust generated from concrete recycling activities and transportation of wastes generated from processing and road building activities are not included in the collective dose assessment. The amount of concrete dust that can become airborne depends mainly on its moisture content, physical properties, and engineered measures used to minimize such releases. The analysis assumed that the amounts of materials released via fugitive emissions are small, such releases are short-lived in duration, and long-term exposures associated with end uses are dominant in terms of collective doses. One hundred percent of the activity in the concrete is assumed to contribute to the collective dose through its end use application. Non-Licensed Facility Worker activities and parameters for concrete are listed in Tables G-5 and G-6.

Table G-5 Non-Licensed Facility Workers Activity Characteristics - Concrete

No Action Alternative, Unrestricted Release Alternative, and Limited Disposition Alternative	Fraction of material (%)	Nominal productivity (t/y)	Work year (h/y)	Work hours per kt of material
Process Activities				
Processing concrete rubble at satellite facility	100	42,525	1,500	29.4
Building road using recycled concrete	50	22,250	1,500	19.5

a Anigstein et al. 2001, Chapter 5
b Tons of scrap consumed by EAF per worker per year
Source: NUREG-1640 (NRC 2003d)

Table G-6 Non-Licensed Facility Workers Activity Characteristics - Concrete

No Action Alternative, Unrestricted Release Alternative, and Limited Disposition Alternative	Distance (mi)	Speed (mph)	Fraction of material (%)	Total mass of material (t)	Work hours per kt of material
Transportation Activities					
Truck driver hauling concrete rubble	231	50	100	1,000	231

a Average duration of trip = 1¼ h
b Based on 58 percent of ferrous metal scrap being consumed by EAF mills and assuming that the dust is evenly divided between the two representative types of truck trailers
c Comprises 4.40 h driving, 3.74 h sleeping in berth, 0.08 h standing by during loading and unloading

Source: NUREG-1640 (NRC 2003d)

Materials Recycling Association (Turley 2002). Therefore analysis of recycling of concrete to make building material is not included in the Draft GEIS.

Ferrous Metal

Non-Licensed Facility Worker activities and groups of affected workers for the No Action and Unrestricted Release Alternatives for ferrous metal are based on the anticipated end uses for recycled ferrous metal and the anticipated processes that would be used in recycling ferrous metal. Non-Licensed Facility Worker activities for ferrous metal include activities associated with transporting the ferrous metal scrap to recycling facilities, recycling of the scrap into finished recycled ferrous metal, processing of the finished ferrous metal into end use products (e.g., automobiles, home appliances, building materials), installation of end use products (e.g., building materials), processing and disposal of wastes (e.g., EAF baghouse dust) generated by recycling processes, processing and use of byproducts (e.g., furnace slag) generated by recycling processes, and transportation of the materials, byproducts, and wastes generated from these activities. Non-Licensed Facility Worker activities and parameters for ferrous metal are listed in Tables G-7 and G-8. The affected Non-Licensed Facility Worker groups for disposal of ferrous metal under the Limited Dispositions Alternative are discussed under the EPA/State-Regulated Disposal Alternative.

Aluminum and Copper

Inventory information on other metals, besides ferrous, indicated these were primarily copper or aluminum, and present in insignificant amounts as compared to ferrous metals. Non Licensed Facility Worker activities for aluminum and copper that would contribute to the collective dose are similar to those for ferrous metal. NUREG-1640 considers dose factors for both copper and aluminum for individual dose estimating purposes. However, regarding collective dose, the detailed results were developed for ferrous metal and the small amounts of copper and aluminum inventory were evaluated using a scoping analysis. A detailed dose assessment was not

Table G-7 Non-Licensed Facility Worker Activity Characteristics – Ferrous metal

No Action Alternative and Unrestricted Release Alternative	Fraction of material (%)	Nominal productivity (t/y)	Work year (h/y)	Work hours per kt of material
Process Activities				
Processing steel scrap at scrap yard	100	1,568–1,950	1,500	323
Handling slag at steel mill	100	400[b]	1,000	200
Handling metal product at steel mill or foundry	100	400[b]	1,500	300
Crane operator (at EAF mill)[a]	100	400[b]	1,750	350
EAF furnace operator[a]	100	400[b]	1,750	350
Operator of continuous caster (at EAF mill)[a]	100	400[b]	1,750	350
Transferring EAF dust at steel mill	58	—	—	0.324
EAF Baghouse maintenance	58	—	27.5	0.024
Processing EAF dust	58	4,990	1,000	1.73
Processing steel slag for road construction	30.6	6,111	1,000	5.86
Handling BOF/foundry dust at landfill	42	4,067	1,500	1.57
Handling slag at landfill	61.5	4,067	1,500	26.6
Handling EAF dust at landfill	58	4,067	1,500	1.29
Building road using steel slag	30.6	35,328	2,000	2.02

a Anigstein et al. 2001, Chapter 5
b Tons of scrap consumed by EAF per worker per year
Source: NUREG-1640 (NRC 2003d)

Table G-8 Non-Licensed Facility Workers Activity Characteristics - Ferrous metal

No Action Alternative and Unrestricted Release Alternative	Distance (mi)	Speed (mph)	Fraction of material (%)	Total mass of material (t)	Work hours per kt of material
Transportation Activities					
Truck driver hauling steel scrap	[a]		100	1,000	62.5
Truck driver hauling slag	60	45	100	117	10
Truck driver hauling EAF dust in dry bulk trailer	1,022	50	29[b]	4.31	4.4
Truck driver hauling EAF dust in dump trailer	1,022	50	29[b]	4.31	8.22[c]
Truck driver hauling steel products	276	50	100	900	248

a Average duration of trip = 1¼ h (as reported in NUREG-1640 (NRC 2003d).
b Based on 58 percent of steel scrap being consumed by EAF mills and assuming that the dust is evenly divided between the two representative types of truck trailers
c Comprises 4.40 h driving, 3.74 h sleeping in berth, 0.08 h standing by during loading and unloading
Source: NUREG-1640 (NRC 2003d)

performed for aluminum and copper because of the small amount of aluminum and copper generated compared to ferrous metal. The results indicate that collective dose for copper and aluminum are about one to two orders of magnitude lower than that of ferrous metals for all alternatives.

Trash

Non-Licensed Facility Worker activities for trash for the No Action, Unrestricted Release, and Limited Dispositions Alternatives include truck drivers transporting trash to EPA/State-regulated disposal facilities and the EPA/State-regulated disposal facility workers that dispose of the trash at the facility. There are no end uses for trash other than EPA/State-regulated disposal considered in the Draft GEIS, and therefore Non-Licensed Facility Worker activities for trash are similar to those described below for trash for the EPA/State-Regulated Disposal Alternative. NRC has assumed that trash generated from licensee facilities will not be reused in commerce and will not be recycled into commerce. Sorting and handling of the trash may be conducted prior to transportation and disposal. The exposure parameters for these activities are anticipated to be similar to the activities conducted by survey workers for trash and result in similar exposure to Non-Licensed Facility Workers as for Licensed-Facility Workers.

2. EPA/State-Regulated Disposal Alternative

Non Licensed Facility Workers

Concrete

Non-Licensed Facility Worker activities and groups of affected workers for the EPA/State-Regulated Disposal Alternative for concrete are based on the activities associated with processing and transportation and disposal of concrete in a EPA/State-regulated Subtitle D landfill. These include activities associated with processing concrete rubble at satellite facilities, transportation of the concrete rubble to the landfill, and unloading and disposal of the concrete rubble by landfill workers. Non-Licensed Facility Worker activities and parameters for the EPA/State-Regulated Disposal Alternative for concrete are listed in Tables G-9 and G-10.

Ferrous metal

Non-Licensed Facility Worker activities and groups of affected workers for the EPA/State-Regulated Disposal Alternative, and also the Limited Dispositions Alternative, for ferrous metal are based on the activities associated with transportation and disposal of ferrous metal scrap in a EPA/State-regulated Subtitle D landfill. These include activities associated with transportation of the ferrous metal scrap to the landfill, and unloading and disposal of the ferrous metal scrap by landfill workers. Non-Licensed Facility Worker activities and parameters for the EPA/State-Regulated Disposal Alternative and Limited Dispositions Alternative for ferrous metal are listed in Tables G-11 and G-12.

Table G-9 Non-Licensed Facility Worker Activity Characteristics – Concrete

EPA/State-Regulated Disposal Alternative	Fraction of material (%)	Nominal productivity (t/y)	Work year (h/y)	Work hours per kt of material
Process Activities				
Processing concrete rubble at satellite facility	100	42,525	1,500	29.4
Handling concrete rubble at landfill	50	4,067	1,500	184

a Anigstein et al. 2001, Chapter 5
Source: NUREG-1640 (NRC 2003d)

Table G-10 Non-Licensed Facility Worker Activity Characteristics – Concrete

EPA/State-Regulated Disposal Alternative	Distance (mi)	Speed (mph)	Fraction of material (%)	Total mass of material (t)	Work hours per kt of material
Transportation Activities					
Truck driver hauling concrete rubble	231	50	100	1,000	231

Source: NUREG-1640 (NRC 2003d)

Table G-11 Non-Licensed Facility Worker Activity Characteristics – Ferrous metal

EPA/State-Regulated Disposal Alternative and Limited Dispositions Alternative	Fraction of material (%)	Nominal productivity (t/y)	Work year (h/y)	Work hours per kt of material
Process Activities				
Handling ferrous metal scrap at a Subtitle D landfill	100	4,067	1,500	368

a Anigstein et al. 2001, Chapter 5
Source: NUREG-1640 (NRC 2003d)

Table G-12 Non-Licensed Facility Worker Activity Characteristics – Ferrous metal

EPA/State-Regulated Disposal Alternative and Limited Dispositions Alternative	Distance (mi)	Speed (mph)	Fraction of material (%)	Total mass of material (t)	Work hours per kt of material
Truck driver hauling ferrous metal scrap	[a]		100	1,000	62.5

a Average duration of trip = 1¼ h (as reported in NUREG-1640 (NRC 2003d).
Source: NUREG-1640 (NRC 2003d)

<u>Aluminum and Copper</u>

As discussed above, the overall collective dose associated with released aluminum and copper for both Non-Licensed Facility Workers and the General Public is evaluated for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives using a screening model because the collective dose associated with the small amount of aluminum and copper generated would be minimal as compared to the collective dose associated with ferrous metal.

<u>Trash</u>

Non-Licensed Facility Worker activities and groups of affected workers for the EPA/State-Regulated Disposal Alternative for trash are based on the activities associated with transportation and disposal of trash in an EPA/State-regulated Subtitle D landfill and also with processing of trash in an EPA/State-regulated incinerator and subsequent disposal of incinerator ash in an EPA/State-regulated Subtitle D landfill. These include activities associated with transportation of trash to the landfill and unloading and disposal of the trash by landfill workers, and transportation of trash to the incinerator, processing of the trash in the incinerator, and disposal of the incinerator ash by landfill workers.

The collective dose assessment for trash for Non-Licensed Facility Workers accounts for work activities involving truck drivers hauling trash, trash disposal in a landfill, trash incineration and ash disposal in a landfill, and a crane operator loading trash into an incinerator.

Based on light water reactor (LWR) industry practices, separate waste streams for various types of scrap metals (e.g., plastic, wood, glass, etc.) are not considered for recycling. First, these materials may be thrown into a trash bin for disposal in landfills and not sorted out as is done for residential trash and recyclables. Secondly, the composition of LWR trash primarily (90 percent), in decreasing order, consists of plastics that are not of recyclable grades, paper, PVC, cloth, rubber, absorbent materials, and wood. Consequently, no analysis was made for separate types of trash. Only the composite category defined as “trash” was considered and analyzed for landfill disposal and incineration.

General Public

Potential exposure of the General Public associated with the EPA/State-Regulated Disposal Alternative for trash includes both disposal of the trash in Subtitle D landfills and disposal of the trash by incineration in EPA/State-regulated incinerators, and subsequent disposal of the incinerator ash in an EPA/State-regulated landfill.

Concrete

General Public exposure parameters for the EPA/State-Regulated Disposal Alternative for concrete is based on the radionuclide transport pathways associated with disposal of this material in an EPA/State-regulated Subtitle D landfill. NRC has assumed that concrete is not incinerable and that all EPA/State-regulated disposal of concrete would be to Subtitle D landfills. Radionuclide transport pathways associated with Subtitle D landfill disposal include groundwater and surface water transport pathways by which radionuclides could be transported from the landfill to the General Public. Processing of concrete, transportation of the concrete rubble to the landfill, and unloading of the concrete rubble by landfill workers have the potential to create fugitive dust emissions, however, these potential transport pathways are not evaluated in the collective dose assessment. The collective dose assessment is based on the assumption that one hundred percent of the activity associated with the released concrete transported to the General Public is transported through groundwater and surface water transport pathways and subsequently to drinking water and irrigation water. The collective dose assessment is based on exposure of the General Public through consumption of drinking water and consumption of food, including meat, milk, and vegetables, grown with irrigation water. This assumption provides for a higher collective dose than would partitioning the transport between the groundwater and surface water transport pathways and the air (fugitive dust) pathway.

Ferrous Metal, Aluminum, and Copper

General Public exposure parameters for the EPA/State-Regulated Disposal Alternative and the Limited Dispositions Alternatives for ferrous metal, aluminum, and copper are based on the radionuclide transport pathways associated with disposal of these materials in a EPA/State-regulated Subtitle D landfill. NRC has assumed that these solid materials are not incinerable and that all EPA/State-regulated disposal of these materials under the EPA/State-Regulated Disposal Alternative and the Limited Dispositions Alternative would be to Subtitle D landfills. Radionuclide transport pathways associated with Subtitle D landfill disposal include groundwater and surface water transport pathways by which radionuclides could be transported from the landfill to the General Public. The collective dose assessment is based on exposure of the General Public through consumption of drinking water and consumption of food, including meat, milk, and vegetables, grown with irrigation water. This assumption provides for a higher collective dose than would partitioning the transport between the groundwater and surface water transport pathways and the air (fugitive dust) pathway.

Trash

The radionuclide transport and exposure pathways for Subtitle D landfill disposal of trash are the same as for Subtitle D landfill disposal of concrete, ferrous metal, aluminum, and copper, described above, and include surface water and groundwater transport pathways. The radionuclide transport and exposure pathways for incineration of trash include exposures associated with air emissions from trash incineration and exposures associated with releases of landfill leachate to surface water and groundwater from landfill disposal of both trash and incinerator ash.

The collective dose assessment for incineration of trash includes transport of radionuclides that are not removed from the incinerator off gas by the air emissions control equipment and that are emitted to the atmosphere. These particulate radionuclides are assumed to deposit on the ground in the vicinity of the incinerator and result in General Public exposure through both inhalation of the particulate and direct radiation from radionuclides deposited on the ground. Deposited radionuclides also result in General Public exposure through uptake of radionuclides from the soil into food, including meat, milk, and vegetables.

3. Radiological Impact Assessment Methodology

An assessment of the potential radiation dose to critical groups was conducted in NUREG-1640. A critical group is defined as the group receiving the highest mean dose from among all of the exposure pathways associated with the given type of material (e.g., ferrous metal, concrete, trash) for the Alternative. The critical group for a given material and a given Alternative may be a group of members of the General Public exposed to radiation from end use products made from recycled material, or a group of Non-Licensed Facility Workers exposed to radiation from disposal of the materials in Subtitle D landfills. The critical group dose assessment for the Limited Dispositions Alternative for concrete is based on use of recycled concrete in road bed, as are the assessments for the No Action and Unrestricted Release Alternatives. The critical group dose assessment for ferrous metal, concrete, aluminum, and trash for the Limited Dispositions Alternative is based on disposal of these materials in an EPA/State-regulated landfill. The level of radiation exposure to the critical group is directly related to the dose limit associated with the Alternative. For a dose limit of 1 mrem/yr, for example, no critical group would experience a radiation dose greater than 1 mrem/yr.

Collective dose considers the amount of radiation, time of exposure, and number of individuals exposed and is reported in units of “person-rem.” The collective dose report (SC&A 2003) provided estimates of collective doses to the Licensed Facility Workers, Non-Licensed Facility Workers, and the General Public. Details of this collective dose assessment are provided in Appendix D.

Concrete

Figure G-1 illustrates the radiation exposure scenarios for concrete for all the Alternatives. The collective dose assessment for concrete for the No Action, Unrestricted Release, and Limited Dispositions Alternatives evaluates the collective dose associated with the recycling of concrete into road bed material. The collective dose assessment for concrete for the EPA/State-Regulated Disposal Alternative evaluates the collective dose associated with disposal of the concrete in Subtitle D landfills.

Ferrous Metal

Figure G-2 illustrates the radiation exposure scenarios for ferrous metal for all the alternatives. The collective dose assessment for ferrous metal for the No Action and Unrestricted Release Alternatives evaluates the collective dose associated with the recycling of ferrous metal into various end use products. The collective dose assessment for ferrous metal for the EPA/State-Regulated Disposal and Limited Dispositions Alternatives evaluates the collective dose associated with disposal of the ferrous metal in Subtitle D landfills.

Trash

Figure G-3 illustrates the radiation exposure scenarios for trash for all the alternatives. The collective dose assessment for trash for the No Action, Unrestricted Release, and Limited Dispositions Alternatives evaluates the collective dose associated with the disposal of trash in an EPA/State-regulated Subtitle D landfill. The collective dose assessment for trash for the EPA/State-Regulated Disposal Alternative evaluates the collective dose associated with disposal of the trash in Subtitle D landfills and with disposal of the trash in an EPA/State-regulated incinerator and subsequent disposal of the incinerator ash in an EPA/State-regulated landfill. There are no recycling or reuse scenarios for trash included in the collective dose assessment. Even if there were some recycling of this trash, its amount, compared to the much larger volumes of other materials intended for recycling, would be insignificant in terms of collective doses. The collective dose assessment accounts for work activities involving truck drivers hauling trash, trash disposal in a landfill, trash incineration and ash disposal in a landfill, and crane operator loading trash into an incinerator. Doses to offsite receptors consider the impacts associated with effluent discharges from landfill and incinerator operations.

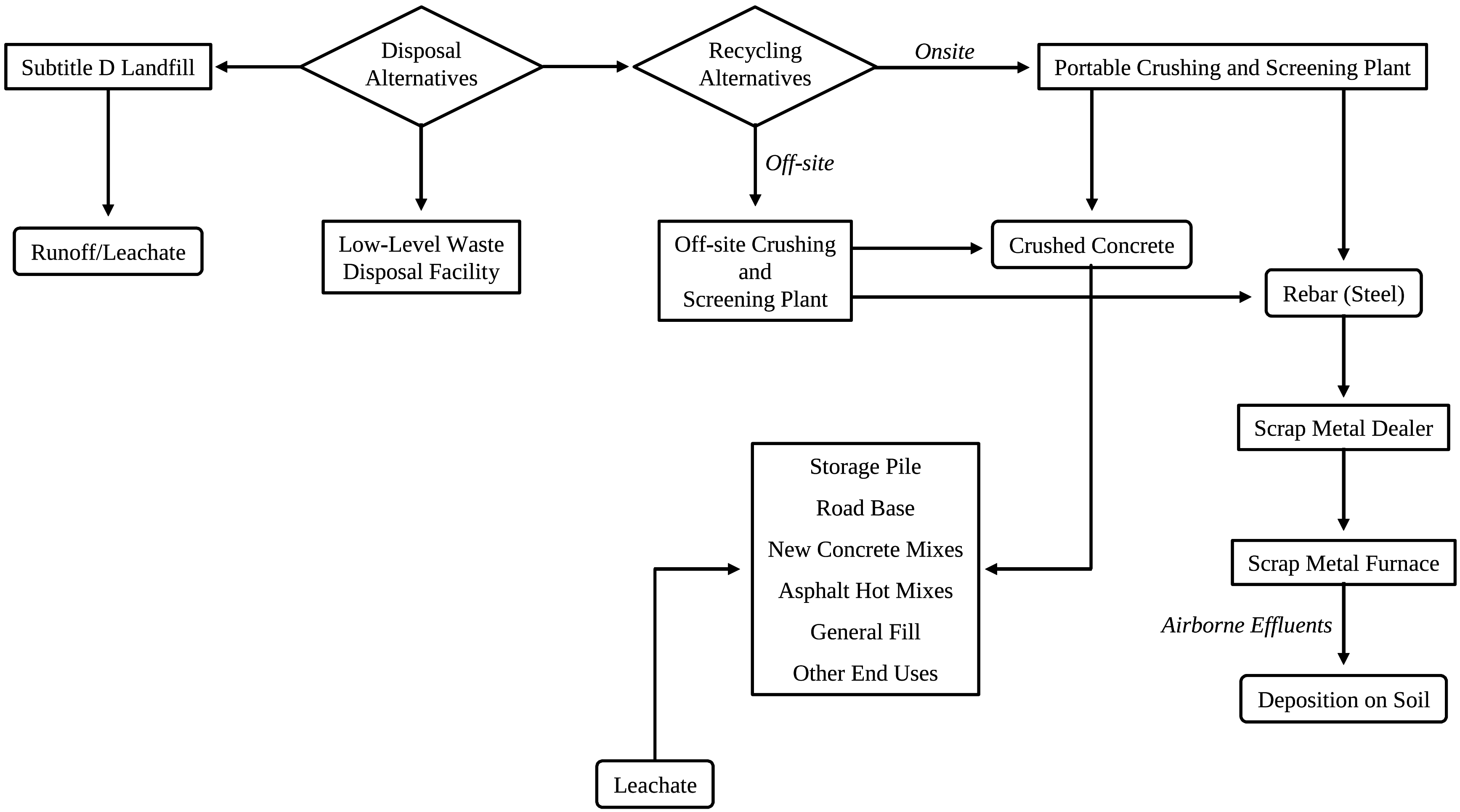
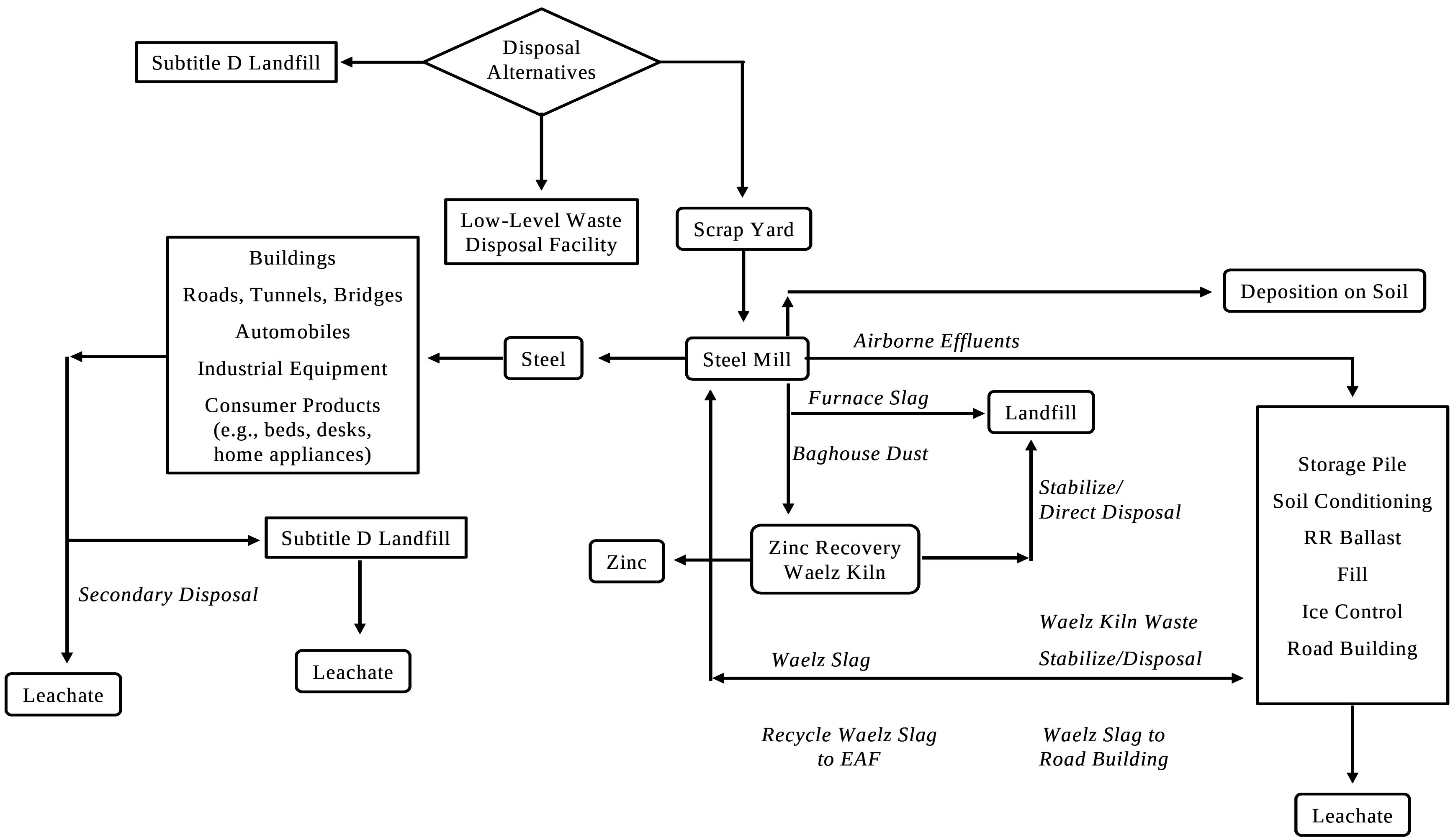


Figure G-1 Potential Exposure Scenarios for Concrete



1 **Figure G-2 Potential Exposure Scenarios for Ferrous Metal**

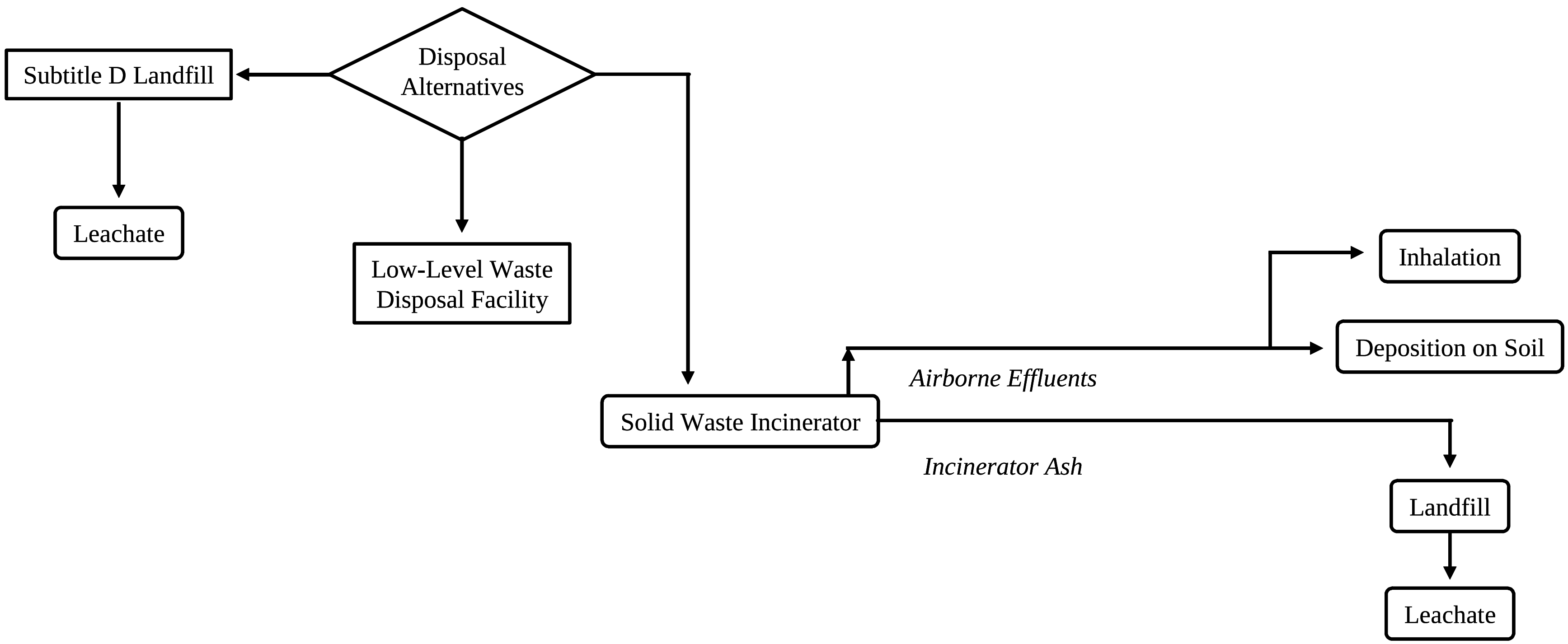


Figure G-3 Potential Exposure Scenarios for Trash

APPENDIX H
WATER RESOURCES - SUPPLEMENTAL INFORMATION

This appendix provides supporting information for Section 3.4 (Water Resources). Sections 1 to 3 discuss potential exposure pathways. Sections 4 describes the affected environment and Section 5 describes environmental consequences.

1. Exposure Pathways for the No Action and Unrestricted Release Alternatives

The affected environment for the No Action and Unrestricted Release Alternatives includes all waters which come into contact with the materials released from a licensed site during the generation and handling of the materials on the licensed facility site; processing at a recycling facility; handling and disposal of byproducts and waste products from those processing activities; and the handling and utilization of end use products.

These waters potentially lead to direct exposure to the wastewater, runoff or leachate, or represent potential paths for contaminants to enter ground water or surface water from leachate or runoff during processing or in connection with end use products such as concrete roadbed material. Runoff includes waters which come in contact with the subject material or its residue and traverses over the ground, along natural or manmade drainage channels, or collects in natural or manmade catchment areas. Leachate includes waters which come in contact with the subject material and percolate to a containment barrier and which may be removed, processed, or otherwise managed by facility personnel. Both runoff and leachate may eventually reach surface water bodies or ground-water aquifers and escape beyond the limits of the delineated work area, i.e., the operational or physical limits bounding Non-Licensed Facility Worker exposures.

1.1 Concrete

Potential exposure pathways for the No Action and Unrestricted Release Alternatives for concrete are based on crushing, screening, and recycling the processed concrete as aggregate for a variety of end uses, e.g. general fill, road base material, new concrete and asphalt mixes. Crushing and screening of the concrete is also anticipated to occur under the EPA/State-Regulated Disposal, LLW Disposal, and Limited Dispositions Alternatives, and the affected environment and potential water quality impacts associated with these activities are common to all of the Alternatives. The following sections describe the affected environment for potential Non-Licensed Facility Workers, General Public, and non-radiological ecological exposures.

<u>Non-Licensed Facility Worker Exposure</u>

Potential exposure pathways for concrete for Non-Licensed Facility Workers include activities associated with the handling of concrete at the licensee facility site or at offsite satellite facilities; recycling of the concrete into aggregate and subsequent reuse; and disposal of concrete dust generated from concrete recycling.

Ingestion of drinking water from onsite ground-water wells or surface water sources has not been included as a Non-Licensed Facility Worker exposure pathway. Non-radiological water-related potential Non-Licensed Facility Worker exposures are limited to skin irritation through direct skin contact with highly alkaline water. The pH of cement falls between 12 and 13, which is highly caustic. Runoff and leachate from crushed concrete would have lower pH values. NPDES permits typically limit the maximum pH of discharges to 9.0, but higher values could exist prior to the discharge point.

End uses of recycled concrete aggregate such as road bed construction material, general fill, or other applications with a high specific surface area may continue to generate leachate or runoff with elevated pH. End uses which bind the recycled concrete aggregate in cement or asphalt would not produce such leachate or runoff from the aggregate itself.

<u>General Public Exposure</u>

Potential General Public exposure pathways include the use of ground water, or surface water fed by ground-water flow, as a drinking water supply from a source located near the site of activities associated with handling of concrete at the licensee facility site or at offsite satellite facilities; recycling of the concrete as aggregate; end use of recycled concrete aggregate; and disposal of concrete dust generated from concrete recycling.

Potential non-radiological, General Public exposures include ingestion of water with high pH, and perhaps elevated levels of calcium, aluminum, or iron. Standard monitoring of public drinking water supplies limits the risk of exposure to elevated levels of these constituents. Since significant exposure by direct runoff flows into surface waters would be precluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body. Private ground water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

<u>Ecological Exposure</u>

Potential non-radiological ecological exposure pathways include the existence of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with handling of concrete at the licensee facility site or at offsite satellite facilities; recycling of the concrete as aggregate; end use of recycled concrete aggregate; and disposal of concrete dust generated from concrete recycling.

Aquatic and riparian animals face potential exposure to water containing high pH, and perhaps elevated levels of calcium, aluminum, or iron. Since significant exposure by direct runoff flows into surface waters is precluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body.

1.2 Ferrous Metal

Potential exposure pathways for the No Action and Unrestricted Release Alternatives for ferrous metal are based on the anticipated end uses for recycled ferrous metal and the anticipated processes that would be used in recycling ferrous metals. The following sections describe the affected environment for potential Non-Licensed Facility Worker, General Public, and ecological exposures.

Non-Licensed Facility Worker Exposure

Potential Non-Licensed Facility Worker exposure pathways for ferrous metal include activities associated with the handling of scrap ferrous metal at the licensed facility site; recycling of the scrap into finished recycled ferrous metal; processing into end use products (e.g., automobiles, home appliances, building materials); installation of end use products (e.g., building materials); processing and use of byproducts (e.g., furnace slag, electric arc furnace (EAF) baghouse dust) generated by recycling processes; and disposal of wastes (e.g., EAF baghouse dust) generated by recycling processes.

Locations used for materials handling at the licensee facility or laydown areas for scrap stockpiling, segregation, loading, unloading, or other handling at the recycling facility have the potential to generate both leachate and surface water runoff. The total volume of runoff plus leachate will depend on natural precipitation and water used for dust suppression. The division between runoff and leachate will depend on the drainage systems and details in the laydown areas. All outdoor ferrous metal recycling activities have the potential to contaminate ground water or surface water, either by the escape of leachate past the barrier systems, if any, or by runoff which escapes the delineated work area.

Several processes in metal recovery and recycling involve process water for cooling or dust control. Wet cleaning systems remove basic oxygen furnace (BOF) dust in a slurry form. Ferrous metal mills may use water or water based fluids for pickling or cooling. End use manufacturing processes often use water for cleaning or cooling.

Byproduct materials from ferrous metal production also require substantial quantities of water for processing. Ground granulated blast-furnace slag (GGBFS) production requires rapid water quenching to control slag crystal growth and particle size. By contrast, air-cooled blast furnace slag (ACBFS) production mechanically crushes and screens the larger slag skulls resulting from the slower cooling process. Water is used to suppress dust in the crushing operation. Slag piles are intentionally exposed to precipitation to hydrate residual lime and therefore reduce potential future volumetric instability in construction applications. Uses of slag in portland cement concrete products include road base courses and structural building concrete, including residential slabs and foundations. Slag asphalt is also used as a pavement alternative to standard hot mix asphalt.

Ingestion of drinking water from onsite ground-water wells or surface water sources has not been included as a Non-Licensed Facility Worker exposure pathway. Potential Non-Licensed Facility Worker exposures from runoff or leachate generated by contact with ferrous metal scrap are expected to be limited to oils and greases on non-structural components such as pumps and other machinery. Potential Non-Licensed Facility Worker process water exposures are limited to dermal exposure through direct skin contact.

General Public Exposure

Potential General Public exposure pathways include the use of ground water or surface water as a drinking water supply from a source located near the site of activities associated with handling of scrap ferrous metal at the licensee facility site; recycling of the scrap into finished recycled ferrous metal; processing of the finished ferrous metal into end use products; processing and use of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes.

Potential non-radiological General Public exposures from ferrous metal include ingestion of water containing contamination from oils and grease, and containing elevated levels of iron, manganese, or other metals. Standard monitoring of public drinking water supplies limits the risk of exposure to elevated levels of these constituents. Since significant exposure by direct runoff flows into surface waters is precluded by NPDES controls, the remaining pathway involves ground-water flow to a surface water body. Private ground water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

Ecological Exposure

Potential ecological exposure pathways for ferrous metal include the existence of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with handling of scrap ferrous metal at the licensee facility site; recycling of the scrap into finished recycled ferrous metal; processing of the finished ferrous metal into end use products; processing and use of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes.

Aquatic and riparian animals face potential non radiological exposure to water containing elevated levels of metals, such as manganese and chromium. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body.

1.3 Aluminum

Potential exposure pathways for the No Action and Unrestricted Release Alternatives for aluminum are based on the anticipated end uses for recycled aluminum and the anticipated processes that would be used in recycling aluminum. The following sections describe the affected environment for potential Non-Licensed Facility Worker, General Public, and ecological exposures in the secondary aluminum industry.

Non-Licensed Facility Worker Exposure

Potential Non-Licensed Facility Worker exposure pathways include activities associated with handling of scrap aluminum at the licensee facility site; recycling of the scrap into finished recycled aluminum; processing of the finished aluminum into end use products (e.g., automobiles, home appliances, building materials); installation of end use products (e.g., building materials); processing of byproducts (e.g., furnace dross) generated by recycling processes; and disposal of wastes (e.g., baghouse dust) generated by recycling processes.

Locations used for material handling at the licensee facility or laydown areas for scrap stockpiling, segregation, loading, unloading, or other handling at the recycling facility have the potential to generate both leachate and surface water runoff. Secondary aluminum processing includes scrap shredding; scrap drying, delacquering, or decoating; thermal chip drying, furnace operations, in-line fluxing; and dross cooling.

General Public Exposure

Potential General Public exposure pathways include the use of ground water or surface water as a drinking water supply from a source located near the site of activities associated with the handling of scrap aluminum at the licensee facility site; recycling of the scrap into finished recycled aluminum; processing of the finished aluminum into end use products; installation of end use products; processing of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes.

Potential non-radiological General Public exposures include ingestion of leachate-contaminated water containing elevated levels of lead, copper, cadmium, and other metals. Standard monitoring of public drinking water supplies limits the risk of exposure to elevated levels of these constituents. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway involves ground-water flow. Private ground water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

Ecological Exposure

Potential ecological exposure pathways for aluminum include the existence of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with the handling of scrap aluminum at the licensee facility site; recycling of the scrap into finished recycled aluminum; processing of the finished aluminum into end use products; installation of end use products; processing of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body.

1.4 Copper

Potential exposure pathways for the No Action and Unrestricted Release Alternatives for copper are based on the anticipated end uses for recycled copper and the anticipated processes that would be used in recycling copper. The following sections describe the affected environment for potential Non-Licensed Facility Worker, General Public, and ecological exposures.

Non-Licensed Facility Worker Exposure

Potential Non-Licensed Facility Worker exposure pathways for copper include activities associated with the handling of scrap copper at the licensee facility site; recycling of the scrap into finished recycled copper; processing of the finished copper into end use products (e.g., water pipes); processing of byproducts (e.g., furnace slag) generated by recycling processes; and disposal of wastes (e.g., baghouse dust) generated by recycling processes.

Non-radiological water-related potential Non-Licensed Facility Worker exposures from copper scrap are limited to dermal exposure.

General Public Exposure

Potential General Public exposure pathways for copper include the use of ground water or surface water as a drinking water supply from a source located near the site of activities associated with the handling of scrap copper at the licensee facility site; recycling of the scrap into finished recycled copper; processing of the finished copper into end use products; processing of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway involves ground-water flow. Private ground-water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

Ecological Exposure

Potential ecological exposure pathways for copper include the existence of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with the handling of scrap copper at the licensee facility site; recycling of the scrap into finished recycled copper; processing of the finished copper into end use products; processing of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body.

1.5 Trash

This analysis assumes that the disposition of trash under all alternatives would be limited to disposal, and that there are no other anticipated end uses for trash. Specifically, recycling options have been excluded from this analysis because it is unlikely that trash from operations would be recycled. Therefore, there are no potential exposure pathways under the No Action and Unrestricted Release Alternatives other than those described for the EPA/State-Regulated Disposal Alternative in Section 2.

2. Exposure Pathways for the EPA/State-Regulated Disposal Alternative

The affected environment for the EPA/State-Regulated Disposal Alternative includes all waters which come into contact with the materials released from a licensed site during the release and handling of the materials on the site; transportation of the materials to a disposal facility; processing or placement of the materials at the disposal facility; and subsequent operation of the disposal facility. The analysis begins at the point that the material has been released. The disposal facilities considered under the EPA/State-Regulated Disposal Alternative are limited to EPA/State-regulated Subtitle D solid waste landfills, and EPA/State-regulated solid waste incinerators for trash.

2.1 Subtitle D Landfill Disposal

Disposal in EPA/State-regulated Subtitle D landfills presents similar potential non-radiological exposure pathways for concrete, ferrous metal, aluminum, copper, and trash; however, the nature of the potential exposures depends on the contaminants present in each material. This section describes the affected environment for potential Non-Licensed Facility Worker, General Public, and ecological exposures.

Potential pathways for disposal in an EPA/State-regulated Subtitle D landfill include runoff or leachate from material piles at the licensee facility during sorting, stockpiling, handling, and loading activities; leachate collected at the material disposal facility; and collected leachate escaping and contaminating surface waters. Landfill leachate escaping an engineered landfill barrier system and entering ground water is not considered a significant pathway.

The above pathways present potential exposures risks from leachate or runoff during processing or in connection with disposal. Both runoff and leachate may eventually reach surface water bodies and escape beyond the limits of the delineated work area, i.e. the operational or physical limits bounding Non-Licensed Facility Worker exposures.

Subtitle D of the Resource Conservation and Recovery Act (RCRA) of 1976 (42 USC 82, Subchapter IV) authorized regulation of State or regional solid waste plans. RCRA Subtitle D covers solid wastes, including hazardous wastes specifically excluded from RCRA Subtitle C. The promulgated solid waste regulations appear in 40 CFR Part 190 to 282, with Part 257 (Criteria For Classification Of Solid Waste Disposal Facilities And Practices) and Part 258 (Criteria For Municipal Solid Waste Landfills) specifying the siting, design, operational, monitoring, and closure requirements. Subtitle D landfills that receive or have received any industrial waste from facilities requiring an NPDES discharge permit are themselves required to have an NPDES discharge permit. Subtitle D landfills have additional restrictions on run-on and run-off control, discharges to surface water bodies, and contamination of ground water.

<u>Non-Licensed Facility Worker Exposure</u>

For disposal in an EPA/State-regulated Subtitle D landfill, potential Non-Licensed Facility Worker non-radiological exposure pathways involving water resources for concrete, ferrous metal, aluminum, copper, and trash result from activities associated with release and disposal of these materials. These include activities associated with the handling of the materials at the licensee facility site, and placement and storage of the materials at an EPA/State-regulated Subtitle D landfill. Potential exposure pathways involving the transportation of materials are not considered significant.

Non-radiological water-related potential Non-Licensed Facility Worker exposures are limited to dermal exposure to leachate or runoff water. Leachate or runoff from aluminum or copper is not expected to cause skin irritation. Leachate or runoff from concrete may have elevated pH and cause irritation or rashes due to its caustic nature. Leachate or runoff from ferrous metal may contain oils or greases which can cause skin irritation following prolonged exposure. The precise characteristics of the leachate or runoff from trash will depend on the components of the trash, but may be similar to leachate from municipal solid waste. Since the contact time is hours or days, instead of months or years, the contaminant concentrations would be much lower. Leachate and runoff from trash piles is apt to contain more biological pathogens.

Municipal solid waste landfill leachates characteristically exhibit slight acidity (pH>4.5), and contain elevated levels of ammonia, chlorides, zinc, copper, cadmium, lead, nickel, chromium, and mercury. Organic compounds detected in Subtitle D landfill leachate include organic acids, ketones, aromatic compounds, chlorinated aromatic compounds, ethers, phthalates, halogenated aliphatic compounds, alcohols, amino-aromatic compounds, nitro-aromatic compounds, phenols, heterocyclic compounds, pesticides, sulfur substituted aromatic compounds, polyaromatic hydrocarbons, polychlorinated biphenyls, and organophosphates (Reinhart et al. 1998). In sufficient concentration, several of these can cause an acute skin reaction. In lower concentrations, compounds such as PCBs, pesticides, and organophosphates can cause serious chronic health problems.

General Public Exposure

For disposal in an EPA/State-regulated Subtitle D landfill, potential General Public non-radiological exposure pathways involving water resources for concrete, ferrous metal, aluminum, copper, and trash are based on the activities associated with release of these materials at the licensee facility, and disposal of these materials in an EPA/State-regulated Subtitle D landfill. These pathways include the use of ground water or surface water as a drinking water supply from a source located near the site of activities associated with the handling of the materials at the licensee facility site, and placement and storage of the materials at the landfill/disposal facility. Ingestion of drinking water from ground-water wells or surface water sources along transportation routes has not been included as a General Public pathway.

Potential non-radiological, water-related, General Public exposures from concrete material piles include ingestion of water with high pH, and perhaps elevated levels of calcium, aluminum, or iron. Exposures from ferrous metal material piles include ingestion of water containing contamination from oils and grease, and containing elevated levels of iron, manganese, or other metals. The aluminum and copper scrap is not anticipated to be contaminated with oils, grease, or other hazardous substances. The composition of runoff or leachate from trash is unknown, but can be expected to contain harmful contaminants. Leachate from landfills may contain concentrated metals, and hazardous organic and inorganic compounds. Standard monitoring of public drinking water supplies limits the risk of exposure to elevated levels of harmful constituents. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway involves ground water. Private ground water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

Ecological Exposure

For disposal in an EPA/State-regulated Subtitle D landfill, potential ecological non-radiological exposure pathways involving water resources for concrete, ferrous metal, aluminum, copper, and trash are based on the activities associated with release of these materials at the licensee facility, and disposal of these materials in an EPA/State-regulated Subtitle D landfill. The potential pathways include exposure of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with the handling of the materials at the licensee facility site, and placement and storage of the materials at the landfill/disposal facility. Exposure along transportation routes has not been included as an ecological pathway.

Aquatic and riparian animals face potential non-radiological exposure to runoff or leachate from material piles containing high pH from concrete, oils and greases from ferrous metal, and various organic and inorganic compounds from trash. Aluminum and copper scrap is not anticipated to be contaminated with oils, grease, or other hazardous substances. Leachate from landfills may contain concentrated metals, and hazardous organic and inorganic compounds. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body. Potential ecological exposures to ground water extracted from a well and used for irrigation are not considered significant.

2.2 EPA-Regulated Incineration of Trash

Potential exposure pathways for trash are based on the anticipated processes that would be used in disposing of trash in an EPA/State-regulated incineration facility. This section describes the affected environment related to incineration of trash for potential Non-Licensed Facility Worker, General Public, and ecological exposures involving water resources.

The EPA regulations pertaining to incineration, 40 CFR Part 60 - Standards of Performance for New Stationary Sources, deal primarily with air emissions. 40 CFR Part 240 - Guidelines for the Thermal Processing of Solid Wastes, Section 240.204-1 additionally requires that all waters discharged by a solid waste thermal processing facility “shall be sufficiently treated to meet the most stringent of applicable water quality standards, established in accordance with or effective under the provisions of the Federal Water Pollution Control Act, as amended.”

Solid waste combustion facilities typically generate process wastewater from the tipping floor runoff system, pollution control systems, and ash quenching. These process wastewaters can often be recycled for ash quenching. Typical facilities use a few gallons per ton of waste burned (EPA 1995).

Non-Licensed Facility Worker Exposure

Potential Non-Licensed Facility Worker exposure pathways for EPA/State-regulated incineration of trash include activities associated with release and combustion of the trash. Incinerator ash would subsequently be disposed in an ash landfill.

Runoff and leachate from trash could contain many of the same contaminants as Subtitle D landfill leachate, but since the contact time is hours or days, instead of months or years, the contaminant concentrations are much lower. Leachate and runoff from trash piles is apt to contain more biological pathogens.

General Public Exposure

Potential General Public exposure pathways for EPA/State-Regulated Incinerator disposal of trash include activities associated with release and combustion of trash in an incinerator. Incinerator ash would subsequently be disposed in an ash landfill.

Standard monitoring of public drinking water supplies limits the risk of exposure to elevated levels of harmful constituents. Private ground water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

Ecological Exposure

Potential non radiological ecological exposure pathways involving water resources for trash incineration include the exposure of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with release, combustion of trash in an incinerator, and subsequent disposal of the incinerator ash in an ash landfill.

Leachate or runoff from trash piles at the licensee facility may pick up harmful contaminants. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway involves ground water. Ground-water contamination at incineration sites has proved rare.

3. Exposure Pathways for the LLW Disposal Alternative

The affected environment for the LLW Disposal Alternative includes all waters which come into contact with materials released from licensed facilities, including release and handling of the materials on the site; transportation of the materials to a LLW disposal facility; and placement of the materials at the disposal facility. The analysis begins at the point that the material has been released. LLW disposal facility regulations appear in 10 CFR Part 61.

The LLW Disposal Alternative presents non-radiological exposure pathways similar to those discussed for EPA/State-regulated Subtitle D landfills, but the performance of the leakage barriers, the leachate management system, and the operational practices may differ. Potential exposure pathways include runoff or leachate from material piles at the licensee facility during sorting, stockpiling, handling, and loading activities; leachate collected at the disposal facility; and collected leachate escaping and contaminating surface waters.

Potential non-radiological exposure pathways for the EPA/State-Regulated Disposal Alternative and LLW Disposal Alternative for concrete, ferrous metal, aluminum, copper, and trash are similar; but the nature of the potential exposures depends on the contaminants present in each material. This section describes the affected environment for potential Non-Licensed Facility Worker, General Public, and ecological exposures.

Non-Licensed Facility Worker Exposure

Potential Non-Licensed Facility Worker (i.e., truck drivers) non-radiological exposure pathways involving water resources for the LLW Disposal Alternative for concrete, ferrous metal, aluminum, copper, and trash are based on the activities associated with the disposal of these materials in an LLW disposal facility. This includes activities associated with the handling, placement, and storage of the materials at the licensed disposal facility. Potential water-related Non-Licensed Facility Worker exposure pathways involving the transportation of materials are not considered significant.

Non-radiological water-related potential Non-Licensed Facility Worker exposures are limited to contact with leachate or runoff water. However, truck drivers would not be assumed to to be exposed to either leachate or runoff water. Leachate or runoff from aluminum or copper is not expected to cause skin irritation.

General Public Exposure

Potential General Public non-radiological exposure pathways involving water resources for concrete, ferrous metal, aluminum, copper, and trash are based on the activities associated with release, and disposal of these materials in LLW disposal facility. These pathways include the use of ground water or surface water as a drinking water supply from a source located near the site of activities associated with the handling of the materials at the licensee facility site, and placement and storage of the materials at the landfill/disposal facility. Ingestion of drinking water from ground-water wells or surface water sources along transportation routes has not been included as a General Public pathway.

Potential non-radiological, water-related, General Public exposures from concrete material piles include ingestion of water with high pH, and perhaps elevated levels of calcium, aluminum, or iron. Exposures from ferrous metal material piles include ingestion of water containing contamination from oils and grease, and containing elevated levels of iron, manganese, or other metals. The aluminum and copper scrap is not anticipated to be contaminated with oils, grease, or other hazardous substances. The composition of runoff or leachate from trash is unknown, but can be expected to contain harmful contaminants. Leachate from landfills may contain concentrated metals, and hazardous organic and inorganic compounds. Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body. Standard monitoring of public drinking water supplies limits the risk of exposure to elevated levels of harmful constituents. Private ground water wells or private surface water supplies fed from a ground water source remain potential exposure pathways for ingestion.

Ecological Exposure

For disposal in LLW disposal facility, potential ecological non-radiological exposure pathways involving water resources for concrete, ferrous metal, aluminum, copper, and trash are based on the activities associated with release of these materials at the licensee facility, and disposal of these materials in a LLW disposal facility. The potential pathways include exposure of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with the handling of the materials at the licensee facility site, and placement and storage of the materials at the landfill/disposal facility. Exposure along transportation routes has not been included as an ecological pathway.

Aquatic and riparian animals face potential non-radiological exposure to runoff or leachate from material piles containing high pH from concrete, oils and greases from ferrous metal, and various organic and inorganic compounds from trash. Aluminum and copper scrap is not anticipated to be contaminated with oils, grease, or other hazardous substances. Leachate from landfills may contain concentrated metals, and hazardous organic and inorganic compounds.

NRC regulations for disposal facility performance objectives (10 CFR 61.41) address only radiological discharge restrictions. However, 10 CFR 51.10 states "In accordance with section 511(c)(2) of the Federal Water Pollution Control Act (86 Stat. 893, 33 U.S.C 1371(c)(2)) the NRC recognizes that responsibility for Federal regulation of nonradiological pollutant discharges into receiving waters rests by statute with the Environmental Protection Agency." Since significant exposure by direct runoff flows into surface waters is excluded by NPDES controls, the remaining pathway is ground-water flow to a surface water body. Potential ecological exposures to ground water extracted from a well and used for irrigation are not considered significant.

4.0 Affected Environment

This section describes the affected environment under all the Alternatives. In addition to workers and the general public, ecological receptors are also addressed.

Surface Water

The affected environment for surface water includes Licensed and Non-Licensed Facility Workers potentially exposed to wastewater, runoff, or collected leachate either created by direct contact with the materials released from a licensed site during the generation, handling, processing, usage, or disposal of the released materials; or created by direct contact with any byproducts, end use products, or waste products derived from the released materials. Activities which may generate wastewater, runoff, or leachate include material handling and stockpiling at licensed facilities; material handling and stockpiling at recycling facilities; recycling processing at manufacturing facilities; end use of recycled concrete aggregate or ferrous metal slag; disposal in an EPA/State-regulated Subtitle D landfill; disposal of ash from an EPA/State-regulated incinerator; and disposal in a LLW disposal facility.

For the purposes of this discussion, wastewater, runoff, and leachate include flows that are generated and handled in engineered environments, effectively separate from the natural environment, and are considered to be controlled flows. In general, these industrial discharges require NPDES permits under 40 CFR Part 122. Wastewater refers to water or water-based fluids directly used in the material processing (e.g. cooling or wash water) and either reused or discharged. Runoff refers to water which comes into contact with the materials (e.g. via precipitation or dust control spray) and is later collected in the facility stormwater system and handled as storm water discharge associated with industrial activity as defined by 40 CFR 122.26(b)14. Leachate refers to water which comes into contact with and percolates through the materials, and which may be retained by an engineered barrier system (e.g. landfill liner), collected, processed and discharged. These wastewater, runoff, and collected leachate discharges may be treated onsite, sent to a Publicly Owned Treatment Facility (POTW) or other offsite treatment facility, or discharged directly into surface waters in accordance with each facility's point source discharge permits. Any potential non-radiological exposures following treatment and post-treatment discharge are considered insignificant.

The affected environment for surface water also includes the General Public and Ecological Receptors potentially exposed to surface water bodies into which wastewater, runoff, or collected leachate flows or is discharged, either directly or through a ground-water pathway. Natural or manmade surface water bodies may be either offsite or onsite but lie outside the area of industrial activity. NPDES stormwater restrictions preclude contaminated discharges proceeding directly into surface waters in sufficient volume, frequency, or concentration to significantly impact such waters, therefore the only remaining exposure pathway is ground-water flow to a surface water body. A surface water body fed by impacted ground water is unlikely to cause non-drinking water impacts to the General Public due to dilution or, in its absence, due to the limited expected exposure from a stagnant water body. The affected environment for surface water includes aquatic or riparian animals or vegetation living in or along ground-water fed surface water bodies at or near the site of activities associated with the release, handling, processing, usage, or disposal of the released materials.

Concrete

All Alternatives generate potential surface water exposure pathways from concrete handling, stockpiling, and loading at the licensee facility and disposal of all or part of the concrete in LLW disposal facilities. All Alternatives except the LLW Disposal Alternative generate additional potential surface water exposure pathways from concrete disposal in an EPA/State-regulated landfill. The No Action, Unrestricted Release, and Limited Dispositions Alternatives generate additional potential surface water exposure pathways from concrete handling and stockpiling at recycling facilities, recycling processing, and concrete end use activities.

All outdoor locations used for concrete handling at the licensee facility or laydown areas for concrete stockpiling, segregation, loading, unloading, or other handling at the recycling facility, have the potential to generate both leachate and surface water runoff. The total volume of runoff and leachate will depend on natural precipitation and water used for dust suppression. The division between runoff and leachate will depend on the drainage systems and details in the laydown areas.

Under the No Action, Unrestricted Release, and Limited Dispositions Alternatives, activities may include crushing, screening, and recycling of the concrete into aggregate and subsequent reuse, and disposal of concrete dust generated from concrete recycling. Potential uses for recycled concrete aggregate include general fill, road base material, aggregate for new concrete and asphalt mixes. Crushing of the concrete is also anticipated to occur under the EPA-Regulated Disposal Alternative and the LLW Disposal Alternative, but only to the extent required to facilitate transportation.

Ferrous Metal

All Alternatives generate potential surface water exposure pathways from ferrous metal handling, stockpiling, and loading at the licensee facility and disposal of all or part of the ferrous metal in LLW disposal facilities. All Alternatives except the LLW Disposal Alternative generate additional potential surface water exposure pathways from ferrous metal disposal in an EPA/State-regulated landfill. The No Action and Unrestricted Release Alternatives generate additional potential surface water exposure pathways from ferrous metal handling and stockpiling at recycling facilities, recycling processing, and ferrous metal end use activities.

Potential surface water exposure pathways for Licensed and Non-Licensed Facility Workers include exposure to runoff and collected leachate during scrap ferrous metal handling and stockpiling activities. These activities may occur at the licensed facility site or off-site. All outdoor locations used for material handling at the licensee facility or off-site; or laydown areas for scrap stockpiling, segregation, loading, unloading, or other handling at the recycling facility have the potential to generate both leachate and surface water runoff. The total volume of runoff plus leachate will depend on natural precipitation. The division between runoff and leachate will depend on the drainage systems and details in the laydown areas.

Potential surface water exposure pathways for Workers at Non Licensed Facilities also include activities associated with recycling of scrap into finished recycled ferrous metal; processing of the finished ferrous metal into end use products (e.g., automobiles, home appliances, building materials); installation of end use products (e.g., building materials); processing and use of byproducts (e.g., furnace slag, EAF baghouse dust) generated by recycling processes; and disposal of wastes (e.g., EAF baghouse dust) generated by recycling processes.

Several processes in ferrous metal recovery and recycling involve process water for cooling or dust control. Wet cleaning systems remove BOF or EAF dust in a slurry form. Ferrous metal mills may use water or water based fluids for pickling or cooling. End use manufacturing processes often use water for cleaning or cooling.

Byproduct materials from ferrous metal production also require substantial quantities of water for processing. Ground granulated blast-furnace slag production requires rapid water quenching to control slag crystal growth and particle size. By contrast, air-cooled blast furnace slag production mechanically crushes and screens the larger slag skulls resulting from the slower cooling process. Water is used to suppress dust in the crushing operation. Slag piles are intentionally exposed to precipitation to hydrate residual lime and therefore reduce potential future volumetric instability in construction applications. Uses of slag in portland cement concrete products include road base courses and structural building concrete, including residential slabs and foundations. Slag asphalt is also used as a pavement alternative to standard hot mix asphalt.

Trash

All the Alternatives generate potential surface water exposure pathways from trash handling, stockpiling, and loading at the licensee facility and disposal of all or part of the trash in LLW disposal facilities. All Alternatives except the LLW Disposal Alternative generate additional potential surface water exposure pathways from trash disposal in an EPA/State-Regulated Subtitle D landfill or disposal of ash from an EPA/State-regulated incinerator.

This analysis assumes that the disposition of trash under all alternatives would be limited to disposal, and that there are no other anticipated end uses for trash. Specifically, recycling options have been excluded from this analysis because it is unlikely that trash would be recycled. The potential surface water exposure pathways under the No Action, Unrestricted Release, and Limited Dispositions Alternatives are the same as those described for the EPA-Regulated Disposal Alternative.

The surface water affected environment for trash includes all runoff and collected leachate derived from waters which come into contact with the trash released from a licensed site during the release and handling of the trash on the site; transportation of the trash to a disposal facility; processing or placement of the trash at the disposal facility; and subsequent operation of the disposal facility. The disposal facilities considered are limited to EPA-regulated Subtitle D solid waste landfills, EPA-regulated solid waste incinerators for trash, and LLW disposal facilities.

Potential surface water exposure pathways for disposal in an EPA/State-regulated Subtitle D landfill or a LLW disposal facility include runoff or leachate from trash piles at the licensee facility during sorting, stockpiling, handling, and loading activities; and collected leachate at the material disposal facility.

Potential Non-Licensed Facility Worker exposure pathways involving surface water for EPA/State-regulated incineration of trash include activities associated with generation and combustion of the trash. Solid waste combustion facilities typically generate process wastewater from the tipping floor runoff system, pollution control systems, and ash quenching. Process wastewater can often be recycled for ash quenching, reducing the total water volume required. Typical facilities use a few gallons per ton of waste burned (EPA 1995). Incinerator ash would subsequently be disposed in an ash landfill. Ash landfill leachate could contribute to additional surface water exposures.

<u>Ground Water</u>

Ground water refers to any water in the soil interstitial pore spaces, including water found in phreatic aquifers, confined aquifers, and the vadose zone, but excluding pore water in any soil excavated. Process wastewater, surface runoff, or leachate which is not retained by or escapes barrier systems and subsequently seeps into the soil becomes ground water for the purposes of this discussion. The affected environment for ground water includes Workers at Licensed

Facilities, Workers at Non Licensed Facilities, the General Public, and Ecological Receptors potentially exposed to compromised ground water. Ground water which discharges into a surface water body is considered surface water and has been previously discussed. Drinking water issues, even if the water is obtained from ground-water wells, are discussed separately.

Ground-water wells may be used at Licensed Facilities or Non-Licensed Facilities as a source for process water or dust suppression water. Due to mixing and dilution with unaffected ground water, concentrations of contaminants in extracted ground water will be lower than the concentrations in the escaped wastewater, runoff, and leachate.

Ground-water wells may be used beyond the boundaries of Licensed Facilities and Non Licensed Facilities for agricultural or residential water supply. Standard monitoring of public water supplies limits the risk of exposure to elevated levels of harmful constituents. However, private ground-water wells remain potential exposure pathways. The General Public faces potential non-drinking water exposures to affected ground water through dermal contact only. Ground water has little to no ecological influence until it is extracted from a well.

<u>Drinking Water</u>

The affected environment for drinking water includes Workers at Licensed Facilities, Workers at Non Licensed Facilities, and the General Public. Process wastewater, surface runoff and leachate have the potential to escape their engineering controls and seep into the underlying soil, becoming ground water. This ground water may be extracted from wells, or it may discharge into surface water bodies. Ground water or surface water bodies may be used as sources for drinking water.

Standard monitoring and treatment of public drinking water supplies limits the risk of exposure to elevated levels of contaminants from the Alternatives. Ingestion of drinking water from onsite ground-water wells has not been included as an exposure pathway for Workers at Licensed Facilities or Workers at Non Licensed Facilities. Wells on industrial property regularly serving more than 25 persons are regulated as public water supplies. Drinking water wells on industrial property, especially in industries with potential sources of contamination, are usually monitored regularly for water quality and are not considered to be a significant exposure pathway.

Ingestion of drinking water from private ground-water wells or private surface water supplies may lead to potential exposures. Since significant exposure by direct runoff flows into surface waters would be precluded by NPDES controls, only surface water bodies fed from a ground-water source are potential exposure pathways. Surface water bodies with low enough turnover and dilution to be impacted by ground-water flow would generally be unattractive candidates for a drinking water source. In areas of the country where alternative surface water supplies are rare, precipitation is also generally low, so initial leachate and runoff contamination of ground-water supplies will be minimal.

5.0 Environmental Consequences

Environmental consequences for Workers at Licensed Facilities and Workers at Non Licensed Facilities are limited to dermal exposure to surface water in the form of process wastewater, runoff, and collected leachate. There are not anticipated to be any significant ground-water or drinking water impacts to workers.

The General Public does not face any significant environmental consequences from any of the Alternatives related to surface water. The General Public may experience impacts from dermal exposure to ground water extracted from a private well, or ingestion of drinking water from a private ground-water well or private ground-water fed surface water body. However such exposure is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required, e.g. high runoff or leachate volumes, high runoff or leachate concentrations, limited ground-water dilution, the presence of a drinking water well downgradient of and close to the runoff or leachate source, and a combination of ground-water gradient and permeability conducive to ground-water mobility.

Ecological receptors only face potential environmental consequences from surface water in ground-water fed surface water bodies. Ground water extracted from a well and used for agricultural or residential irrigation is not considered a significant pathway for ecological impacts.

Water quality effects are primarily associated with point source and area source water discharges from the storage, handling, and processing of solid materials. For the No Action and Unrestricted Release Alternatives, the effects are generated mostly by runoff discharges from rubblization of concrete and runoff and process wastewater discharges from recycling of ferrous metal. The incremental quantity of these discharges would be small as compared to the overall amount of discharges generated from the total amount of concrete and ferrous metal being recycled annually in the U.S. The impact on water quality would be equally small. Similarly, the quantity of additional leachate and potential effects on ground water associated with disposal of solid materials under the EPA/State-Regulated Disposal and LLW Disposal Alternatives would be small compared with the overall amount of leachate being generated annually by these facilities. Therefore the overall effects on water quality associated with all of the alternatives would be small when compared with other sources of discharges. The quantities of materials released and therefore the volumes of surface water potentially impacted will differ between the alternatives. The contaminant concentrations in impacted waters may also be higher in scenarios in which greater volumes of material are released.

5.1 No Action Alternative

The surface water, ground water, and drinking water environmental consequences for the No Action Alternative are identical in nature to those discussed below under the Unrestricted Release Alternative.

5.2 Unrestricted Release Alternative

The Unrestricted Release Alternative includes all activities associated with material handling, stockpiling, and loading at licensee facilities; material unloading, handling, stockpiling, and loading at recycling facilities; transportation of released materials; processing at recycling or manufacturing facilities; handling and utilization of end use products; handling and disposal of byproducts and waste products from processing activities; and direct disposal of released materials.

5.2.1 Surface Water

Activities under the Unrestricted Release Alternative generate surface water runoff or leachate, or use water directly in recycling processes to convert the materials into marketable products. The waters which contact the materials or their byproducts have the potential to acquire contaminants or deleterious characteristics. These waters may eventually contact Workers at Licensed Facilities, Workers at Non Licensed Facilities, the General Public, or ecological receptors.

Concrete

Surface water impacts related to concrete under the Unrestricted Release Alternative stem from runoff or leachate generated by precipitation or water used for dust suppression. The precipitation becomes alkaline through contact with the concrete rubble or its residual byproducts. The increased alkalinity of the water depends on the specific surface area of the concrete and the duration of the water-concrete contact. Runoff would remain in contact with the concrete rubble piles for minutes or hours. Leachate could accumulate and concentrate for weeks or months.

This analysis considers four likely stages in the concrete recycling process:

- Concrete separated from other materials, aggregated, and stockpiled;

- Concrete crushed and screened to create a more useable product, or crushed to facilitate transportation;

- Crushed concrete recycled as concrete aggregate and concrete rubble as fill material; and

- Concrete dust from the crushing operation disposed in a landfill.

The quantity of runoff or leachate generated depends primarily upon the amount of precipitation and the areal extent of the piles of concrete rubble, recycled concrete aggregate, or concrete dust. The impact is on water quality, specifically the pH of the water. The results for pH from reported NPDES discharges generally do not exceed 9.0, but higher values could exist prior to the discharge point. The pH of cement itself falls between 12 and 13. A leaching study of construction and demolition waste reports concrete leachate consistently with pH between 11 and 12 (Townsend 1998), which is strongly alkaline. Table H-1 provides estimates of the pH of the runoff and leachate waters for concrete for the Unrestricted Release Alternative.

Table H-1 Estimated pH for Concrete Runoff and Leachate - Unrestricted Release Alternative

Affected Waters	Exposure Location	Estimated pH
Material Generation		
Runoff from material piles	Licensee Facility	9.5
Leachate collected from material piles	Licensee Facility	11
Concrete Recycling		
Runoff from material piles	Recycling Facility	10[1]
Leachate collected from material piles	Recycling Facility	11.5[1]
Concrete End Use		
Runoff from Recycled Concrete Aggregate in road construction	Road Construction Site	9.5
Runoff from Recycled Concrete Aggregate in general fill	Area of fill	9.5
Concrete Dust Disposal		
Collected landfill leachate	Industrial Landfill	12

[1] Concrete at recycling facilities is assumed to have a greater specific surface area than concrete at the licensee facility due to additional crushing

Licensed and Non-Licensed Facility Workers may suffer acute and chronic skin impacts from contact with leachate waters. Normal human skin is slightly acidic with a pH between 4.5 and 5.5. Leachate with a pH of 11.5 is 1 million to 10 million times as alkaline as skin. Strongly alkaline material is caustic and corrosive to skin, eyes, and mucous membranes. Prolonged or repeated contact with runoff waters would produce less severe irritation due to the generally lower pH, but may still lead to chronic skin irritation. However, such exposure is unlikely to occur because workers would avoid contact with leachate or wear personal protective equipment in conducting activities.

End uses of recycled concrete aggregate such as road bed construction material, general fill, or other applications with a high specific surface area may continue to generate leachate or runoff with elevated pH. End uses which bind the recycled concrete aggregate in cement or asphalt would not produce such leachate or runoff from the aggregate itself.

Leachate or runoff that seeps into ground water and ultimately reaches a surface water body, especially a small pond, could raise the pH of the surface water body. Aquatic and riparian animals and vegetation face potential exposure to water containing pH in excess of 8 in surface water bodies impacted by high pH ground water. Waters with elevated pH depress biological activity, and pH in excess of 8 can be detrimental to fish. Reducing water with a pH of 12 to a pH of 8 would require dilution by a factor of 10,000. Nevertheless, such exposure is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required and the natural acidity of the majority of lakes and ponds.

There are no anticipated surface water impacts to the General Public from concrete-related activities.

Ferrous Metal

Surface water impacts related to ferrous metal under the Unrestricted Release Alternative stem from runoff or leachate generated by precipitation, and from ferrous metal recycling process wastewater discharges. Table H-2 identifies the contaminants of concern in the waters associated with various ferrous metalmaking activities.

Table H-2 Ferrous Metal Exposure Pathways for Surface Water – Unrestricted Release Alternative

Affected Waters	Exposure Location	Contaminants
Material Generation		
Runoff from material piles	Licensee Facility	oils and grease
Leachate collected from material piles	Licensee Facility	oils and grease
Scrap Recycling		
Runoff from scrap piles	Recycling Facility/Ferrous metal Mill	oils and grease
Leachate collected from scrap piles	Recycling Facility/Ferrous metal Mill	oils and grease
Blast furnace wastewater	Ferrous metal Mill	high pH, zinc
EAF Dust process wastewater	Ferrous metal Mill	lead, cadmium
EAF Dust stabilization wastewater	Ferrous metal Mill	lead, cadmium
Runoff from slag pile	Ferrous metal Mill	pH = 7.5 to 9.5
Leachate collected from slag pile	Ferrous metal Mill	pH = 8 to 11
Slag End Use		
Ground granulated blast-furnace slag or crushed slag cement production (runoff or process water)	Cement plant	high pH, metals
Ground granulated blast-furnace slag or crushed slag asphalt production (runoff or process water)	Asphalt plant	high pH, metals
Slag cement or slag asphalt in roads (runoff, dust suppression water)	Road Construction Site	high pH, metals
Air-cooled blast furnace slag for embankments and fills (runoff, dust suppression water)	Earthwork, landscaping site	high pH, metals
EAF Dust Secondary Processing		
EAF dust process wastewater	Processing facility	lead, cadmium
Residue disposal		
EAF dust landfill collected leachate	Industrial Landfill	lead, cadmium
Slag landfill collected leachate	Industrial Landfill	high pH, metals

Licensed and Non-Licensed Facility Workers may suffer skin disorders from contact with runoff or leachate waters from piles of scrap ferrous metal. The quantity of runoff or leachate generated during each process or activity depends primarily upon the amount of precipitation and the areal extent of the piles of ferrous metal scrap at the licensee facilities and recycling facilities. Runoff and leachate from ferrous metal scrap piles may contain oils and grease from nonstructural components such as pumps and other machinery. The oils and grease may cause skin irritation if the exposures are extended, but adherence to safe work practices and the use of personal protective equipment such as gloves and appropriate work clothing would minimize direct exposure.

Workers at Non-Licensed Facilities may suffer skin disorders from contact with runoff or leachate waters from ferrous metal slag or EAF baghouse dust. Ferrous metal slag leachate can have pH values as high as 11, which is strongly alkaline and can cause damage to skin, eyes, and mucous membranes. EAF baghouse dust can have high concentrations of zinc and other metals, but the impact would be limited by the peak expected annual production of 36 tons/year.

There are no anticipated surface water impacts to the General Public from ferrous metal-related activities.

Potential ecological impacts involving surface water for the Unrestricted Release Alternative for ferrous metal include the existence of aquatic or riparian animals or vegetation living in or along surface water bodies at or near the site of activities associated with handling of scrap ferrous metal at the licensee facility site; recycling of the scrap into finished recycled ferrous metal; processing of the finished ferrous metal into end use products; processing and use of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes. Leachate or runoff that seeps into ground water and ultimately reaches a surface water body, especially a small pond, could raise the pH or metal content of the surface water body. Aquatic and riparian animals or vegetation face potential exposure to water containing elevated levels of metals, such as manganese and chromium. Waters with elevated pH depress biological activity, and pH in excess of 8 can be detrimental to fish. The low probability of the simultaneous occurrence of the combination of factors required to affect surface water chemistry through ground-water flow limits the potential for impacts from indirect discharges, and the mild acidity of the majority of lakes and ponds provides natural protection against the most likely impact, an increase in pH level.

Trash

The surface water impacts from trash for the Unrestricted Release Alternative are the same as those described for the EPA/State-Regulated Disposal Alternative.

5.2.2 Ground Water

Activities under the Unrestricted Release Alternative can impact through the escape of process wastewater, leachate, or runoff past engineering barriers and seepage into the soil.

Concrete

Licensed Facility and Non-Licensed Facility Workers are not anticipated to have any significant concrete-related non-drinking water impacts from ground water. It is unlikely that even workers routinely involved in activities involving sprayed water, such as dust suppression on concrete rubble piles, would suffer skin or eye irritation because the high volumes of water required for these activities would generally dilute to low levels any deleterious components in the small volumes of escaped runoff or leachate.

The General Public may face impacts from ground water extracted from residential wells and used for bathing or swimming. The pH of runoff and leachate from concrete-related activities varies from 9.5 to 12. Reducing ground water with a pH of 12 to a pH of 8.0 would require dilution by a factor of 10,000. The Center for Disease Control warns that swimming pool water with a pH above 8.0 may cause skin and eye irritation. Ground water that reaches a private well could exceed that standard, but the low probability of the simultaneous occurrence of the combination of factors required minimizes the risk of exposure.

Ferrous Metal

Licensed Facility and Non-Licensed Facility Workers are not anticipated to have any significant non-drinking water impacts from ground water. It is unlikely that even workers routinely involved in activities involving sprayed water, such as slag quenching, would suffer skin or eye irritation because the high volumes of water required for these activities would generally dilute to low levels any deleterious components in the small volumes of escaped runoff or leachate.

The General Public may face impacts from ground water extracted from residential wells and used for bathing or swimming. Leachate from slag may have a pH as high as 11. Reducing ground water with a pH of 11 to a pH of 8.0 would require dilution by a factor of 1,000. Swimming pool water with a pH above 8.0 may cause skin and eye irritation. Ground water that reaches a private well could exceed that standard, but the low probability of the simultaneous occurrence of the combination of factors required minimizes the risk of exposure.

Trash

This analysis assumes that the disposition of trash under all the Alternatives would be limited to disposal, and that there are no anticipated recycling or other end uses for trash because it is unlikely that trash would be recycled. Therefore, there are no potential exposure pathways under the Unrestricted Release Alternative for trash other than those described below for the EPA/State-Regulated Disposal Alternative.

5.2.3 Drinking Water

Licensed and Non-Licensed Facility Workers are not anticipated to have any significant drinking water impacts. Impacts to the General Public are discussed below.

Concrete

Potential General Public drinking water exposure pathways involving concrete related activities include the use of ground water, or surface water fed by ground-water flow, as a drinking water supply from a source located near the site of activities associated with handling of concrete at a licensee facility, handling of concrete at a recycling facility, recycling of the concrete as aggregate, end use of recycled concrete aggregate, disposal of concrete dust generated from concrete recycling, or direct disposal of concrete. Potential impacts include ingestion of water with high pH, and perhaps elevated levels of calcium, aluminum, or iron. Reducing water with a pH of 12, typical of concrete dust leachate, to the upper limit of the National Secondary Drinking Water Standards, pH = 8.5, would require dilution by a factor of over 3,000. Ground water that reaches a private well could exceed the standard, but General Public exposure to impacted drinking water from a private ground-water well or private ground-water fed surface water body is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required.

Ferrous Metal

Potential General Public exposure pathways involving water resources include the use of ground water or surface water as a drinking water supply from a source located near the site of activities associated with handling of scrap at the licensee facility site; recycling of the scrap into finished recycled product; processing of the finished material into end use products; processing and use of byproducts generated by recycling processes; and disposal of wastes generated by recycling processes. Potential impacts include ingestion of water containing contamination from oils and grease, and containing elevated levels of iron, manganese, or other metals. Reducing water with a pH of 11, typical of ferrous metal slag leachate, to the upper limit of the National Secondary Drinking Water Standards would require dilution by a factor of over 300. Ground water that reaches a private well could exceed the standard, but exposure to impacted drinking water from a private ground-water well or private ground-water fed surface water body is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required.

Trash

This analysis assumes that the disposition of trash under all Alternatives would be limited to disposal, and that there are no other anticipated end uses for trash. Specifically, recycling options have been excluded from this analysis. Therefore, there are no potential exposure pathways under the Unrestricted Release Alternative for trash other than those described below for the EPA/State-Regulated Disposal Alternative.

5.3 EPA/State-Regulated Disposal Alternative

Under the EPA/State-Regulated Disposal Alternative all of the potentially clearable concrete, ferrous metal, and trash would be disposed of in EPA/State-regulated Subtitle D landfills. Some or all of the trash could be disposed in EPA/State-regulated incinerators. These disposal options are also available under the No Action, Unrestricted Release, and Limited Dispositions Alternatives.

5.3.1 Surface Water

<u>Subtitle D Landfill Disposal of Concrete, Ferrous Metal, and Trash</u>

Under the EPA/State-Regulated Disposal Alternative, released concrete, ferrous metal, and trash would be disposed in EPA/State-regulated Subtitle D landfills. Workers at Licensed Facilities would face similar surface water impacts during material generation, segregation, and stockpiling of ferrous metal at the licensee facility as those incurred under the Unrestricted Release Alternative. Concrete could have lower water-related impacts under the EPA/State-Regulated Disposal Alternative because less crushing and screening could be performed at the licensee facility than under the Unrestricted Release Alternative, reducing the specific surface area of the concrete rubble and the likelihood for pH impacts to runoff and leachate.

Surface water impacts to Workers at Licensed Facilities include contact with runoff or collected leachate from trash piles during handling, stockpiling, or loading activities. Surface water impacts to Workers at Non Licensed Facilities from trash are limited to contact with runoff produced during the processing or placement of the trash at the landfill and leachate collected during subsequent operation of the landfill.

The precise characteristics of the runoff from trash will depend on the components of the trash, but may be similar to leachate from municipal solid waste. Since the contact time for runoff is hours or days, instead of the months or years for leachate, the contaminant concentrations in runoff are expected to be much lower than the concentrations in leachate. Runoff from trash piles is apt to contain more biological pathogens than leachate.

Municipal solid waste landfill leachates characteristically exhibit slight acidity (pH>4.5), and contain elevated levels of ammonia, chlorides, zinc, copper, cadmium, lead, nickel, chromium, and mercury. Organic compounds detected in Subtitle D landfill leachate include organic acids, ketones, aromatic compounds, chlorinated aromatic compounds, ethers, phthalates, halogenated aliphatic compounds, alcohols, amino-aromatic compounds, nitro-aromatic compounds, phenols, heterocyclic compounds, pesticides, sulfur substituted aromatic compounds, polyaromatic hydrocarbons, polychlorinated biphenyls, and organophosphates (Reinhart et al. 1998). In sufficient concentration, several of these can cause an acute skin reaction. In lower concentrations, compounds such as PCBs, pesticides, and organophosphates can cause serious chronic health problems. However, such exposures are unlikely to occur because workers would avoid contact with leachate and wear personal protective equipment when conducting activities that could lead to leachate contact.

There are no anticipated surface water impacts to the General Public from EPA/State-regulated disposal of concrete, ferrous metal, or trash.

Potential ecological receptors include aquatic or riparian animals and vegetation living in or along surface water bodies at or near the site of activities associated with handling of materials at the licensee facility site; and disposal of material in an EPA/State-regulated landfill. Leachate from landfills may contain concentrated metals, and hazardous organic and inorganic compounds. Leachate or runoff that seeps into ground water and ultimately reaches a surface water body, especially a small pond, could alter the pH of or introduce organic and inorganic compounds into the surface water body.

<u>EPA/State-Regulated Incineration of Trash</u>

The surface water impacts to Workers at Licensed Facilities from trash are the same whether the disposal destination is an EPA/State-regulated Subtitle D landfill disposal or an EPA/State-regulated incinerator, and include contact with runoff or collected leachate from trash piles during handling, stockpiling, or loading activities. Activities associated with EPA/State-regulated incineration of trash have different potential surface water impacts for Workers at Non Licensed Facilities. The process wastewater from the tipping floor runoff system contains many of the components found in MSW landfill leachate, but since the contact time is hours or days, instead of months or years, the contaminant concentrations are much lower. Tipping floor runoff water is apt to contain more biological pathogens than MSW leachate. Process wastewater from pollution control systems will develop acidic characteristics, primarily from SO_2 in the combustion gases. Extended dermal contact with these waters can cause skin irritation. Such exposures are unlikely to occur because workers would avoid contact with process wastewater and wear personal protective equipment when conducting activities that could lead to contact.

There are no anticipated surface water impacts to the General Public from EPA/State-regulated incineration of trash. Ground-water contamination at incineration sites has proven rare, so impacts to aquatic or riparian animals at or near ground-water fed surface water bodies are not expected.

5.3.2 Ground Water

Licensed and Non-Licensed Facility Workers are not anticipated to have any significant non-drinking water impacts from ground water. No activities associated with the handling, stockpiling, transportation, placement of trash in an EPA/State-regulated landfill, or placement of incinerator ash in an ash landfill would require the use of ground water. Solid waste combustion facilities typically use water for cleaning the tipping floor, pollution control systems, and ash quenching. Ground-water contamination at incineration sites has proved rare, so worker contact with ground water extracted for these uses is not expected to cause any significant impacts.

The General Public may experience non-drinking water ground-water impacts from water extracted from private residential wells located near licensee facilities, EPA/State-regulated Subtitle D landfills, or incinerator ash landfills. Standard landfill ground-water monitoring helps to reduce this risk. MSW landfill leachates characteristically contain elevated levels of ammonia, chlorides, zinc, copper, cadmium, lead, nickel, chromium, and mercury. Organic compounds detected in Subtitle D landfill leachate include organic acids, ketones, aromatic compounds, chlorinated aromatic compounds, ethers, phthalates, halogenated aliphatic compounds, alcohols, amino-aromatic compounds, nitro-aromatic compounds, phenols, heterocyclic compounds, pesticides, sulfur substituted aromatic compounds, polyaromatic hydrocarbons, polychlorinated biphenyls, and organophosphates (Reinhart et al. 1998). In sufficient concentration, several of these can cause an acute skin reaction. In lower concentrations, compounds such as PCBs, pesticides, and organophosphates can cause chronic health problems. General Public dermal exposure to impacted water from a private ground-water well is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required.

5.3.3 Drinking Water

For disposal in an EPA-regulated Subtitle D landfill, potential General Public impacts are based on the use of a private ground-water or surface water source as a drinking water supply from a source located near the site of activities associated with the handling of the materials at the licensee facility site, placement and storage of the materials at the landfill, or placement of ash from trash incineration in a landfill.

The composition of runoff or leachate from trash varies, but can be expected to contain a host of harmful contaminants. MSW landfill leachates characteristically exhibit slight acidity (pH>4.5), and contain elevated levels of ammonia, chlorides, zinc, copper, cadmium, lead, nickel, chromium, and mercury. Organic compounds detected in Subtitle D landfill leachate include organic acids, ketones, aromatic compounds, chlorinated aromatic compounds, ethers, phthalates, halogenated aliphatic compounds, alcohols, amino-aromatic compounds, nitro-aromatic compounds, phenols, heterocyclic compounds, pesticides, sulfur substituted aromatic compounds, polyaromatic hydrocarbons, polychlorinated biphenyls, and organophosphates (Reinhart et al. 1998). Many of these components, if ingested, can cause health problems.

Incineration of trash in an EPA/State-regulated incinerator generates ash which is disposed in an ash landfill. Leachate from incinerator ash may contain high concentrations of metals.

General Public exposure to impacted drinking water from a private ground-water well or private ground-water fed surface water body is expected to be minimal due to the low probability of the simultaneous occurrence of the combination of factors required.

5.4 Low-Level Waste Disposal Alternative

Under the LLW Disposal Alternative, all of the potentially clearable materials released from licensed facilities would be transported and placed in a LLW disposal facility.

For the purposes of this analysis, all potentially clearable solid materials released by licensed facilities are assumed to be sent to a disposal facility in Clive, Utah (Section 2.4.4). The Envirocare disposal facility incorporates waste cells constructed over naturally clayey soils. A 2-foot thick layer of compacted clay lines the bottom of each cell. The Envirocare facility is located in a remote desert location with an arid to semi-arid climate. The site is over 20 miles from the nearest permanent human habitation.

5.4.1 Surface Water

Surface water impacts to Workers at Licensed Facilities under the LLW Disposal Alternative include contact with runoff or collected leachate from trash piles during handling, stockpiling, or loading activities, as well as contact with runoff at the disposal facility.

The concentrated placement of all the released materials in a single location would concentrate the surface water related impacts in the vicinity of the disposal facility. The volume of additional waste at a single facility would likely require the opening of additional cells and the increase in areal extent would increase the potential for runoff generation. Based on a peak annual disposal volume of 2.3 million tons (2.1 metric tons) and an estimated average bulk specific gravity of 2.0, the peak annual volume of materials equals 1.05 million cubic meters. Assuming a typical cell depth of 15 meters, the peak annual volume would require the opening of about 7 hectares of new disposal cells annually. Annual rainfall in Clive, Utah is about 3.0 cm/year (7 in/year). The volume of water which would fall on 7 hectares equals about 21,000 m^3/year. Actual leachate generation would be significantly less due to the potential evaporation rate of 152 cm/year (60 in/year), and placement of interim covers.

The runoff would need to be removed from the cells and evaporated onsite. The exact constituents of the runoff depend on the segregation or mixing of waste types at the disposal facility. Runoff from trash would be expected to exhibit characteristics similar to MSW leachate. MSW leachate is typically acidic, and contains a wide variety of organic chemicals, inorganic chemicals, and pathogens. Runoff from areas of concrete disposal would have a higher pH. The high evaporation rates at the Envirocare facility would have the effect of concentrating the contaminants, except volatile components, in the remaining runoff thus increasing the potential dermal exposure hazards. Rigorous worker training at the Envirocare facility, adherence to safe work practices, and the use of personal protective equipment such as gloves and appropriate work clothing would minimize direct exposure.

There are no anticipated surface water impacts to the General Public from the LLW Disposal Alternative.

Potential ecological impacts involving surface water for the LLW Disposal Alternative depend on the existence of aquatic or riparian animals living in or along surface water bodies at or near the site of activities associated with handling of materials at the licensee facility site and disposal of material in the Envirocare facility. Since there are no ground-water fed surface water bodies in the vicinity of the Envirocare facility, there are no anticipated ecological impacts at or near the disposal facility.

5.4.2 Ground Water

Workers at the Envirocare disposal facility are unlikely to use ground water in ways which would lead to non-drinking water ground-water impacts. There are no General Public impacts expected from non-drinking water ground water use at the disposal facility or offsite as the nearest residence is 20 miles from the Envirocare site.

5.4.3 Drinking Water

Workers at the Envirocare disposal facility are unlikely to use ground water in ways which would lead to drinking water impacts. There are no General Public impacts expected from use of drinking water at the disposal facility or offsite, as the nearest residence is 20 miles from the Envirocare site.

5.5 Limited Dispositions Alternative

The following sections describe the environmental impacts associated with the Limited Dispositions Alternative.

5.5.1 Surface Water

The surface water environmental consequences for concrete are identical in nature to those discussed under the Unrestricted Release Alternative (Section 5.2.1).

Surface water impacts for ferrous metal and trash are identical in nature to those discussed under the EPA/State-Regulated Disposal Alternative (Section 5.3.1).

5.5.2 Ground Water

The ground-water environmental consequences for concrete are identical in nature to those discussed under the Unrestricted Release Alternative (Section 5.2.2). Ground-water impacts for ferrous metal and trash are identical in nature to those discussed under the EPA/State-Regulated Disposal Alternative (Section 5.3.2).

5.5.3 Drinking Water

The drinking water environmental consequences for concrete are identical to those discussed under the Unrestricted Release Alternative (Section 5.2.3). Drinking Water impacts for ferrous metal and trash are identical in nature to those discussed under the EPA/State-Regulated Disposal Alternative (Section 5.3.3).

APPENDIX I
AIR QUALITY - SUPPLEMENTAL INFORMATION

This appendix provides supporting information for Section 3.5 (Air Quality). Section 1 describes the affected environment, Section 2 describes the air emissions from each alternative, and Section 3 discusses the environmental consequences.

1.0 Affected Environment

The affected environment, as defined for the purposes of the air quality impact assessment, includes the ambient air affected by non radiological air pollutants emitted from activities associated with the release, handling, processing, transportation, and disposal of solid materials generated from licensed facilities under the Alternatives, and the General Public potentially exposed to such non radiological air pollutants. The affected environment also includes environmental receptors potentially affected by air emissions from activities associated with the Alternatives.

This section describes the environmental setting and baseline national air emissions to which air emissions associated with the Alternatives are compared in the environmental consequences analysis and also includes a discussion of baseline ambient air quality. National air emissions rather than baseline ambient air quality, is used as the baseline for assessment of air quality impacts because site-specific baseline ambient air quality cannot be determined for the Draft GEIS.

1.1 Baseline Ambient Air Quality

Air quality is assessed by measurements collected at thousands of air quality monitoring stations around the country, and these monitoring data are used to assess baseline ambient air quality associated with site-specific actions. Management of air quality is generally conducted on a local or regional scale and is achieved by controlling air emissions sources within the area that contribute to violations of the NAAQS. Potential air quality environmental consequences of site-specific actions are generally compared to baseline ambient air quality data. However, site-specific analyses cannot be conducted for the Alternatives, as the specific quantities of licensee-released materials that would flow into and through each air quality management area, and the affect of those activities on associated local air concentrations, cannot be estimated. Therefore, the air emissions estimated for each of the Alternatives are compared to total national emissions for each air pollutant for which there is an ambient air quality standard, and no site-specific baseline ambient air quality data are included in the Draft GEIS.

1.2 Emissions

Management of air quality is achieved by controlling sources that contribute the air pollutants associated with each air quality standard. Emissions from air emissions sources are typically estimated using emission factors. An emission factor is a parameter that describes the air pollutant emission rate of a particular process in terms of some common and easily quantified activity that is directly related to the emissions activity. For example, emissions from secondary ferrous metal processing (recycling) are estimated by applying an emission factor that represents the average emission rate of particulate matter for each ton of scrap ferrous metal processed. If the total tons of scrap ferrous metal to be processed in a ferrous metal mill is known, the total emissions resulting from the process can be estimated by multiplying the total tons throughput by the emission factor in units of pounds of emissions per ton of ferrous metal processed.

Many of the processes associated with the Alternatives are regulated to ensure that emissions are controlled to specified levels. The types and performance of air pollution control equipment in use at any given facility will differ. Typically, air pollutant emission factors are expressed as the uncontrolled emission rate, and the result of the estimate produced for any specific facility is adjusted to account for the control efficiency of the air pollution control system.

Air quality management programs are typically implemented on a local or urban area scale. Information on the specific rates of activities conducted within the specific local or urban scale air quality management areas is required to complete these local analyses. Activity rate data would include, for example, total vehicle miles traveled in the area each year, or the total tons of ferrous metal produced in the area each year. However, the quantities of licensee-released materials that would flow into and through each air quality management area for each of the Alternatives cannot be estimated for the Draft GEIS, and, therefore, no site-specific or region-specific air quality analyses can be conducted. Since the affect of meteorology and climatology on environmental impacts is only relevant for local analyses, it is not meaningful to discuss meteorology and climatology in this study.

Since air emissions associated with activities conducted under each Alternative can only be estimated on a national scale, the total national emissions (in units of tons per year) of each pollutant for each process and activity associated with each Alternative is used as the environmental setting (air quality baseline) for the purposes of evaluating the air quality impacts of the Alternatives. The national emissions of each pollutant from each industry sector and process (e.g., ferrous metal production) are included in the EPA National Emissions Inventory (NEI) (EPA 2004a). The same emission factors used by EPA to prepare the NEI are applied to appropriate estimates of the material flow through each process to estimate the incremental effects on air quality associated with each Alternative.

The NEI, used in this Draft GEIS to establish the affected environment, is prepared annually by the Emission Factors and Inventories Group (EFIG) within the EPA Office of Air Quality Planning and Standards (OAQPS). The development of the annual NEI by EPA is a requirement of the Clean Air Act. The EPA coordinates closely with State air quality planning agencies to ensure that the database is as accurate as possible and that local conditions are represented to the extent possible. The EPA NEI database is available at http://www.epa.gov/ttn/chief/net/1999inventory.html (EPA 2004a). Emissions estimates are available in the NEI for each of the specific process activities that can be quantified, as well as for the equipment and transportation activities that are associated with the Alternatives.

The total national emissions (in units of tons per year) of each pollutant for each process and associated activity is used as the environmental setting (air quality baseline) for the purposes of evaluating the air quality impacts of the alternatives. The national emissions of each pollutant from each industry sector and process (e.g., ferrous metal production) are included in the NEI. A summary of national emissions by source activity for the processes related to the alternatives for 1999 is provided in Table I-1. The annual period 1999 is used as the baseline measure because it is the most recent annual, national, air emissions inventory that has received extensive quality assurance.

Table I-1 National Annual Air Metric Emissions from Specific Processes for 1999 (metric tons per year)

Source Category	SO_2	VOC	PM10	PM2.5	NO_x	CO
Concrete Recycling	10	43	51	47	115	200
Secondary Ferrous Metal Production	7,997	3,361	7,609	7,074	5,326	22,346
Secondary Copper	48	336	1,833	1,792		
Secondary Aluminum	1,272	18,068	11,640	11,148	2,745	1,701
Subtitle D Landfills	1	1,393	609	250	13	65
Solid Waste Incinerators	11,852	1,190	2,393	2,128	30,127	10,775

Source: EPA NEI database at http://www.epa.gov/ttn/chief/net/1999inventory.html.

2.0 Air Emissions From Alternatives

The EFIG maintains a compilation of the recommended emission factors for use in estimating emissions from various air emissions source types, including air emissions processes and activities associated with each Alternative. The record of emission factors for stationary sources is the Compilation of Air Pollutant Emission Factors, AP-42, Fifth Edition, Volume 1: Stationary Point and Area Sources http://www.epa.gov/ttn/chief/ap42/index.html (EPA 2003e). Emission factors for highway mobile sources (e.g., diesel trucks) are developed by use of the MOBILE6 model that is maintained and updated by the EPA Office of Transportation and Air Quality (OTAQ) (EPA 2003f). Emission factors for mobile sources are dependent on the vehicle type, vehicle age, and speed, among other influences. Highway emission factors for heavy duty trucks that would be used to transport materials under the Alternatives will be developed using the MOBILE6 model. Input conditions representative of the average conditions anticipated for transportation of materials under the Alternatives will be selected to derive these average emission factors. The emission factors will then be applied to estimates of the total miles of transport required for each of the alternatives.

Emissions from heavy equipment operations are estimated by the use of another model developed by OTAQ called the NONROAD model (EPA 2003g). This model includes assumptions about the distribution and activity levels of various types of off road mobile sources. The output of the model provides estimates for specific types of equipment. Emissions from non-road heavy equipment (e.g., ferrous metal scrap pile loaders), are developed by applying an estimate of the total anticipated hours of operation for a representative type of heavy equipment that is commonly used for the particular type of process. The appropriate emission factor for that type of heavy equipment is used to derive a reasonable estimate of the air emissions for each Alternative.

2.1 Concrete

Fugitive Particulate Emissions

Concrete released from licensed facilities for the No Action, Unrestricted Release, and Limited Dispositions Alternatives would be broken up to remove ferrous metal reinforcing bars, and to create pieces in size ranges that can be moved and loaded onto trucks at the licensed facilities. These size-reduction processes can emit fugitive dust. Additional fugitive releases may be generated as the material is loaded into trucks for removal from the site. Similarly, other size-reduction processes at transfer station operations at which concrete rubble is processed are also potential sources of fugitive dust emissions. The fugitive dust generated by these mechanical activities includes mass in the smaller size range (<2.5 μm diameter particles) and has the potential to be transported to downwind receptor locations. Most of the particles larger than 10 μm are removed from the atmosphere by gravitational settling near the air emission source and are not generally considered in air quality analyses. Depending upon wind speed and direction and other atmospheric conditions, populations living close to the licensee's facility or to other facilities where concrete rubble is processed for size reduction could be exposed to ambient air concentrations of fugitive dust. Such exposures would depend upon the hours of operation of the processes and dust suppression measures that are applied during the process.

Combustion Source Emissions

Movement and size-reduction of concrete would involve use of heavy equipment, such as dozers and loaders. Such equipment is commonly powered by diesel engines. Diesel engines emit NO_x and VOC, the precursors of ozone, CO, particulate matter in the fine size fraction, and CO_2. The precursors of ozone and the particulate matter emissions have the potential to combine with other pollutants generated by mobile and stationary sources in the general area to affect regional air quality.

Transportation Emissions

Under the No Action and Unrestricted Release Alternatives large pieces of concrete would be loaded into heavy duty trucks or rail cars at the licensee facility for transport to the concrete recycling process facilities. Transport of concrete rubble does not have a high potential to generate fugitive emissions, however, transportation of crushed aggregate suitable for use at a roadway construction site could contribute fugitive emissions during transport if the truck trailer is not securely covered. Truck engines used to transport materials would emit NO_x, VOC, CO, particulate matter in the fine size range and CO_2. The General Public along the transportation routes would be exposed to the diesel combustion exhaust and any fugitive emissions released.

Process Emissions

Once the concrete reaches the concrete recycling process site, additional mechanical processing would be conducted to further reduce the concrete rubble into the appropriate aggregate size range for end use as road bed fill. The process involves grinding and crushing and would generate fugitive dust. Wind erosion could result in the generation of fugitive particulate emissions from aggregate storage piles. The mass of emissions would depend on the length of time the storage pile remains undisturbed, the moisture content of the aggregate, and the wind speed. The potential for population exposure would depend upon the wind speed and direction and the distance between the facility and human receptors.

Table I-2 summarizes air emission sources, processes and activities by material type (concrete, ferrous metal and trash disposal) for the No Action, Unrestricted Release and Limited Disposition Alternatives.

2.2 Ferrous Metal, Aluminum, and Copper

Processing of ferrous metal, aluminum, and copper for recycling under the No Action and Unrestricted Release Alternatives involves similar activities with similar air emissions characteristics. Similar processes and activities are associated with the release of the materials at the licensee sites and the transport of the materials to the recycling facilities. There are specific differences in the magnitude and constituents of air emissions from the recycling processes for ferrous metal, aluminum, and copper as a result of the furnace types used to melt the scrap and the characteristics of the metals themselves, but the process activities for the secondary metals processing are similar for all three materials. This section provides a generic description of the process and the specific emissions characteristics for the different kinds of furnaces used to melt metal scrap.

<u>Fugitive Particulate Emissions</u>

Fugitive dust emissions sources associated with the processing of the metal scrap at the licensed facility are associated with the bulk loading of the scrap metal into trucks or railcars. These processes have only a minimal potential for dispersion of the fugitive emissions from the licensed facility site because the emissions are characterized by large particle sizes that settle under gravitational influences and do not tend to disperse from the source.

<u>Process Emissions</u>

Several different types of cutting machines or shredders might be used to reduce the size of the scrap metal pieces for transport either at the licensed facility site or at secondary processing facilities. The scrap metal processing could result in metal fumes emissions. Ozone precursors would be generated from the diesel or gasoline engines used to power the equipment.

While the processes that are used at the recycling facilities to recycle ferrous metal, aluminum, and copper are conceptually the same, different types of furnaces are used for each metal. Therefore, different emission rates and constituents are associated with each metal recycling process. The scrap metal is processed by reducing the scrap to the molten state in a furnace, separating the impurities from the metal, and casting the recovered metal into intermediate or final products. Recovered metal is often cast into ingots that would then be further processed into finished materials (e.g., automobile engine blocks) at some other facility, or cast into new products at the recycling facility site.

Table I-2 Air Emissions Sources, Processes, and Activities Associated with No Action, Unrestricted Release, and Limited Dispositions Alternatives

Material	Activity	Air Emissions Source	Exposed General Public
Concrete (No Action, Unrestricted Release, and Limited Dispositions Alternatives)	Crushing/Grinding	Fugitive Dust	Vicinity of licensed facility
	Loading for Transport	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of licensed facility, and incremental contribution to urban and regional air quality inventory
	Transport to Road Bed Material Processing Facility	Fugitive Dust Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Unloading/Storage Piles	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of processing facility, and incremental contribution to urban and regional air quality inventory
	Processing into Road Bed Material	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of processing facility, and incremental contribution to urban and regional air quality inventory
	Transport to Road Building Site	Fugitive Dust Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Final Use - Roadbed Construction	Fugitive Dust Heavy Equipment Engine Emissions	Near road construction site, and incremental contribution to urban and regional air quality inventory
	Disposal of Concrete Dust in Landfill	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of landfill, and incremental contribution to urban and regional air quality inventory

Table I-2 Air Emissions Sources, Processes, and Activities Associated with No Action, Unrestricted Release, and Limited Dispositions Alternatives (continued)

Material	Activity	Air Emissions Source	Exposed General Public
Ferrous Metal, Copper, Aluminum (No Action and Unrestricted Release Alternatives)	Sorting/sizing for removal	Torches and Cutting Tools Heavy Equipment Engine Emissions	Vicinity of licensed facility, and incremental contribution to urban and regional air quality inventory
	Loading for Transport	Heavy Equipment Engine Emissions	Vicinity of licensed facility, and incremental contribution to urban and regional air quality inventory
	Transport to Recycling Facility	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Unloading/Storage/Preparation for Recycling	Torches and Cutting Tools Heavy Equipment Engine Emissions	Vicinity of processing facility, and incremental contribution to urban and regional air quality inventory
	Smelting/Refining	Furnace	Vicinity of processing facility
	Transport to Secondary Casting	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Secondary Melting casting	Furnace	Vicinity of secondary processing facility
	Molding/cutting/shaping in new use	Torches and Cutting Tools	Near reuse manufacturing facility
	Transport of Final Product to point of use	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Transport of Recycling Process wastes to Landfill	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
Trash Disposal (No Action, Unrestricted Release, and Limited Dispositions Alternatives)	Unloading and disposal of trash at EPA/State-regulated landfill	Heavy Equipment Engine Emissions	Vicinity of landfill or disposal facility
	Disposal in EPA/State-regulated landfill	Heavy Equipment Engine Emissions	Vicinity of landfill or disposal facility

The principal air pollutant emitted from any type of secondary metals processing activity is particulate matter. The particulate matter results from the condensation of metal fumes that are emitted from the molten metal processes when they are released into the ambient air. The resulting particulate matter is primarily in the form of metal oxides. These metal oxide emissions form in the small size ranges that can disperse from process stacks and vents into the ambient air and then disperse from the facility location. Particulate emissions from secondary metal processing facilities are subject to air quality regulations and subject to air emissions control requirements.

Processing and disposal of the impurities generated as slag from these furnaces can also cause emissions of particulate matter. These processes are conducted in ways that minimize the release of air pollutants.

Ferrous Metal

Scrap ferrous metal is recycled by incorporating scrap into a furnace along with virgin ferrous metal scrap (i.e., scrap ferrous metal generated at the ferrous metal mill from ferrous metal processing) and pig iron. The mixture is melted and impurities are extracted. The final ferrous metal melt is tapped and used to form either cast products, ingots or rolled sheets for use in a variety of applications. The furnaces used to process scrap ferrous metal can be part of an integrated ferrous metal mill where iron ore is processed in addition to ferrous metal, but it is more often completed at specialty iron and ferrous metal foundries that concentrate on secondary ferrous metal processing. Most of the furnaces used to process ferrous metal do not use external heat sources. The main types of secondary ferrous metal furnaces are basic oxygen furnaces and electric arc furnaces (EAF). Scrap ferrous metal may also be melted directly in a foundry. In the blast furnace process, molten pig iron from a blast furnace is used to melt the scrap. Scrap may also be melted by heat generated through electrical resistance in EAFs. Oxygen lancing is often used to remove impurities by forming oxides that create the furnace slag. The oxidation reactions are exothermic and create additional heat for the process. Some smaller foundries use gas fired furnaces to melt scrap ferrous metal. The primary air pollutant emissions from ferrous metal furnaces are particulate matter resulting from fumes released by the melt. These fumes are most commonly in the form of metal oxides. Ferrous metal blast furnaces and foundries emit combustion products from combustion of fuel to provide heat to melt the ferrous metal. EAF furnaces result in secondary emissions of combustion products from generation of electricity.

Aluminum

Aluminum scrap is processed primarily in reverberatory furnaces. Reverberatory furnaces are generally natural gas fired immediately above the melt and have a curved roof that redirects the rising heat back into the melt. Emissions from the furnace fuel use are estimated as a separate process. The primary emissions from aluminum recycling are particulate matter resulting from fumes released by the melt, and combustion products from burning of natural gas.

Copper

Copper scrap may be processed in cupola furnaces, reverberatory furnaces, or electric arc furnaces. Copper scrap is generally mixed with virgin copper and clean scrap. The pure metal is separated from the impurities and tapped to form ingots or in some applications is cast directly into new products, such as copper pipe. The copper recycling processes emits metal fume particulate matter and combustion emissions.

2.3 Trash

Under the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives, trash released from licensed facilities is assumed to be directly disposed in a Subtitle D landfill. Air emissions sources and emission factors associated with disposal of trash are discussed in Section 3.3.

3.0 Environmental Consequences

Total national air emissions (in units of tons per year) from processes and activities associated with the Alternatives are estimated using emission factors. For example, the total amount of particulate matter (PM) associated with the recycling of ferrous metal under the Unrestricted Release Alternative is estimated by multiplying the total amount of ferrous metal released from licensed facilities that is recycled in ferrous metal mills (in units of tons per year) by a factor for the amount of particulate matter emitted per ton of ferrous metal recycled (in units of mass particulate matter per ton ferrous metal processed). The same emission factors used to prepare the NEI are applied to appropriate estimates of the material flow through each process to estimate the incremental effects on air quality associated with each Alternative.

Approximately 15 to 20 million tons of concrete and approximately 2 million tons of ferrous metal would be released from licensed commercial nuclear reactor facilities under any of the Alternatives (Appendix F). It is assumed that all of the concrete would be sent for recycle as road-bed. The amount of ferrous metal is compared to approximately 82 million metric tons per year in the United States. Conversely, approximately 6,600 metric tons of copper and 200 tons of aluminum are anticipated to be released from commercial nuclear reactor facilities. Therefore, air quality impacts associated with recycling and disposal of aluminum and copper are not discussed quantitatively in the Draft GEIS. Less than 0.07 million tons of trash would be released from licensed nuclear reactor facilities, and less than 0.9 million tons of trash is anticipated to be released from licensed facilities other than commercial nuclear reactors. This compares with estimates of approximately 209 million tons per year of municipal solid waste. The air quality impact analysis for trash is based on the disposal of trash in either EPA/State-regulated landfills, EPA/State-regulated incinerators, or LLW disposal facilities. Trash is not assumed to be recycled or reused under any of the Alternatives.

Sources and activities associated with the Alternatives to which NESHAP standards apply are shown in Table I-3. Process emissions of hazardous air pollutants (HAPs) would be released from the recycling of ferrous metal under the No Action and Unrestricted Release Alternatives, The emission factors for HAPs for ferrous metal recycling are small compared to the emission

Table I-3 Summary Table – Total Air Emissions from Alternatives (metric tons)

Total Emissions					
No Action Alternative and Unrestricted Release Alternative	PM_{10}	SO_2	NO_x	VOC	CO
Concrete (recycling)	1,219	Neg.	4,654	1,132	910
Ferrous metal (recycling)	8,362	2,905	7,248	4,614	--
Trash (landfill disposal)	67	Neg.	186	94	94
TOTAL EMISSIONS	9,648	2,905	12,124	5,839	1,004
EPA/State-Regulated Disposal Alternative					
Concrete (landfill disposal)	1,210	Neg.	4,583	1,132	910
Ferrous metal (landfill disposal)	36	Neg.	776	60	326
Trash (landfill disposal)	67	Neg.	186	94	94
Trash (incineration)	171	117	337	94	157
TOTAL EMISSIONS	1,417	117	5,696	1,285	1,394
Limited Dispositions Alternative					
Concrete (recycling)	1,219	Neg.	4,646	1,132	910
Ferrous metal (landfill disposal)	36	Neg.	776	60	326
Trash (landfill disposal)	67	Neg.	186	94	94
TOTAL EMISSIONS	1,320	Neg.	5,570	1,285	1,330
LLW Disposal Alternative					
TOTAL EMISSIONS	93	7	889	94	94
Annual Emissions					
No Action Alternative and Unrestricted Release Alternative					
Annual Emissions (metric tons/year)	205	62	258	124	21
EPA/State-Regulated Disposal Alternative					
Alternative Not Including Trash Incineration Annual Emissions (metric tons/year)	28	Neg.	118	26	28
Alternative Including Trash Incineration Annual Emissions (metric tons/year)	30	3	121	27	30
LLW Disposal Alternative					
Annual Emissions (metric tons/year)	2	0.2	19	2	2
Limited Dispositions Alternative					
Annual Emissions (metric tons/year)	33	Neg.	139	32	33

Neg = Negligible

factors for the criteria (NAAQS) air pollutants for ferrous metal recycling, in terms of emissions per ton of ferrous metal recycled. Therefore, the HAP emissions from ferrous metal recycling would be small as compared to the total inventory of HAPs emitted on a national basis. Similarly, the HAP emissions associated with disposal of material in Subtitle D landfills or EPA/State-regulated incinerators would also be small as compared to the total inventory of HAPs emitted from landfill disposal and incineration of solid waste. In addition, the facilities where these materials would be processed are already subject to HAP emissions limitation standards whether or not the materials from licensed facilities are processed. Therefore, HAP emissions from ferrous metal recycling and landfill disposal and incineration of wastes generated from ferrous metal recycling are not discussed quantitatively in the DGEIS.

3.1 No Action Alternative

Air emissions sources, processes, and activities that are anticipated to contribute air pollutant emissions for the No Action, Unrestricted Release, and Limited Dispositions Alternatives for each material are listed in Table I-4. Air emissions sources, processes, and activities associated with the No Action Alternative are similar to those for the Unrestricted Release Alternative for recycling of concrete, ferrous metal, aluminum, and copper and disposal of trash. Under the Limited Dispositions Alternative, concrete would be recycled and other material would be disposed of in landfills. Air emissions associated with the No Action Alternative would be similar to those for the Unrestricted Release Alternative based on the amount of solid material that would be released and potentially recycled under these two Alternatives. For the purposes of the air emissions environmental consequences analysis it is assumed that all of the released solid material for both the No Action and Unrestricted Release Alternatives are recycled and that none is disposed of, and for the Limited Dispositions Alternative, it is assumed that all of the concrete is recycled. These assumptions maximize the air emissions estimated for the Alternatives. Sources, activities, and air emissions for the Unrestricted Release Alternative are presented in Section 3.2 below.

3.2 Unrestricted Release Alternative

As discussed in Section 3.1, air emissions sources, processes, and activities for the No Action Alternative are similar for those for the Unrestricted Release Alternative with respect to the recycling of concrete, ferrous metal, aluminum, and copper and disposal of trash and also for the Limited Dispositions Alternative for concrete and trash (Table I-4). The activities that result in air emissions for each of the materials assessed can be grouped in four general categories: materials processing, heavy equipment operation, recycling operations, and transportation. Each of the materials must be segregated and sized to allow transportation from the site. These processes require the use of heavy equipment, such as crushers, and equipment to load the processed materials into trucks or railcars. The materials are then transported to appropriate processing or disposal facilities by trucks or railroad. Similar types of heavy equipment are used to unload the materials at a suitable processing or disposal facility. At a processing facility the materials are used as feed stock for the process that results in the recyclable materials. Finally, the processed materials and unwanted waste products from the processing activity must be transported to the end use site or to the appropriate disposal site. These processes and their associated air emissions are described below for each of the solid materials.

Table I-4 Air Emissions Sources, Processes, and Activities Associated with No Action, Unrestricted Release, and Limited Dispositions Alternatives

	Activity	Regulated Pollution	Exposure Location
Concrete	Crushing/Grinding	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of licensed facility; Vicinity of the processing facility
	Loading, Unloading, Storage Piles	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of licensed facility; Vicinity of the processing facility
	Transportation from licensed facility and to final use site, or to landfill	Fugitive Dust Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Final Use - Roadbed Construction	Fugitive Dust Heavy Equipment Engine Emissions	Near road construction site, and incremental contribution to urban and regional air quality inventory
	Disposal of Concrete Dust in Landfill	Fugitive Dust Heavy Equipment Engine Emissions	Vicinity of landfill, and incremental contribution to urban and regional air quality inventory
Ferrous metal	Sorting/sizing for removal	Torches and Cutting Tools Heavy Equipment Engine Emissions	Vicinity of licensed facility
	Loading and unloading	Heavy Equipment Engine Emissions	Vicinity of licensed facility, and vicinity of processing facility
	Transportation between processing facilities, or landfill (for Limited Dispositions Alternative)	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Smelting/Refining/Casting	Furnace	Vicinity of processing facility
	Molding/cutting/shaping in new use	Torches and Cutting Tools	Near reuse manufacturing facility
	Transport of Final Product to point of use	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
Trash	Loading and unloading for transport	Heavy Equipment Engine Emissions	Vicinity of licensed facility, and vicinity of processing facility
	Transportation from licensed facility to waste incinerator or landfill	Heavy-Duty Truck Highway Emissions	Along the transportation route, and incremental contribution to urban and regional air quality inventory
	Disposal in EPA/State-Regulated Landfill	Heavy Equipment Engine Emissions	Vicinity of the landfill

<u>Transportation</u>

Transportation of the intermediate and completely processed concrete aggregate, ferrous metal, and trash will contribute exhaust emissions from truck engines. Exhaust emissions from heavy duty diesel trucks are calculated by the application of emission factor models that represent the distribution of truck engines in service. Those emission factors are applied to estimates of the miles traveled by trucks with each engine type.

There is also a possibility of fugitive dust emissions from the load. A cover is required for trucks and railcars that are transporting these types of materials to limit the fugitive dust emissions and the contributions from this type of activity are assumed to be negligible. There is no approved or recommended method to estimate these emissions. Therefore, fugitive emissions are not included in the emissions estimate from transportation processes.

Air emissions estimates for transportation activities associated with the Unrestricted Release and Limited Dispositions Alternatives represent the total emissions expected for transportation of all of the materials to be released from licensed facilities. Material specific estimates used in this air quality analysis were estimated by allocating the transportation emissions based on the relative quantities of the materials. Table I-5 summarizes the allocation of the transportation emissions for concrete, ferrous metal and trash. Total emissions for all heavy duty diesel trucks for 1999, the most recent year for which data have been published by EPA, is 2,390,000 metric tons per year for NO_x, and 130,909 metric tons per year for PM10. The average annual national emissions for NO_x and PM10 for transportation of concrete are well under 0.001 percent of total heavy duty diesel emissions and are insignificant from an air quality management perspective.

Table I-5 Unrestricted Release and Limited Dispositions Alternatives Transportation Emissions

Material	Quantity Released (10^6 tons)[1]	Material Mass Fraction	Total Emissions (metric tons/year)			
			NO_x	**PM10**	**SO_2**	**CO_2**
Concrete (metric tons)	20	0.89	5	0.2	Neg.	5,062
Ferrous metal (metric tons)	2	0.11	0.62	0.02	Neg.	626
Trash (metric tons)	0.066	0.003	0.12	Neg.	Neg.	17
Unrestricted Release Alternative Total (metric tons)	22	1	6	0.22	0.05	5,075
Total US Annual Emissions[2]	–	–	2,390,900	130,909	90,909	na

[1]Solid Material Generated by Commercial Nuclear Power Reactors.
[2] (EPA 2004a) NEI Total emissions for all heavy duty diesel engines in 1999. CO_2 emissions are not reported in the NEI totals.

Concrete

Initially, large pieces of reinforced concrete are generated during the demolition process. These large pieces must be broken up into smaller pieces that can be loaded into trucks and to remove the ferrous metal reinforcing bars. The concrete that is targeted for disposal is loaded into trucks for transportation to landfills. The concrete that is to be used as road bed aggregate is loaded into trucks for transport to a facility that will break the pieces into smaller sizes, using similar equipment as that used at the licensed facility. Finally, the sized aggregate is transported to the road construction site, and the unusable pieces to a disposal facility.

Concrete Rubbilization

The size-reduction processes can emit fugitive dust. Additional fugitive releases may be generated as the material is loaded into trucks for removal from the site. Similarly, other size-reduction processes at transfer station operations at which concrete rubble is processed are also potential sources of fugitive dust emissions. The fugitive dust generated by these mechanical activities includes mass in the smaller size range (<10 μm diameter particles) and has the potential to be transported to downwind receptor locations. Most of the particles larger than 10 μm are removed from the atmosphere by gravitational settling near the air emission source and are not generally considered in air quality analyses. Depending upon wind speed and direction and other atmospheric conditions, populations living close to the licensee's facility or to other facilities where concrete rubble is processed for size reduction could be exposed to ambient air concentrations of fugitive dust. Such exposures would depend upon local meteorological conditions, the hours of operation of the processes, and dust suppression measures that are applied during the process.

Fugitive dust emissions from these types of operations are typically controlled by wetting the materials or some other dust suppression method. Emissions from these activities are low and estimates are not included as a separate source category in routine air emissions inventories. Emission factors for stone and aggregate crushing, screening and secondary crushing processes are used as a surrogate to represent an estimate of the contribution of these processes to air emissions loads. Emission factors for fugitive dust emissions in the PM10 size range from the crushing processes range from 0.0007 to 0.015 expressed in units of lbs/ton of processed material. The emission factors for fugitive dust during loading and unloading processes range from 0.000016 to 0.0001 (lb/ton loaded or unloaded). Emission factors for the 2.5 μm size range have not been finalized for many of these processes. EPA estimates PM2.5 emissions in the NEI by applying size fraction assumptions to source categories that lack a PM2.5 emission factor. Emissions of PM10 associated with the Alternatives are compared to annual PM2.5 emissions estimates to provide a conservative assessment of the potential air impacts.

Total fugitive dust emissions generated by crushing and sorting the concrete is estimated to be 157.5 metric tons if all 19.8 million tons of the concrete is completely processed into road bed aggregate. This total assumes two loading and unloading operations (one at the licensed facility and one at the aggregate processing facility). Emissions are smaller for the concrete that is disposed in a landfill because less crushing and screening is required. If it is assumed that these operations will occur uniformly over a 47 year period, the annual emissions are 3.35 metric tons per year. The annual emissions of the smaller size fraction PM2.5 represented in the 1999 NEI inventory (EPA 2004a) for crushing and screening processes is 46.2 short tons.

Heavy Equipment Operation

A variety of types of equipment that use heavy duty diesel engines can be used to process the concrete. These engines emit particulate matter in both size ranges, oxides of nitrogen (NO_x), carbon monoxide (CO), volatile organic compounds (VOC), and small amounts of HAP pollutants. The emission factors for these engines are represented in units of grams per horsepower-hour. The following assumptions were used to develop emissions estimates for the heavy equipment engines. Primary crusher engines rated at 200 horsepower can process 10 short tons of concrete per hour. Bull dozers rated at 100 horsepower can create piles of concrete at a rate of 10 short tons per hour. Finally, front end loaders rated at 100 horsepower, can load five tons of concrete per hour into trucks. These assumptions result in emissions estimates of 1,050 metric tons of particulate matter, 4,376 metric tons of NO_x, 910 metric tons of CO, and 1,132 metric tons of VOC.

Road Bed Construction

The aggregate produced from recycled concrete is assumed to be incorporated into road bed underlayment during road construction. Following road way preparation, and before paving, this aggregate is spread on the road bed to serve as a support for the paving materials, and to stabilize the materials under the asphalt or concrete used as paving material. There is a potential for fugitive dust emissions during these processes, but in most cases dust suppression methods are applied during road construction. EPA has not published recommended emissions estimation methods or emission factors for this activity, and typically emissions from these processes are not included in standard air emissions inventories. Since emissions are expected to be minimal, and there is no recommended estimation method, emissions from this activity are not addressed quantitatively in this Draft GEIS.

Overall criteria pollutant emissions from processing and transportation of concrete released from licensed facilities under the Unrestricted Release and Limited Dispositions Alternatives represents a small fraction of the total national emissions associated with processing and transportation of concrete generated from all demolition and concrete recycling operations nationwide. A comparison of total estimated criteria pollutant emissions associated with the Unrestricted Release and Limited Dispositions Alternatives and total national emissions is shown in Table I-6. Overall emissions from recycling of concrete released from licensed facilities is estimated to be 0.2 percent or less of national emissions from concrete recycling.

Ferrous Metal

Processing ferrous metal for recycling under the Unrestricted Release Alternative involves the same general categories of emission sources as those described for concrete. Ferrous metal would not be recycled under the Limited Dispositions Alternative, but would be disposed of in landfills. Air emissions from landfill disposal of ferrous metal are included in Section 3.3. The process of breaking the concrete into smaller pieces to remove ferrous metal reinforcing bars is

Table I-6 Unrestricted Release and Limited Dispositions Alternatives Emissions from Concrete Recycling (metric tons)

	PM_{10}	VOC	NO_x	CO
Concrete Rubblization (metric tons)	158	Not applicable	Not applicable	Not applicable
Heavy Equipment Operation (metric tons)	1,050	1,132	4,376	910
Transportation (metric tons)	10	Not available	278	Not available
Road Bed Construction	[emission factors for road bed construction unavailable]			
Total Emissions (metric tons)	1,219	1,132	4,654	910
Annual Emissions (metric tons/year)	26	24	99	19
National Average Emissions (metric tons per year, all heavy duty diesel highway vehicles)	145,152	36,817	1,404,080	217,531
Percent of National Average	0.02	<0.01	< 0.01	<0.01

(1) Total emissions are projected to occur over a period of 47 years.

the same process described for concrete and no additional fugitive dust emissions would be generated solely because of the extraction of ferrous metal reinforcing bars. Heavy equipment will be used to load the ferrous metal into trucks, transportation sources will create air emissions during the transport of the ferrous metal, and emissions result from the furnaces where the ferrous metal is melted to be recast into ingots, sheets, rolls or bars.

Smelting Furnace

The recycled ferrous metal scrap is assumed to be recycled in one of three specific furnace types. Since it is not possible to determine the exact flow of ferrous metal to different reprocessing facilities, an average emission factor has been used. The average emission factor is based on the assumption that all of the recycled ferrous metal scrap is processed in one of the three primary furnace types used in commercial ferrous metal recycling. The three types of furnaces are electric arc furnace, the basic oxygen furnace (or an oxygen lanced foundry), and the open hearth foundry furnace. NUREG-1640 provides an estimate of the percent of scrap ferrous metal recycled in the U.S. that flows through each of these major recycling furnace types. Table I-7 summarizes the PM10 emission factors for each furnace type (EPA Compilation of Emission Factors, EPA Publication AP-42). NRC has assumed for the purposes of the air emissions impact assessment that the percent of ferrous metal scrap throughput directed to each furnace type for the licensee-released scrap ferrous metal is the same as that for the U.S. as a whole. The percent throughput estimate is used as a weighting factor for each process-specific particulate emission factor to derive a weighted average emission factor for the scrap ferrous metal smelting process. This factor is multiplied by the estimated total tonnage of scrap ferrous metal to be released under the Unrestricted Release Alternative to derive the emission rate for the smelting process. The weighting calculation for the particulate emission factor is summarized in Table I-7.

Table I-7 Ferrous Metal Scrap Smelting Particulate Emission Factor Derivation

Furnace Type	Emission Factor (lb/ton)	Fractional Throughput	Weighting Contribution
Electric Arc Furnace	13	0.581	7.553
Open Hearth Foundry	11	0.216	2.376
Oxygen Lanced Foundry	10	0.203	2.03
Weighted Average emission factor			11.959 lb/ton (5.98 kg/MG)

Application of the weighted average emission factor, and assuming that all 2.45 million tons of ferrous metal is recycled yields a total emission estimate for uncontrolled particulate matter of 13,319 metric tons. Typically, ferrous metal furnaces employ a particulate matter control device that achieves an average of 95 percent control efficiency. Applying that level of control yields 666 metric tons of particulate matter from the furnace operation. Additional particulate matter emissions result when metal fumes condense during the pours to form ingots, rolls, or sheets of ferrous metal that can be used in further processing. The emission factor for that process is 2.8 lb/ton (1.4kg/MG). Since it is more difficult to control those emissions resulting from the pours, no control efficiency is applied to the emissions from that process. It is assumed that the complete processing of recycled ferrous metal requires two melts and two pours. The first set of melt and pour is assumed to create an ingot, roll of sheet output, convenient for storage and transport to a second processing site where some final use product is cast. The total emissions of particulate matter for the recycling operation is 8,362 metric tons or 178 metric tons per year. That total represents 8.8 percent of the total annual particulate matter emissions from secondary ferrous metal production in the 1999 NEI inventory.

The emissions of SO_2, NO_x, CO and VOC associated with ferrous metal furnaces is dependent on the fuels used, and other operating characteristics of the furnaces. The emissions of these other air pollutants are assumed to change by the same 8.8% factor that was calculated for particulate matter.

Heavy Equipment Operation

Heavy equipment powered with heavy duty diesel engines are used to collect the scrap ferrous metal at the demolition site, transfer the ferrous metal to trucks or rail cars, and to transfer the ferrous metal to the feed stock at the ferrous metal processing furnaces. Similar types of equipment as those described for the removal of concrete are used to remove the ferrous metal. The estimate for emissions from heavy equipment used to process ferrous metal assumes that a bull dozer rated at 100 horsepower can aggregate 2 short tons of scrap ferrous metal per hour, and that a front end loader can transfer 20 short tons of ferrous metal per hour into trucks or rail cars. The total emissions assume two cycles of the transfer process, one at the licensed facility and one at the processing facility.

Summary

Overall criteria pollutant emissions from processing and transportation of ferrous metal released from licensed facilities under the Unrestricted Release Alternative represents a small fraction of the total national emissions associated with processing and transportation of ferrous metal generated from all ferrous metal recycling operations nationwide. A comparison of total estimated criteria pollutant emissions associated with the Unrestricted Release Alternative and total national emissions is shown in Table I-8. The emissions resulting from the smelting operation may approach 8% of the emissions from a typical year of ferrous metal processing. Overall emissions from the transportation and recycling of ferrous metal released from licensed facilities are estimated to be <0.01 percent of the average annual emissions that result from the combined effect of heavy equipment, heavy-duty highway diesel engines and recycling.

Table I-8 Unrestricted Release Alternative
Air Emissions from Ferrous Metal Recycling
(metric tons)

	PM_{10}	SO_2	VOC	NO_x
Smelting Furnace	8,325	2,905	4,554	7,022
Heavy Equipment Operation	36	-	60	772
Transportation	0.864	NA	NA	2,294
Total Emissions	8,362	2,905	4,614	7,248
Total Emissions (metric tons/year)	178	62	98	154
National Average Emissions (metric tons per year)	43,999	9,121	33,538[1]	547,788
Percent of National Average	0.4	0.67	2.9	<0.01

(1) Secondary ferrous metal production only.

Trash

Under the No Action, Unrestricted Release, and Limited Dispositions Alternatives, trash would be disposed of in an EPA/State-regulated landfill. No recycling or reuse of trash is anticipated under any Alternative. Air emissions from trash landfill disposal and trash incineration are discussed under the EPA/State-Regulated Disposal Alternative in Section 3.3.

3.3 EPA/State-Regulated Disposal Alternative

The EPA/State-Regulated Disposal Alternative has similar emissions characteristics to the No Action, Unrestricted Release, and Limited Dispositions Alternatives with respect to handling and transportation of the materials released at licensed facilities. Under the No Action, Unrestricted Release, and Limited Dispositions Alternatives and the EPA/State-Regulated Disposal Alternative, materials released from licensed facilities would be processed to size and sorted at the licensed facility, and then transported from the licensed facility. These activities and their emissions characteristics would be identical for the EPA/State-Regulated Disposal Alternative.

However, under the EPA/State-Regulated Disposal Alternative, all of the materials would be disposed rather than recycled. Mobile source emissions and fugitive dust emissions would be associated with the placement of the materials in EPA/State-regulated disposal facilities.

Concrete and Ferrous Metal

Under the EPA/State-Regulated Disposal Alternative solid materials would not be recycled but would be transported to an EPA/State-regulated landfill for disposal. For concrete, the same rubbilization, heavy equipment, and transportation activities would be conducted under the EPA/State-Regulated Disposal Alternative as under the No Action, Unrestricted Release, and Limited Dispositions Alternatives, and the air emissions per ton of concrete processed are assumed to be identical. Under the EPA/State-Regulated Disposal Alternative, the rubbilized concrete would be transported in trucks an average of 58 miles (93.3 kilometers) to an EPA/State-regulated disposal facility rather than transported an average of 198 miles (318.6 kilometers) to a recycling location. Fugitive particulate emissions from disposal of concrete rubble in a EPA/State-regulated landfill would be negligible (see assumptions in Appendix K).

For ferrous metal the overall emissions would be lower under the EPA/State-Regulated Disposal Alternative and the Limited Dispositions Alternative than under the No Action and Unrestricted Release Alternatives, as under the EPA/State-Regulated Disposal Alternative and Limited Dispositions Alternative there would be no process emissions from smelting of the ferrous metal. Air emissions from transportation of ferrous metal to the EPA/State-regulated disposal facility are assumed to be identical to those estimated for the No Action and Unrestricted Release Alternatives.

Trash

Trash released by licensed facilities is assumed to be sent to either EPA/State-regulated landfills or to EPA/State-regulated solid waste incinerators. Trash will be collected and sorted if necessary to produce waste piles at the licensed facilities. Heavy equipment will be used to load that waste into trucks for transport to the landfill or incinerator location. The potential for fugitive dust emissions during these processes is minimal, since trash will contain a very small amount of particulate matter that can be dislodged to find its way into the air. The loaded trucks will generate air emissions during transport. Additional heavy equipment will be used to transfer the trash to feed stock at the incinerator, or to place the trash in the landfill. The assumptions used to estimate air emissions from the removal of trash and the resulting emissions estimates are described.

Heavy Equipment Operation

It is assumed that a bull dozer rated at 100 horsepower can gather 0.5 short tons of released trash per hour, and that front loaders rated at 100 horsepower can load 0.5 short tons of trash into trucks per hour. The same assumption is used for unloading at the facility and moving the material into place as either a feed stock for an incinerator or into position in the landfill. The emissions estimates for the assumed 66,000 metric tons of trash from power generating reactor units yields an estimate of 67 metric tons of PM10, 186 metric tons of NO_x, and 94 metric tons of CO.

Transportation

Transportation air emissions for the EPA/State-Regulated Disposal Alternative for trash are the same as the estimates for the No Action, Limited Dispositions, and Unrestricted Release Alternatives for trash.

EPA/State-Regulated Landfill Disposal

Typically, operations at EPA/State-regulated landfills are controlled to keep the potential for fugitive emissions at a minimum. Currently, there are no recommended approaches to estimate these emissions and it is assumed that any fugitive dust emissions from the landfilling process are negligible.

EPA/State-Regulated Incineration

Under the EPA/State-Regulated Disposal Alternative, trash could be incinerated. EPA/State-regulated solid waste incinerators are designed to achieve near complete combustion of the organic material included in the trash stream. Therefore, a well designed and operated incinerator typically results in very low emissions of CO. As with all combustion sources some of the nitrogen in the air supplied to the unit would be oxidized to NO_x during the combustion process. The emission rates of VOC and PM from the incinerator would depend on the specific combustor design and operation, the nature of the trash, and the characteristics of the incinerator air emission control system. Inorganic materials in the trash could be released as particulate matter in the incinerator flue gas stream to the incinerator stack, and these emissions would disperse into the atmosphere and be transported to off site receptors. Some organic materials in the trash may not achieve complete oxidation and result in formation of products of incomplete combustion, which would also be emitted in the stack gas. Depending upon the composition of the trash and the conditions of the incineration process and air emission control system, polycyclic organic matter and chlorinated dioxins and furans could be formed in the incinerator and emitted in the stack gas. Incinerators are subject to emissions limitation standards to control the amount of these hazardous air pollutants and the incremental contribution of the trash released from licensed facilities is negligible.

There are three primary types of combustion technology used in solid waste incinerators: mass burn, refuse-derived fuel (RDF), and modular combustors. Mass burn units charge the combustion chamber with waste that has not been separated or processed prior to firing. Typically, these units operate by moving the waste material through the combustion zone on a grate and add both underfeed and overfeed air. The excess air facilitates near complete combustion but can also increase the particulate matter emissions, by causing some of the PM to entrain into the flue gas stream rather than being collected in the ash pit beneath the traveling grate.

In RDF combustors the fuel is processed by shredding or by finely dividing the fuel into a dust that is suitable for co-firing with pulverized coal. The waste is typically processed by sorting out all noncombustible materials and shredding the remaining fuel. The use of the shredded fuel increases the heat value of the fuel and facilitates near complete combustion.

Modular combustors also use unprocessed waste as the fuel but include two chambers. In one style of modular combustor the initial chamber is operated in a starved air mode to drive off volatile organic compounds (VOC) and CO. The exhaust is then subject to a second round of combustion with excess air to achieve the near complete combustion result. Another form uses excess air in the initial chamber and refires the exhaust in the second chamber again. The use of these designs is dependent on the nature of the waste stream.

The impacts of trash disposal from licensed facilities is estimated by applying the expected emissions from the use of heavy equipment to collect and transfer the material from the facilities to trucks and then from the trucks to the disposal site. Emissions from the highway transport of the trash are assumed to be negligible in comparison to the overall average annual heavy duty highway diesel vehicle emissions. Similarly, fugitive dust emissions during the process of landfill disposal are assumed to be negligible.

Overall criteria pollutant emissions from heavy equipment operation, transportation, and landfill disposal or incineration of trash released from licensed facilities under the EPA/State-Regulated Disposal Alternative represents a small fraction of the total national emissions associated with solid waste transportation, landfill disposal, and incineration. Emissions impacts from landfill disposal are estimated to be less than for the incineration option since landfill disposal does not include the combustion process. A comparison of total estimated criteria pollutant emissions associated with the EPA/State-Regulated Disposal Alternative and total national emissions is shown in Table I-9. Overall emissions are estimated to be 0.01 percent or less of the national emissions for solid waste disposal.

Table I-9 EPA/State-Regulated Disposal Alternative – Trash Air Emissions from Trash Landfill Disposal/Incineration

	PM_{10}	NO_x	CO
Heavy Equipment (metric tons)	67	186	94
Transportation (metric tons)	negligible	0.11	negligible
Landfill Disposal	negligible	negligible	negligible
Incineration (metric tons)	104	151	58
Total Emissions			
Landfill Disposal (metric tons)	67	186	94
Incineration (metric tons)	171	202	152
National Average Emissions (metric tons per year)			
Landfill Disposal	27,880	280,083	207,811
Incineration	29,810	307,415	216,109
Percent of National Average			
Landfill Disposal	<0.01	<0.01	<0.01

Table I-9 EPA/State-Regulated Disposal Alternative – Trash Air Emissions from Trash Landfill Disposal/Incineration

Incineration	0.01	<0.01	<0.01

3.4 Low-Level Waste Disposal Alternative

Activities that would generate air emissions for the LLW Disposal Alternative would be similar to those for the EPA/State-Regulated Disposal Alternative, with the exception that trash would not be incinerated under the LLW Disposal Alternative and solid materials may be transported to the LLW disposal facility by railcar in addition to by truck.

For this Alternative all of the potentially clearable materials generated from licensed facilities would be transported to a LLW disposal facility. For the purposes of this analysis all materials are assumed to be taken to the Envirocare disposal facility in Utah. For the LLW Disposal Alternative, all of the processes associated with handling and loading the solid materials would be identical to those discussed above for the No Action, Unrestricted Release, Limited Dispositions, and EPA/State-Regulated Disposal Alternatives. The transportation emissions would be much higher for the LLW Disposal Alternative, however, because the average transportation distance from the licensed facilities to the LLW disposal facility is 1,544 miles (2,482 kilometers) rather than 58 miles (93.3 kilometers) for the EPA/State-Regulated Disposal Alternative. The transportation emissions calculated for the LLW Disposal Alternative are 7 metric tons or 0.15 metric tons per year for SO_2, 703 metric tons or 15 metric tons per year for NO_x, and 26 metric tons or 0.6 metric tons per year for PM10. These emission totals are insignificant relative to the total annual emissions for heavy duty diesel trucks based on national emissions trends.

3.5 Limited Dispositions Alternative

For the Limited Dispositions Alternative, it is assumed that air emissions from reuse of tools and equipment are negligible. Air emissions from recycling of concrete into road bed material under the Limited Dispositions Alternative would be similar to the air emissions for concrete under the No Action and Unrestricted Release Alternatives as discussed in section 3.2. Air emissions from EPA/State-regulated landfill disposal of ferrous metal and trash would be similar to the air emissions for ferrous metal and trash landfill disposal under the EPA/State-Regulated Disposal Alternative as discussed in Section 3.3. Thus, as discussed in Sections 3.2 and 3.3, the impacts to air quality for the Limited Dispositions Alternative would be small.

APPENDIX J
COMPARISON OF TYPES OF DISPOSAL FACILITIES

1.0 INTRODUCTION

The Alternatives consider several disposal options for solid materials cleared from Licensed Facilities, including disposal in an EPA/State-regulated Subtitle D Landfill and disposal in an Low Level Waste Disposal Facility. This appendix provides a more detailed comparison of four disposal facility types to the landfill (hereafter referred to as the "SC&A Reference Landfill") used for both the Scenario C and Scenario D analyses in SC&A 2003.

The four disposal facility types analyzed include:

a) Subtitle D Municipal Solid Waste Landfills,
b) Subtitle D Industrial Landfills,
c) Subtitle D Construction and Demolition Landfills, and
d) Low Level Waste Disposal Facilities

The comparative analysis presented herein identifies specific disposal facility parameters that contribute to the analytical results reported in SC&A 2003, Section 9.2 Exposures Due to Disposal of Cleared Material in a Landfill. The analysis tabulates the parameters for each of the four disposal facility types of interest, as well as for the SC&A Reference Landfill. The SC&A Reference Landfill used in both Scenario C and Scenario D has some characteristics of Subtitle D Municipal Solid Waste Landfills and some characteristics of Subtitle D Industrial Landfills. A sensitivity analysis evaluates the effect of varying the individual parameters.

The Resource Conservation and Recovery Act (RCRA) of 1976 (42 USC 82, Subchapter IV) is a federal statute which deals with the disposal of hazardous and solid wastes. RCRA Subtitle C governs the hazardous waste program. Hazardous waste is defined as a listed waste or a characteristic waste (*40 CFR Part 261*). A listed hazardous waste is waste that is found on specific EPA lists of hazardous wastes. A characteristic hazardous waste is a waste that exhibits any one of four characteristics (i.e. ignitability, reactivity, corrosivity, or toxicity). Hazardous waste excludes household hazardous wastes. RCRA Subtitle D provides the regulation of non-hazardous waste, as well as hazardous waste specifically excluded from RCRA Subtitle C. Subtitle D of RCRA also authorized regulation of State or regional solid waste plans. The promulgated solid waste regulations appear in *40 CFR Part 239 to 282*, with Part 257 Criteria For Classification Of Solid Waste Disposal Facilities And Practices and Part 258 Criteria For Municipal Solid Waste Landfills specifying the siting, design, operational, monitoring, and closure requirements.

This appendix includes three attachments. Attachment 1 provides spreadsheets containing input and output data which support the graphs appearing within this appendix. Attachment 2 provides an analysis of the availability of existing capacity for the various disposal facility types. Attachment 3 provides a detailed regulatory comparison of Subtitle C and Subtitle D landfills.

2.0 ANALYTICAL APPROACH

The comparative analysis looks at radionuclide migration from the waste materials to the leachate generated within the disposal facilities and its subsequent release to the environment. We define release as a point of potential leachate contact with a human or ecological receptor. Leachate may be extracted with a leachate collection system, may escape a bottom liner if present, or may pass directly into underlying soils in the absence of a bottom liner. The operation of a leachate collection system is assumed to have no effect on the leaching of activity from the waste. Collected leachate is assumed to be discharged to surface water. No credit for reduction in radioactivity is taken for treatment of the leachate prior to surface water discharge. Leachate which is not collected by a leachate collection system is assumed to eventually enter groundwater. The points of release are the discharge of leachate, the extraction of groundwater from a well, or the discharge of groundwater into a surface water body.

The analytical procedure used in SC&A 2003 is repeated for each of the four disposal facility types to determine the ratio of radionuclide releases from each of the disposal facility types to the radionuclide releases from the SC&A Reference Landfill. The SC&A 2003 analysis used a combination of deterministic and probabilistic input parameters for the SC&A Reference Landfill. In the comparative analysis, mean values reported in SC&A 2003 are substituted for probabilistic input parameters for the SC&A Reference Landfill.

The SC&A 2003 analysis methodology is summarized below. For each equation, we identify parameters which are held constant in the comparative analysis because they are independent of disposal facility type and parameters which may differ because they are dependent on disposal facility type. The SC&A 2003 equations referenced are identified by the equation numbers used in SC&A 2003.

SC&A 2003 Equation 9.3

The release in any subsequent year k of the nth radionuclide due to the disposal of activity α_i in year j is calculated by:

$$R_n(j+k) = f_d \alpha_1(j) \beta_n L_n \left(1 - L_n\right)^k e^{-\lambda_n k} \quad 0 \le k \le 1000 - j \qquad \text{(J.1)}$$

where landfill independent variables include:

f_d = fraction of activity disposed of in the landfill (dimensionless), user specified

$\alpha_l(j)$ = total activity released from the licensee l during year j (Ci), calculated by the material pulse model

β_n = radionuclide n fraction of total activity, user specified

λ_n = n^{th} radionuclide decay constant (yr^{-1})

and landfill dependent variables include only:

L_n = first-order leach rate constant for the nth radionuclide (yr^{-1})

To compare different disposal facility types, Equation J.1 reduces to:

$$R_n(j+k) = \left[f_d \alpha_1(j)\beta_n\right] L_n (1-L_n)^k e^{-\lambda_n k} \quad \text{(J.2)}$$

$$R_n(j+k) = \left[C_1\right] L_n (1-L_n)^k e^{-\lambda_n k} \quad \text{(J.3)}$$

The sum of all annual releases of radionuclide n equals:

$$\sum_{i=0}^{k} R_n(j+i) = CL_n\left[1 + (1-L_n)^1 e^{-\lambda_n 1} + \ldots + (1-L_n)^{(k-1)} e^{-\lambda_n (k-1)} + (1-L_n)^k e^{-\lambda_n k}\right] \quad \text{(J.4)}$$

Multiplying both sides of Equation J.4 by the annual release decay factor yields:

$$(1-L_n)e^{-\lambda_n}\sum_{i=0}^{k} R_n(j+i) = CL_n\left[(1-L_n)^1 e^{-\lambda_n 1} + (1-L_n)^2 e^{-\lambda_n 2} + \ldots + (1-L_n)^k e^{-\lambda_n k} + (1-L_n)^{(k+1)} e^{-\lambda_n (k+1)}\right] \quad \text{(J.5)}$$

Subtracting Equation J.5 from Equation J.4 yields:

$$\left[1-(1-L_n)e^{-\lambda_n}\right]\sum_{i=0}^{k} R_n(j+i) = CL_n\left[1-(1-L_n)^{(k+1)} e^{-\lambda_n (k+1)}\right] \quad \text{(J.6)}$$

$$\sum_{i=0}^{k} R_n(j+i) = CL_n \frac{1-(1-L_n)^{(k+1)} e^{-\lambda_n (k+1)}}{1-(1-L_n)e^{-\lambda_n}} = CL_n \frac{1-\left[(1-L_n)e^{-\lambda_n}\right]^{(k+1)}}{1-(1-L_n)e^{-\lambda_n}} = Cf(L_n) \quad \text{(J.7)}$$

Therefore when comparing two disposal facilities with the same inventory, disposal timing, and activity levels of disposed radionuclides, the only characteristic which affects the total radionuclide activity released is the leach rate constant. The ratio of the total activity released from each disposal facility type compared to the total activity released from the SC&A Reference Landfill equals:

$$\sum_{i=0}^{k} R_n(j+i) = \frac{f(L_n)}{f(L_n)_{REF}} \left[\sum_{i=0}^{k} R_n(j+i) \right]_{REF} \tag{J.8}$$

SC&A 2003 Equation 9.4

The first-order leach rate constant is defined by RESRAD Equation E.3 (ANL 2001) as the following:

$$L_n = \frac{I}{\theta^{cz} T_0 R_{dn}^{cz}} \tag{J.9}$$

where each of the following variables are landfill dependent:

I = infiltration rate (m/yr)

$\theta^{(cz)}$ = volumetric water content[1] of the contaminated zone (dimensionless)

T_0 = initial thickness of the contaminated zone (m)

$R_{dn}^{(cz)}$ = retardation factor in the contaminated zone for radionuclide n (dimensionless)

SC&A 2003 Equation 9.5

In Equation J.9, the retardation factor for radionuclide n, R_{dn}, is the ratio of the average pore water velocity to the radionuclide transport velocity. On the basis of the assumption that the adsorption-desorption process can be represented with a linear isotherm (ANL 2001), the retardation factor can be calculated with RESRAD, Equation E.8:

$$R_{dn} = 1 + \frac{\rho_b K_{dn}}{p_t R_s} \tag{J.10}$$

[1] Volumetric water content equals the volume of water per unit volume of waste (all phases).

where landfill dependent variables include:

ρ_b = bulk waste density (g/cm3)

K_d = distribution coefficient (cm^3/g)

p_t = total porosity (dimensionless)

R_s = saturation ratio (dimensionless)

Since the volumetric water content in Equation J.9 is defined as the product of the total porosity and the saturation ratio, Equation J.10 can be rewritten as follows:

$$R_{dn} = 1 + \frac{\rho_b K_{dn}}{p_t R_s} = 1 + \frac{\rho_b K_{dn}}{\theta^{cz}} \tag{J.11}$$

For each disposal facility type, the release of radionuclides is a function of the 5 parameters which define the leach rate constants. These 5 parameters are listed below.

I = infiltration rate (m/yr)

$\theta^{(cz)}$ = volumetric water content of the contaminated zone (dimensionless)

T_0 = initial thickness of the contaminated zone (m)

ρ_b = bulk waste density (g/cm3)

K_d = distribution coefficient (cm^3/g)

3.0 DESCRIPTION OF LANDFILL TYPES

This section describes the 5 disposal facility types (including the SC&A Reference Landfill) and determines the value of each of the 5 parameters required to calculate the leach rate constants. No attempt has been made in this analysis to examine the effect of disposal facility location, distance from the Licensed Facility generating the material for disposal, area of the disposal facility, or distance to potential downgradient receptors. The SC&A 2003 analysis used as its primary source for landfill-specific parameters the Nationwide Database of Landfill Sites information published in Appendix D of EPA 2003 (EPA 2003i). The EPA database contains landfill specific data on 790 Subtitle D industrial landfills from a nationwide 1985 survey.

Given the broad geographic distribution of the EPA data for Subtitle D Industrial Landfills and the broad distribution of Subtitle D Municipal Solid Waste Landfills and Subtitle D Construction and Demolition Landfills throughout the nation, this analysis assumes that any regional weightings applied in the SC&A 2003 analysis would also apply reasonably well to the other two landfill types. This leads to the proposition that a comparative analysis of the ratio of total radionuclide activity released from each landfill type based on nationwide mean landfill parameters would be equally valid as an analysis based on regionally weighted parameters since any adjustment for regional weighting would apply equally to all Subtitle D landfill types, within the limits of the precision of the overall analysis. Since any solid materials within the scope of the Proposed Action destined for disposal at a LLW disposal facility are assumed to be sent to the Clive, Utah disposal facility run by Envirocare, the comparative analysis uses site specific parameters to calculate the LLW disposal facility leach rate constant.

3.1 SC&A Reference Landfill

3.1.1 Landfill Description

The SC&A Reference Landfill used in SC&A's Scenario C and Scenario D combines characteristics of both Subtitle D Municipal Solid Waste Landfills and Subtitle D Industrial Landfills. The SC&A Reference Landfill has a clay cap and a leachate collection system, both of which are assumed to function for 50 years after emplacement of the waste[2]. After the end of the 50 year period leachate is assumed to enter groundwater. The SC&A Reference Landfill does not have a bottom liner.

Several of the input parameters used in the SC&A 2003 analysis are subject to alternative interpretation. For the purposes of this comparative analysis, the accuracy of the SC&A 2003 input parameters is in itself not important to the relative ranking of landfill types, but does affect the accuracy of the results for the SC&A Reference Landfill itself. In the comparative analysis, the objective is to replicate the SC&A Reference Landfill input parameters to establish a benchmark value for released activity, albeit with the substitution of deterministic values for probabilistic distributions. The discussion of each input parameter allows the reader to judge

[2] The 50 year time frame is base on the midpoint of the assumed 40 year operating life of the SC&A Reference Landfill (i.e. 20 years) plus a 30 year post-closure period during which the clay cap and leachate collection system would continue to be maintained.

each parameter's validity, and the transparency of the analytical method allows the reader to evaluate the effect of selecting different input parameters.

3.1.2 Infiltration

Infiltration in SC&A Equation 9.4 pertains to the rate at which water/leachate percolates into and through the contaminated zone. SC&A 2003 used landfill leakage values from Table 4.3 in EPA 2003, but these exfiltration values represent the rate at which leachate emanates from the base of the landfill into the underlying soils, not the rate of infiltration.

For the first 50 years following waste emplacement, the SC&A analysis used the reported exfiltration values for the EPA 2003 Clay Liner case as infiltration values. The EPA 2003 Clay Liner case modeled flow from a landfill with no leachate collection system and with the following profile[3,4], from top to bottom:

- a 1-ft. (0.30m) layer of loam to support vegetation and drainage
- a 1-ft. (0.30m) percolation layer
- a 3 ft. (0.91m) clay cover with a hydraulic conductivity of 1.0E-07 cm/sec
- a 10-ft. (3.0m) waste layer
- a 3-ft. (0.91m) clay liner with a hydraulic conductivity of 1.0E-07 cm/sec

After 50 years, the SC&A 2003 analysis assumes that the clay cap fails, and that the infiltration rate will be similar to the exfiltration rates reported for the No Liner case in EPA 2003. The landfill profile in the EPA 2003 No Liner case consists only of a 2 ft. thick final cover of either a sandy loam, silty loam, or silty clay loam soil randomly selected according to a nationwide frequency distribution. The thickness of the EPA 2003 No Liner case waste layer is not indicated. The final cover soils in the EPA 2003 No Liner case have the following properties shown in Table J-1.

[3] EPA 2003 contains discrepancies in the modeled landfill profile. The text in EPA 2003 Section 4.3.1 indicates the presence of a 1 ft. percolation layer above the bottom liner, but the more detailed description in EPA 2003 Appendix A, Section A.1.3 omits this layer and specifically refers to a four layer model. Table A.1 in Appendix A places the 1 ft. percolation layer between the vegetation support layer and the clay cover.

[4] Differences between the EPA 2003 landfill profile and the SC&A Reference Landfill profile do not affect the relative ranking of the disposal facility types, but do affect the accuracy of the results for the SC&A Reference Landfill.

Table J-1 Properties of Final Cover Soil Types

Soil Type	Total Porosity (vol/vol)	Saturated Hydraulic Conductivity (cm/sec)
Sandy loam	0.453	0.000720
Silt loam	0.501	0.000190
Silty clay loam	0.471	0.000042

Source: EPA 2003, Table A.6

Table J-2 indicates the cumulative frequency distribution of landfill exfiltration for the No Liner and Clay Liner cases from EPA 2003. The data apply to flow through closed landfills. EPA 2003 does not specify the number of annual cycles analyzed for each alternative, nor whether the flow conditions reached steady state. In the absence of a leachate collection system, the steady-state infiltration rate will eventually match the steady-state exfiltration rate, but the time required to reach steady state could be a significant fraction of or could exceed the initial 50 year operating and post-closure period analyzed in SC&A 2003. The length of time required to reach steady-state flow conditions increases with landfill thickness due to internal leachate storage, and increases in more arid climates due to low infiltration rates.

Table J-2 Cumulative Frequency Distribution of Landfill Exfiltration Rates

percent	No Liner Exfiltration Rate (m/yr)	Clay Liner Exfiltration Rate (m/yr)
0	0.000010	0.000010
10	0.013500	0.009440
25	0.065800	0.025300
50	0.109000	0.043200
75	0.274000	0.044500
80	0.312000	0.047700
85	0.353000	0.047700
90	0.411000	0.048600
95	0.456000	0.048600
100	1.080000	0.052600

Source: EPA 2003 Table 4.3 (see also SC&A 2003 Table 9.29)

For the SC&A Reference Landfill, the comparative analysis uses the 50th percentile EPA 2003 Clay Liner exfiltration rate (4.32E-02 m/yr) for the first 50 years and the 50th percentile EPA 2003 No Liner exfiltration rate (1.09E-01 m/yr) for times beyond 50 years.

3.1.3 Volumetric Water Content

Volumetric water content equals the product of total porosity times the saturation ratio. To calculate the volumetric water content of the contaminated zone, both the total porosity and the saturation ratio should correspond to waste material. The SC&A 2003 analysis used total porosity data for soil from *Development of Probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 Computer Codes*, NUREG/CR-6697 (ANL 2000) based on a correlation for soil between total porosity and soil particle diameter. The mean value of the total porosity distribution for a generic soil type in NUREG/CR-6697 equals 0.425.

The SC&A 2003 analysis calculates the probability distribution of saturation ratio as a function of the infiltration rate, saturated hydraulic conductivity, and a soil specific exponential parameter, as defined by Equation J.12.

$$R_s = \left(\frac{I}{K_s} \right)^{\frac{1}{2b+3}} \qquad \text{(J.12)}$$

where

I	=	infiltration rate (m/yr)
K_s	=	saturated hydraulic conductivity (m/yr)
b	=	a soil specific exponential parameter

Although the SC&A 2003 analysis does not explicitly state whether different infiltration rates were used to calculate the saturation ratio[5] for the initial 50 year period and later periods, the comparative analysis assumes that SC&A 2003 uses probability distributions for the EPA 2003 Clay Liner exfiltration rate for the initial 50 years after waste placement and for the EPA 2003 No Liner exfiltration rate thereafter. To compute the saturation ratio for the SC&A Reference Landfill, the comparative analysis uses the 50th percentile values of these distributions for the corresponding time periods.

[5] SC&A 2003 explicitly indicates the use of different infiltration rates to calculate the leach rate constant, but not to calculate the saturation ratio. The saturation ratio of the waste would not respond instantaneously to changes in infiltration rates. Consistency in infiltration rates in the two calculations may not be necessary or desirable.

SC&A 2003 uses the cumulative frequency distribution of saturated hydraulic conductivity values reported in EPA 2003, Table 5.21 (SC&A 2003, Table 9.34). The 50th percentile value, 1.89E+03 m/yr will be used in the comparative analysis.

The soil-specific exponential parameter b is lognormally distributed. ANL 2000 reports that the mean of the lognormal distribution for a generic soil type is 1.06, so the median of b equals $e^{1.06}$, or 2.89.

Table J-3 summarizes the parameters for calculating the volumetric water content for the SC&A Reference Landfill in the comparative analysis.

Table J-3 Parameters for Volumetric Water Content

Parameter	Years ≤ 50	Years > 50
Infiltration, m/yr	0.0432	0.109
Saturated hydraulic conductivity, m/yr	1890	1890
Soil specific exponential parameter b	2.89	2.89
Saturation ratio	0.3	0.33
Total porosity	0.425	0.425
Volumetric water content	0.13	0.14

3.1.4 Thickness

The SC&A 2003 analysis used landfill depth data from Table 2.3 in EPA 2003 (SC&A 2003, Table 9.31), which is based on the database of 790 industrial landfills. The EPA depth data include all landfill layers, not just the waste, so the values reported exceed the actual waste thickness.

The comparative analysis uses the 50th percentile value of landfill thickness equal to 2.57 meters for the SC&A Reference Landfill.

3.1.5 Bulk waste density

The SC&A 2003 analysis used bulk density data from EPA 2003 which was derived from an analysis of the wet bulk densities of 4 major categories of hazardous waste (solvents, paints, petroleum products, and pesticides).

The comparative analysis uses the value 0.89 g/cm^3, which approximates the 50th percentile value based on a linear interpolation between the values for the 0th and the 53rd percentile values.

Table J-4 Industrial Landfill Depth

Probability	Depth (m)
0%	0.51
10%	0.88
25%	1.32
50%	2.57
75%	4.09
80%	4.53
85%	5.20
90%	6.13
95%	7.12
100%	10.10

Source: EPA 2003, Table 2.3

Table J-5 Waste Bulk Density

Cumulative Probability	**Waste Density (g/cm^3)**
0.000	0.7
0.530	0.9
0.550	1.12
0.551	1.13
0.553	1.28
0.640	1.30
0.728	1.33
0.815	1.34
0.826	1.36
0.904	1.46
0.905	1.50
0.906	1.62
0.994	1.63
0.995	1.64
0.996	1.65
0.998	2.1

3.1.6 Distribution Coefficients, K_d

Table 9.33 in SC&A 2003 presents radionuclide specific distribution coefficients K_d in two ways. The table presents values of the mean and standard deviation of the natural logarithm of each K_d probability distribution, providing usable information for a Monte Carlo analysis. The table also presents mean K_d values for each radionuclide for three specific soil types. Although the explanatory text is not explicit in SC&A 2003, Section 9.2.5.3 implies that the K_d probability distribution data were used in the SC&A 2003 analysis. Table J-6 lists the radionuclide-specific median values[6] of K_d from SC&A 2003 Table 9.33.

In a personal communication with SC&A, SC&A said "Equation 9.26 was used to calculate the contaminated zone K_d values, even in the non-regional data case... Therefore, the only difference between the unsaturated zone K_d's and the contaminated zone K_d's is the use of Equation 9.26." The SC&A response to comments further stated "It was always the intent to include a 'Regional Data' analysis as part of the analysis. In a regional analysis, landfill parameters would be selected based on the location of the source of the cleared material. Unfortunately, this portion of the analysis was never implemented, and the landfill parameters were selected based on national distributions. Therefore, Section 9.5 (sic)[7] (except for the K_d adjustment, Section 9.2.5.3) should have been deleted from the report."

SC&A 2003 adjusted the K_d values for total organic carbon (TOC) in accordance with Equation J-13 (SC&A 2003, Equation 9.26). Since the SC&A leaching analysis does not rely on site-specific soil type parameters, it appears that the unadjusted K_d values in the equation correspond to the K_d probability distribution data in SC&A 2003 Table 9.33.

$$\log K_{dcz} = \log K_d - m \log(TOC(1 - fnc)) \quad \text{(J.13)}$$

where

K_{dcz} = effective distribution coefficient corrected for the organic carbon concentration

K_d = distribution coefficient for conditions without the presence of organic carbon

m = slope factor
= 0.74 for Kd $\geq$ 100 L/kg
= 0.40 for Kd < 100 L/kg

[6] The value of K_d listed equals exp(μ), where μ equals the mean of the lognormal distribution Y=log(K_d). The value exp(μ) equals the median value of K_d.

[7] Section 9.2.5 (not 9.5) of SC&A 2003 discusses regional data.

TOC = total organic carbon (TOC) concentration given in parts per million (ppm), which includes all dissolved, suspended, and colloidal organic material

f_{nc} = fraction on non-complexing organic material

Since the K_d distribution data in SC&A 2003 Table 9.33 define a range of values, it is unclear what value of K_d the SC&A 2003 analysis used to select the slope factor m. In the comparative analysis, we have selected the slope factor m based on the median value of K_d. SC&A 2003 reports a median TOC value of 441 ppm derived from leachate in 8 hazardous waste landfills and a median TOC value of 377 ppm derived from leachate in 22 municipal landfills, but does not clearly state which value was used in the analysis. Since the values are so close, and since the ranges of the underlying data are similar (0 to 3,800 ppm for hazardous landfills and 9.4 to 3,400 ppm for municipal landfills), the selection of one value over the other has little effect on the overall analysis. The comparative analysis uses the municipal landfill value of 377 ppm. The fraction of non-complexing material is explicitly set to zero in both the SC&A 2003 analysis and in the comparative analysis of the SC&A Reference Landfill.

Table J-6 Radionuclide-specific Distribution Coefficients for the SC&A Reference Landfill

Radionuclide	K_d (cm^3/g)	Slope factor m	K_{dcz} (cm^3/g)
C-14	11	0.4	1
Fe-55	209	0.74	2.6
Mn-54	158	0.74	2
Co-58	235	0.74	2.9
Co-60	235	0.74	2.9
Ni-63	424	0.74	5.3
Sr-90	32	0.4	3
Nb-95	380	0.74	4.7
Zr-95	1,380	0.74	17.1
Ru-106	1,588	0.74	19.7
Ag-110m	217	0.74	2.7
Sb-125	380	0.74	4.7
I-129	4.6	0.4	0.43
Cs-134	446	0.74	5.5
Cs-137	446	0.74	5.5
Pu-238	953	0.74	11.8
Pu-239	953	0.74	11.82
Pu-240	953	0.74	11.82

Source: SC&A 2003 Table 9.33 (K_d values only)

3.2 Subtitle D Municipal Solid Waste Landfills

3.2.1 Landfill Description

The comparative analysis defines a Subtitle D Municipal Solid Waste Landfill consistent with the requirements of *40 CFR Part 258*, referenced hereinafter as the MSW Reference Landfill. The MSW Reference Landfill has a leachate collection system, a compacted clay bottom liner, and a final compacted clay cover to minimize infiltration. It also requires the use of daily cover. We assume that the landfill is filled in cells during a 40 year operating life, and that the solid materials from Licensed Facilities are placed, on average, at the midpoint of this operating life. We further assume that each cell has only daily cover soils for 10 years, an interim cover for the next 10 years, and a final cover thereafter. The leachate collection system is assumed to function for 30 years after landfill closure.

3.2.2 Infiltration

The rate of infiltration will vary with the type of cover existing in each phase of the landfill's operating life. The three phases can be briefly described as daily cover for years 0 to 10 after waste placement, interim cover for years 10 to 20, intact final cover for years 20 to 50, and failed final cover for more than 50 years after waste placement.

Daily Cover Phase

For the first 10 years following waste placement, the MSW Reference Landfill has the following profile, from top to bottom:

- alternating layers of daily cover and waste consisting of
  - 6-in. (0.15 m.) layers of daily cover material
  - 5-ft. (1.52 m) waste layers
- a 1-ft. (0.30 m) leachate collection layer
- a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec

For the first 10 years after waste placement, the surface of the MSW Reference Landfill consists of alternating sequences of exposed waste and daily cover. The conditions for surface runoff and evapotranspiration of an operating landfill are closer to those of an uncovered waste pile than to those of a closed landfill, although the daily cover may provide some reduction in infiltration. EPA 2003 reports a probability distribution for exfiltration rate from uncovered, unlined waste piles (see Table J-7). The steady-state exfiltration rate from a waste pile approximates the infiltration rate into the waste pile. We verified that the reported exfiltration values were valid for MSW by confirming that the permeability of the waste in the modeled waste pile was similar to the permeability of MSW. This waste pile exfiltration rate resulted from a HELP model (Schroeder 1994) analysis with waste consisting of coal bottom ash having a permeability of

Table J-7 Cumulative Frequency Distribution of Waste Pile Exfiltration

percent	No Liner Exfiltration Rate (m/yr)
0	0.0003
10	0.0602
25	0.1280
50	0.2550
75	0.3910
80	0.4490
85	0.4760
90	0.5380
95	0.6140
100	1.82

Source: EPA 2003, Table 4.4

4.1E-03 cm/sec[8]. This agrees well with Oweis & Khera 1998 reported values of hydraulic conductivity between 3.5E-03 cm/sec and 5.0E-03 cm/sec for municipal solid waste of intermediate density (Oweis & Khera 1998). For the comparative analysis, we use the 50th percentile exfiltration rate for uncovered, unlined waste piles equal to 2.55E-01 m/yr as the infiltration rate for the daily cover phase of the MSW Reference Landfill.

Interim Cover Phase

When the top of the landfill cell reaches its design elevation, the operator typically places an interim cover over the cell. For the period from 10 to 20 years after waste placement, the comparative analysis assumes that the landfill has the vertical profile shown below:

- a 2-ft. (0.61m) interim cover

- alternating layers of daily cover and waste consisting of

  - 6-in. (0.15 m.) layers of daily cover material

  - 5-ft. (1.52 m) waste layers

[8] There is a discrepancy in the reported permeability of coal bottom ash in EPA 2003. Section 4.3.2 refers to coal bottom ash with a moderate permeability of 4.1E-04 cm/sec, but Appendix A says the moderate permeability waste, coal bottom ash, has a permeability of 4.1E-03 cm/sec. Oweis & Khera 1998 reports a hydraulic conductivity range for coal bottom ash between 5.0E-03 cm/sec and 1.0E-01 cm/sec. The 4.1E-03 cm/sec value in EPA 2003 is presumed to be correct.

- a 1-ft. (0.30 m) leachate collection layer

- a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec

The interim cover is typically about 2 ft (0.61 m) thick, and is graded to promote runoff from the landfill. The frequency distribution of interim cover soils types is assumed to be the same as the distribution for cover soils in the EPA 2003 No Liner case. We assume that the steady-state exfiltration rates in the EPA 2003 No Liner case approximate the steady-state infiltration rates into the landfill.

For the comparative analysis, we use the 50th percentile exfiltration rate for the EPA 2003 No Liner closed landfill exfiltration rate, 1.09E-01 m/yr (see Table J-2), as the infiltration rate for the interim cover phase of the MSW Reference Landfill.

Intact Final Cover Phase

For the period from 20 to 50 years after waste placement, the comparative analysis assumes that the landfill has a final cover, and that the landfill has the vertical profile shown below:

- a 6-in. (0.15 m) vegetative support layer
- an 18-in. (0.46 m) infiltration barrier layer with a hydraulic conductivity of 1×10^{-7} cm/sec
- alternating layers of daily cover and waste consisting of
  - 6-in. (0.15 m.) layers of daily cover material
  - 5-ft. (1.52 m) waste layers
- a 1-ft. (0.30 m) leachate collection layer
- a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec

The final cover is assumed to remain intact for the period from 20 to 50 years following waste placement. Since the EPA 2003 Clay Liner landfill case has no leachate collection system, we assume that the steady-state exfiltration rates approximate the steady-state infiltration rates into the landfill. The 18 inch low permeability infiltration barrier layer in the MSW Reference Landfill is only half as thick as the clay cover in the EPA 2003 Clay Liner case. To account for the thinner barrier layer, the comparative analysis uses the 75th percentile EPA 2003 Clay Liner closed landfill exfiltration rate, 4.45E-02 m/yr (see Table J-2), as the infiltration rate for the MSW Reference Landfill with the intact final cover.

Failed Final Cover Phase

After 50 years following waste placement, the final cover is assumed to degrade[9] to the level of an interim cover and leachate collection system operation is discontinued. The comparative analysis uses the 50th percentile EPA 2003 No Liner closed landfill exfiltration rate, 1.09E-01

[9] Degradation of the final cover infiltration barrier is modeled as an instantaneous change at 50 years, but would actually occur gradually, primarily due to settlement. The degradation process could begin before and continue after the 50 year milestone.

m/yr (see Table J-2), as the infiltration rate for the MSW Reference Landfill for times beyond 50 years following waste placement.

3.2.3 Volumetric Water Content

Typical ranges for volumetric water content (Reinhart 2004) values for MSW are 0.036 to 0.205 as placed, 0.3 to 0.4 under free drainage conditions, and 0.5 to 0.6 when saturated (Reinhart 2004). These data imply that the MSW will retain infiltrated water until the water content approaches the free drainage values.

Oweis & Khera 1998 report a range of moisture content for municipal waste between 15 percent and 40 percent of dry weight, i.e. weight of water divided by weight of dry solids. For well-compacted refuse with a total unit weight of 40 lb/ft^3 (0.64 t/m^3), the preceding water contents yield volumetric water contents between 0.08 and 0.18. Saturated unit weights of MSW may reach 1.28 t/m^3, with volumetric water contents up to 75 percent.

The volumetric water content can vary during the life of the MSW in the landfill from less than 0.20 when placed to up to 0.75 when saturated. Since the operating leachate collection system will prevent the development of a leachate mound and therefore prevent saturation of the waste, in the comparative analysis we use a volumetric water content equal to 0.35, the midpoint of the range for free drainage values, for all phases of the MSW Reference Landfill. This value may overstate the volumetric water content in the early life of the landfill, and may understate it after the leachate collection system is shut down.

3.2.4 Thickness

The average thickness of municipal solid waste landfills greatly exceeds the 2.57 meter thickness used in the SC&A Reference Landfill. An analysis of the State of California Solid Waste Information System database (CA IWMB 2004) yielded the following distribution of municipal landfill waste thickness (Table J-8). The 176 sites selected for the analysis included all solid waste landfills or solid waste disposal facilities in the database which accepted municipal waste, and for which the database has total volume capacity and disposal acreage information.

The comparative analysis uses the 50th percentile value of landfill thickness equal to 13.4 meters for the MSW Reference Landfill.

3.2.5 Bulk waste density

For the MSW Reference Landfill, we use a typical bulk waste density for municipal solid waste, making the explicit assumptions that the solid materials from Licensed Facilities constitute a small percentage of the overall volume of materials in the MSW landfill and are widely distributed throughout the landfill. Oweis & Khera 1998 report total unit weights for MSW ranging from 18 lb/ft^3 to 89 lb/ft^3 depending primarily on degree of compaction and moisture content. Measured in situ total unit weights of MSW range from 35 lb/ft^3 to 44 lb/ft^3, which agrees well with the range for moderately to well compacted waste, 30 lb/ft^3 to 45 lb/ft^3. Large scale field tests conducted by measuring the amount of compacted MSW to fill a known or

Table J-8 Municipal Landfill Thickness

percent	Thickness in m
0	0.0
10	2.2
20	4.6
30	8.1
40	11.2
50	13.4
60	17.7
70	21.7
80	29.8
90	41.5
100	80

measurable volume also produce typical total unit weights between 35 lb/ft^3 and 45 lb/ft^3. If the range of total unit weights is driven largely by differences in water content, waste with densities ranging from 35 lb/ft^3 and 45 lb/ft^3 due to water content changes from 15 percent to 40 percent of dry weight would have a dry unit weight of approximately 31 lb/ft^3.

For waste compacted to a given volume, there is a relationship between bulk density and volumetric water content:

$$\rho_b = \theta\rho_w + \rho_d \tag{J.14}$$

where landfill dependent variables include:

ρ_b = bulk waste density
θ = volumetric water content
ρ_w = density of water
ρ_d = dry density

Using the free drainage volumetric water content value of 0.35 and a dry unit weight of 31 lb/ft^3, the bulk waste density for the MSW Reference Landfill becomes 53 lb/ft^3 (0.85 t/m^3).

3.2.6 Distribution Coefficients, K_d

Selection of appropriate K_d values for waste is supported by few studies and is complicated by the number and range of parameters which influence the chemistry of the waste environment. ANL 2001a provides a very thorough discussion of the complexities. As the soil-specific data in SC&A 2003 Table 9.33 show, mean K_d values can vary by about 1 order of magnitude depending on soil type. Within each soil type, K_d values can vary by more than 6 orders of magnitude, with a 4 order of magnitude range being common (ANL 2001a, Table 4).

In the comparative analysis, we have selected the median values of K_d reported in SC&A 2003 Table 9.33, and adjusted[10] them in accordance with Equation J.13. We used the median TOC value of 377 ppm derived from municipal landfill leachate, and explicitly set the fraction of non-complexing material to zero. The radionuclide specific mean values of the distribution coefficients used in the comparative analysis for the MSW Reference Landfill appear in Table J-9 below.

EPA 1999 discusses alternate approaches to estimating K_d values in waste from soil K_d data, but none of the approaches are clearly superior to the methodology suggested in SC&A. Values calculated from a regression analysis suggested in EPA 1999 are presented in Table J-10, but are not used in the comparative analysis for the MSW Reference Landfill. Each of these values fall between the raw soil K_d values and the adjusted K_d values presented in Table J-9.

Table J-9 Radionuclide-Specific Distribution Coefficients for the MSW Reference Landfill

Radionuclide	K_d (cm^3/g)	Slope factor m	K_{dcz} (cm^3/g)
C-14	11	0.4	1
Fe-55	209	0.74	2.6
Mn-54	158	0.74	2
Co-58	235	0.74	2.9
Co-60	235	0.74	2.9
Ni-63	424	0.74	5.3
Sr-90	32	0.4	3
Nb-95	380	0.74	4.7
Zr-95	1380	0.74	17.1
Ru-106	1,588	0.74	19.7
Ag-110m	217	0.74	2.7
Sb-125	380	0.74	4.7
I-129	4.6	0.4	0.43
Cs-134	446	0.74	5.5
Cs-137	446	0.74	5.5
Pu-238	953	0.74	11.8
Pu-239	953	0.74	11.82
Pu-240	953	0.74	11.82

Source: SC&A 2003 Table 9.33 (K_d values only)

[10] The K_d values in SC&A 2003 Table 9.33 come from ANL 2000, Table 3.9-1, which compiled K_d values for soil (not MSW) from five separate sources.

Table J-10 Alternate Estimates of Radionuclide-Specific Distribution Coefficients K_d for MSW Landfills, (cm^3/g)

			Serkiz 2001, Table 13				
Radionuclide	K_{dcz}, Table J-9	EPA 1999 K_d(waste)	DOC = 1 mg C/L pH =5.5	DOC = 10 mg C/L pH =5.25	DOC = 30 mg C/L pH =5.00	DOC = 100 mg C/L pH =4.75	DOC = 1000 mg C/L pH =4.50
C-14	1	7.2	2	2	2	2	2
Fe-55	2.6	56.8					
Mn-54	2	46.7					
Co-58	2.9	61.7					
Co-60	2.9	61.7					
Ni-63	5.3	93.2	400	163	8	3.8	2.2
Sr-90	3	15.3	10	4	0.2	0.1	0.1
Nb-95	4.7	86.3	160	160	160	160	160
Zr-95	17.1	212.9	600	107	17	6	3
Ru-106	19.7	234.9					
Ag-110m	2.7	58.3					
Sb-125	4.7	86.3					
I-129	0.43	3.9	0.6	0.6	0.6	0.6	0.6
Cs-134	5.5	96.6	18	12	5	5	5
Cs-137	5.5	96.6	18	12	5	5	5
Pu-238	11.8	164.3	100	18	3	1	1
Pu-239	11.8	164.3	100	18	3	1	1
Pu-240	11.8	164.3	100	18	3	1	1

Notes:
EPA 1999 values: K_d(waste)= 0.7log(K_d(soil)) + 0.3, K_d(soil) from SC&A 2003 Table 9.33

Since about one third of MSW consists of paper, we also investigated K_d values in a cellulose-rich environment. Serkiz 2001 investigated the effects of cellulose degradation and recommended K_d values for 12 of the 18 radionuclides of interest for 5 different values of pH and dissolved organic content (DOC). In Table J-10 we present the K_d values from Serkiz 2001 for informational purposes, but have not used them in the comparative analysis for the MSW Reference Landfill. The adjusted K_d values presented in Table J-9 generally agree with the Serkiz 2001 values for DOC levels between 10 and 100 mg C/L.

3.3 Subtitle D Industrial Landfills

3.3.1 Landfill Description

The comparative analysis defines a Subtitle D Industrial Waste Landfill consistent with the requirements of *40 CFR Part 257*, referenced hereinafter as the Industrial Reference Landfill. We define the Industrial Reference Landfill as having an equal probability of being unlined or having a compacted clay bottom liner. If it has a clay liner, it also has a compacted clay cover after closure. If it does not have a clay liner, the landfill has a compacted soil cover after closure. The Industrial Reference Landfill does not have a leachate collection system. These two landfill designs correspond to the EPA 2003 No Liner and Clay Liner cases. We assume that the landfill is filled during a 40 year operating life, and that the solid materials from Licensed Facilities are placed, on average, at the midpoint of this operating life. We further assume that the landfill has no cover for 20 years after waste placement and a final cover thereafter.

3.3.2 Infiltration

The rate of infiltration will vary with the surface conditions in each phase of the landfill's operating life. The three phases can be briefly described as no cover for years 0 to 20 after waste placement, intact final cover for years 20 to 50, and failed final cover for more than 50 years after waste placement.

No Cover Phase

For the first 10 years following waste placement, the Industrial Reference Landfill has the following profile, from top to bottom:

- waste material
- either a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec or no bottom liner

For the first 20 years after waste placement, the surface of the Industrial Reference Landfill consists of exposed waste. The conditions for surface runoff and evapotranspiration are similar to those of an uncovered waste pile. HELP modeling reported in Appendix A of EPA 2003 indicated that the permeability of the waste material itself influenced the predicted exfiltration rates. EPA 2003 input values for modeling the low permeability, moderate permeability, and high permeability industrial waste appear in Table J-11.

Table J-11 Moisture Retention Properties for Waste Pile Materials

Waste Type	Total Porosity (vol/vol)	Field Capacity (vol/vol)	Saturated Hydraulic Conductivity (cm/sec)
Low Permeability (electric plant fly ash)	0.5410	0.1870	0.0001
Moderate Permeability (electric plant bottom ash)	0.5780	0.0760	0.0041
High Permeability (fine copper slag)	0.3750	0.0550	0.0410

Source: EPA 2003, Table A.7 and Oweis & Khera 1998

Oweis & Khera 1998 report the annual generated quantities of industrial nonhazardous waste shown in Table J-12. The American Coal Ash Association (ACAA 2003) reports that fly ash contributes approximately 80 percent to the total, and bottom ash 20 percent. Low permeability materials including fly ash, cement and lime kiln dust, and probably silica fume make up approximately 55 percent of the total and have a permeability close to the low permeability waste modeled in EPA 2003. The remainder of the materials more closely approximate the modeled high permeability material, and include bottom ash, slags, probably roofing shingles, and probably foundry wastes for a total of 45 percent of the industrial waste. The comparative analysis considers one Industrial Reference Landfill with low permeability waste, and one Industrial Reference Landfill with high permeability waste.

Table J-12 Quantities and Hydraulic Properties of Industrial Waste

Waste Type	Land Disposal	Quantity, in million tons/yr	Percentage of Land Disposed Industrial Waste	Permeability, in cm/sec
Coal ash	Yes	72	48%	
- fly ash			38%	.000012 (1)
- bottom ash			10%	.022 (1)
Ferrous and nonferrous slags	Yes	34	23%	> 0.5 (2) .045 (3)
Reclaimed paving materials	No	103	N/A	N/A
Construction and demolition	Yes	31.5	Excluded	N/A
Cement and lime kiln dusts	Yes	24	16%	.000021 (4)
Sulfate	No	18	N/A	N/A
Lime	No	2	N/A	N/A
Roofing shingle	Yes	8	5%	Unknown
Foundry	Yes	10	7%	Unknown
Ceramic	No	3	N/A	N/A
Silica fume	Yes	1	1%	Unknown
Small quantity generator hazardous (<1000 kg/month)	No	0.66	N/A	N/A

Sources: (1) Oweis & Khera 1998, (2) USACE 1984, (3) Ziemkiewicz 1998, (4) EPA 1998
Notes:
Construction and demolition waste has been excluded from consideration in industrial landfills, and will be considered in construction and demolition landfills.
If a source document reported a range of permeability values, the geometric mean is listed in the table.

Under steady-state flow conditions, the exfiltration rate from a waste pile approximates the infiltration rate into the waste pile. EPA 2003 reports exfiltration rates from uncovered, unlined waste piles containing low, moderate, and high permeability waste. We calculated the cumulative frequency distribution of the reported waste pile exfiltration data, and present the results in Table J-13. For a difference in waste permeabilities of nearly 3 orders of magnitude between the low and high permeability waste, the 50th percentile exfiltration values differ by only a factor of 3. For the comparative analysis, we use the 50th percentile exfiltration rate for uncovered, unlined waste piles with low permeability waste materials equal to 1.13E-01 m/yr as

Table J-13 Cumulative Frequency Distribution of Waste Pile No Liner Exfiltration Rates (m/yr)

	Permeability of Waste Material (cm/sec)		
percent	Low 5.-E-05	Med 4.1E-03	High 4.1E-02
0	0.0053	0.0003	0.0097
10	0.0056	0.0004	0.0375
20	0.0177	0.0374	0.0959
30	0.0501	0.1340	0.2010
40	0.0845	0.1840	0.2740
50	0.1130	0.2480	0.3420
60	0.1530	0.2840	0.3890
70	0.1800	0.3380	0.4560
80	0.2540	0.4510	0.5360
90	0.3300	0.5330	0.6380
100	1.5400	1.8100	1.8800

Source: EPA 2003, Table A.11

the infiltration rate for the no cover phase of the Industrial Reference Landfill with low permeability waste. We use the 50th percentile exfiltration rate for uncovered, unlined waste piles with high permeability waste materials equal to 3.42E-01 m/yr as the infiltration rate for the no cover phase of the Industrial Reference Landfill with high permeability waste.

Intact Final Cover Phase

For the period from 20 to 50 years after waste placement, the Industrial Reference Landfill has a final cover. We assume that it has an equal probability of having either a compacted clay cover or a compacted soil cover, and that the landfill has the vertical profile shown below:

- a 6-in. (0.15 m) vegetative support layer

- an 18-in. (0.46 m) infiltration barrier layer, either compacted clay with a hydraulic conductivity of 1×10^{-7} cm/sec or compacted soil

- waste material

- either a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-7} cm/sec or no bottom liner

The final cover is assumed to remain intact for the period from 20 to 50 years following waste placement. Since the EPA 2003 Clay Liner landfill case has no leachate collection system, we assume that the steady-state exfiltration rates approximate the steady-state infiltration rates into the landfill. The 18 inch low permeability infiltration barrier layer in the Industrial Reference

Landfill is only half as thick as the clay cover in the EPA 2003 Clay Liner case. To calculate an infiltration rate, we used the combined EPA 2003 No Liner and EPA 2003 Clay Liner closed landfill datasets, which yielded a 50th percentile exfiltration rate equal to 7.61E-02 m/yr (see Table J-2), for input as the infiltration rate for the Industrial Reference Landfill. For the Industrial Reference Landfill, we did not make any specific allowance to account for the thinner barrier layer, relative to the clay cover in the EPA 2003 Clay Liner analysis.

Failed Final Cover Phase

After 50 years following waste placement, the final compacted clay cover is assumed to degrade to the level of the compacted soil cover. The comparative analysis uses the 50^{th} percentile EPA 2003 No Liner closed landfill exfiltration rate, 1.09E-01 m/yr (see Table J-2), as the infiltration rate for the Industrial Reference Landfill for times beyond 50 years following waste placement.

3.3.3 Volumetric Water Content

Table J-11 lists the moisture retention properties for low, medium, and high permeability industrial wastes, consisting of electric plant fly ash, electric plant bottom ash, and fine copper slag, respectively. The table lists the field capacity and the total porosity of each material. The field capacity is the maximum amount of water the material can hold in a gravitational field and corresponds to the volumetric water content under free drainage conditions. The total porosity equals the volumetric water content when the material is fully saturated.

We assume that the industrial waste materials are initially placed at a water content near their field capacity. Over time, infiltration raises the water content to the field capacity and gravitational leachate flow can develop. Without a leachate collection system, the saturation ratio of the waste can increase. After placement of the final cover, the volumetric water content can decrease by drainage (e.g. compacted soil cover and no bottom liner), remain the same (e.g. equal infiltration and exfiltration rates), or increase (e.g. degraded clay cover over an intact bottom clay liner).

For the comparative analysis for the Industrial Reference Landfill with low permeability waste, principally fly ash, we use a volumetric water content equal to its field capacity of 0.187 for all time periods. For the Industrial Reference Landfill with high permeability waste, principally slag, we use a volumetric water content equal to its field capacity under moderate compaction of 0.055 for years 0 to 10, and equal to 0.125 for all later time periods to account for particle crushing and consolidation under increased loading.

3.3.4 Thickness

The comparative analysis uses the 50^{th} percentile value of landfill thickness equal to 2.57 meters derived from the database of 790 industrial landfills and reported in EPA 2003 for the thickness of the Industrial Reference Landfill.

3.3.5 Bulk waste density

For the Industrial Reference Landfill, we use typical bulk waste densities for fly ash and slag for the low permeability and high permeability wastes, respectively, making the explicit assumptions that the solid materials from Licensed Facilities constitute a small percentage of the overall volume of materials in the industrial landfill and are widely distributed throughout the landfill.

Compacted fly ash for embankment fills placed at optimum water content has a typical dry unit weight of 85 lb/ft^3 (1.36 g/cm^3). With a volumetric water content of 0.187, the bulk density equals 92 lb/ft^3 (1.47 g/cm^3). This value is used in the comparative analysis for the Industrial Reference Landfill with low permeability waste.

Slag densities vary greatly depending on the production method. Table J-14 lists typical densities for ferrous slag materials. Slag destined for disposal would not be subjected to additional processing such as crushing, so the range of applicable dry densities is 0.56 to 1.36 t/m^3. For the comparative analysis for the Industrial Reference Landfill with high permeability waste, we selected a dry density of 1.12 t/m^3 which lies at the low end of the air cooled blast furnace slag density range and at the upper end of the expanded blast furnace slag density range. For the comparative analysis, we used a volumetric water content of 0.09 to calculate a bulk density equal to 1.21 t/m^3.

Table J-14 Typical Slag Dry Densities

Type of Slag	Typical Density (t/m^3)
Air cooled blast furnace slag	1.12 to 1.36
Expanded blast furnace slag, coarse aggregate	0.56 to 0.88
Expanded blast furnace slag, fine aggregate	0.80 to 1.12
Crushed blast furnace slag	2
Crushed steel furnace slag	2.6

Source: Jones 2004

3.3.6 Distribution Coefficients, K_d

An EPA technical document reports that coal fly ash, coal bottom ash, and cement kiln dust have very low concentrations of organic compounds (EPA 1997). Slags contain little to no organic matter. In the comparative analysis, we have selected the median values of K_d reported in SC&A 2003 Table 9.33, and made no reduction for TOC concentration (see Table J-9).

3.4 Subtitle D Construction and Demolition Landfills

3.4.1 Landfill Description

The comparative analysis defines a Subtitle D Construction and Demolition (C&D) Landfill consistent with the definitions and requirements of *40 CFR Part 257*, referenced hereinafter as the C&D Reference Landfill. A C&D landfill typically receives one or more of the following types of solid wastes: roadwork material, excavated material, demolition waste, construction/ renovation waste, and site clearance waste. We define the C&D Reference Landfill as having no bottom liner and no leachate collection system, although in some States these are generally required. This landfill designs corresponds to the EPA 2003 No Liner case. We assume that an active landfill cell is filled during a 10 year[11] operating life, and that the solid materials from Licensed Facilities are placed, on average, at the midpoint of this operating life (GA 2003). We further assume that the landfill has a final compacted soil cover thereafter.

3.4.2 Infiltration

The rate of infiltration will vary with the surface conditions in each phase of the landfill's operating life. The two phases can be briefly described as no cover for years 0 to 5 after waste placement, and final cover for all later times.

No Cover Phase

For the first 5 years following waste placement, the C&D Reference Landfill has the following profile, from top to bottom:

- waste material
- no bottom liner

For the first 5 years after waste placement, the surface of the Industrial Reference Landfill consists of exposed waste. The conditions for surface runoff and evapotranspiration are similar to those of an uncovered waste pile. Under steady-state flow conditions, the exfiltration rate from a waste pile approximates the infiltration rate into the waste pile. HELP modeling reported in Appendix A of EPA 2003 indicated that the permeability of the waste material itself influenced the predicted exfiltration rates. The highest permeability value modeled in EPA 2003 equals 4.1E-02 cm/sec (see Table J-11). Construction debris characteristically has large voids, and will have a permeability comparable to a poorly graded clean gravel which can exceed 10^1 cm/sec.
To account for this higher permeability, for the comparative analysis we use the 80th percentile exfiltration rate for uncovered, unlined waste piles with high permeability waste materials equal to 5.36E-01 m/yr (see Table J-13) as the infiltration rate for the no cover phase of the C&D Reference Landfill.

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[11] The average remaining life of 44 C&D landfills was 13.6 years (GA 2003). Although the average remaining life may be half of the average total life of the landfills, individual landfill cells are typically closed when full to minimize infiltration.

Final Cover Phase

After 50 years following waste placement, the C&D Reference Landfill has a final cover of compacted soil, giving the landfill the profile shown below:

- a 6-in. (0.15 m) vegetative support layer
- an 18-in. (0.46 m) infiltration barrier layer of compacted soil
- waste material
- no bottom liner

The cover is typically about 2 ft (0.61 m) thick, and is graded to promote runoff from the landfill. The frequency distribution of cover soils types is assumed to be the same as the distribution for cover soils in the EPA 2003 No Liner case. We assume that the steady-state exfiltration rates in the EPA 2003 No Liner case approximate the steady-state infiltration rates into the landfill. For the comparative analysis, we use the 50^{th} percentile exfiltration rate for the EPA 2003 No Liner closed landfill exfiltration rate, 1.09E-01 m/yr (see Table J-2), as the infiltration rate for the interim cover phase of the C&D Reference Landfill for all times greater than 5 years after waste placement.

3.4.3 Volumetric Water Content

For the C&D Reference Landfill, we make the explicit assumptions that the solid materials from Licensed Facilities constitute the majority of materials in the C&D landfill, at least in the sections of the landfill receiving them. We assume that the materials are initially placed at a water content near their field capacity. Concrete rubble is expected to have an effective field capacity of about 0.03, similar to that of coarse, clean gravel. The effective field capacity neglects any water absorbed into the concrete particles, as this water would remain relatively immobile. This absorbed water content can reach about 10 percent by weight. Steel would also have a similar, low field capacity due to the smooth surfaces and large dimensions of individual pieces.

Without a leachate collection system, the saturation ratio of the waste can increase. After placement of the final cover, the volumetric water content can decrease by drainage (e.g. compacted soil cover and no bottom liner), remain the same (e.g. equal infiltration and exfiltration rates), or increase (e.g. final cover more permeable than underlying soils). For the comparative analysis for the C&D Reference Landfill, we use a volumetric water content equal to the field capacity of 0.03 for all time periods.

3.4.4 Thickness

Many C&D landfills are used for a single demolition project and are located onsite. These tend to be small and have a short operating life. Commercial and public C&D landfills tend to be larger in area, have a greater waste thickness, and have a longer operating life. An analysis of the State of California Solid Waste Information System database (CA IWMB 2004) yielded the following distribution of C&D landfill waste thickness (Table J-15). The 11 sites selected for the analysis included all disposal facilities in the database which accepted primarily construction and demolition waste, which did not accept municipal waste, and for which the database has total volume capacity and disposal acreage information. The data set is small and the extreme values are suspect, possibly due to inconsistent interpretation of reporting requirements.

The comparative analysis uses the 50th percentile value of landfill thickness equal to 5.3 meters for the MSW Reference Landfill.

Table J-15 C&D Landfill Thickness

percent	Thickness in m
0	0.0
10	0.5
20	3.6
30	4.3
40	4.7
50	5.3
60	14.5
70	26.8
80	54.4
90	75.6
100	132.2

3.4.5 Bulk waste density

The bulk density of the solid materials in the C&D Reference Landfill will be dominated by the concrete rubble. The comparative analysis uses 2.10 g/cm^3 as the bulk density for the C&D Reference Landfill.

3.4.6 Distribution Coefficients, K_d

Melendez 1996 reports a mean TOC concentration of 307 ppm based on leachate samples from 7 C&D landfills. However, a substantial percentage of the waste in most C&D landfills consists of wood which would probably not be the case for an industrial landfill receiving large quantities of solid materials from Licensed Facilities. Concrete and steel contain no organic matter. In the comparative analysis, we have selected the median values of K_d reported in SC&A 2003 Table 9.33, and made no reduction for TOC concentration (see Table J-9).

3.5 Low Level Waste Disposal Facilities

3.5.1 Landfill Description

For the purposes of this comparative analysis, all solid materials generated by licensed facilities within the scope of the Proposed Action that are sent to Low Level Waste Disposal Facilities are assumed to be sent to the disposal facility in Clive, Utah. The Clive, Utah disposal facility run by Envirocare incorporates waste cells constructed over naturally clayey soils. The Envirocare facility is located in a remote desert location with an arid to semi-arid climate. The site is over 20 miles from the nearest permanent human habitation.

The Envirocare disposal facility has several distinct operable units licensed for the disposal of different types of waste. Solid materials relevant to the Proposed Action and destined for the Envirocare facility would most likely be classified as Low Activity Radioactive Waste (LARW) or as Class A waste. Envirocare does not have current licenses to dispose of Class B or Class C wastes.

The LARW and Class A operable units have similar engineered barriers. Each has a compacted clay bottom liner, and each cell receives a final cover incorporating a compacted clay layer to minimize infiltration of precipitation and the release of radon. Neither has a leachate collection system beneath the waste, but license restrictions require the removal of accumulated stormwater in the LARW and Class A cells within 24 hours. Stormwater removed is pumped to dedicated holding ponds and evaporated.

Since the engineered components of the LARW and Class A cells are similar, we define a single LLW Reference Disposal Facility for purposes of the comparative analysis. The Envirocare LARW and Class A operable units have license restrictions that limit the duration of an open cell to 6 years. We assume that the solid materials from Licensed Facilities are placed, on average, at the midpoint of this open cell period. Each cell is required to receive a radon barrier before the open cell limitation expires. We assume that the cell receives a final cover 2 years after placement of the radon barrier, i.e. 5 years after waste placement.

3.5.2 Infiltration

The rate of infiltration will vary with the surface conditions in each phase of the disposal facility's operating life. The two phases can be briefly described as no cover for years 0 to 3 after waste placement, radon barrier from 3 to 5 years after waste placement, and final cover for all later times.

No Cover Phase

For the first 3 years following waste placement, the LLW Reference Disposal Facility has the following profile, from top to bottom:

- waste material up to 43 ft. (13.1 m)[12]
- a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-6} cm/sec

For the first 3 years after waste placement, the surface of the Industrial Reference Landfill consists of exposed waste. Envirocare places waste in 12-inch compacted lifts. Soil is

[12] The licenses limit waste thickness to 43 ft. in an LARW cell, and to 54 ft. in a Class A cell. For the analysis, we chose the thinner cell because it produces a higher leach rate constant.

compacted around oversize debris to eliminate voids, or else the oversize debris is surrounded with flowable fill. Because of the compacted surface and attention to void avoidance, the conditions for surface runoff and evapotranspiration are more similar to those of a landfill cover than to an uncovered waste pile.

For the comparative analysis we used the location specific exfiltration rate for Cedar City[13], Utah, for the No Liner closed landfill case as the infiltration rate for the no cover phase of the LLW Disposal Facility. EPA 2003 Appendix A presents exfiltration rates for 3 different cover soils. We chose the highest rate equal to 8.0E-04 m/yr, which corresponds to a sandy loam cover soil.

Radon Barrier Phase

After construction of the radon barrier, the LLW Reference Disposal Facility has the following profile, from top to bottom:

- a 1-ft. (0.30 m) clay radon barrier with a hydraulic conductivity of $1{\times}10^{-6}$ cm/sec
- waste material up to 43 ft. (13.1 m)
- a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of $1{\times}10^{-6}$ cm/sec

The infiltration rate for the radon barrier phase should be less than the no cover phase. For the comparative analysis, we used half the EPA 2003 location specific exfiltration rate for Cedar City, Utah, for the No Liner closed landfill case as the infiltration rate for the radon barrier phase of the LLW Disposal Facility. The infiltration rate used equals 4.0E-04 m/yr.

Final Cover Phase

Upon cell closure, the LLW Reference Disposal Facility has the following profile, from top to bottom:

- a 1.5-ft. (0.46 m) erosion barrier of gravel and rock

- a 0.5-ft. (0.15 m) sandy gravel layer

- a 1-ft. (0.30 m) layer of sacrificial soil

- a 0.5-ft. (0.15 m) sandy gravel layer

- a 1-ft. (0.30 m) clay infiltration barrier with a hydraulic conductivity of $1{\times}10^{-8}$ cm/sec

- a 1-ft. (0.30 m) clay radon barrier with a hydraulic conductivity of $1{\times}10^{-6}$ cm/sec

- waste material up to 43 ft. (13.1 m)

[13] Even though HELP model results are available for Salt Lake City which is closer to Clive, we used Cedar City because its annual precipitation of 10.6 inches is approximately equal to Clive’s.

- a 2-ft. (0.61 m) clay liner with a hydraulic conductivity of 1×10^{-6} cm/sec

For the comparative analysis, we used the EPA 2003 location specific exfiltration rate for Cedar City, Utah, for the Clay Liner closed landfill case as the infiltration rate for the final cover phase of the LLW Disposal Facility. The infiltration rate used equals 1.0E-04 m/yr.

The post-closure plan requires maintenance for a minimum of 30 years after cell closure. Because of the low potential for settlement and the protection against erosion and dessication, we assume that the clay infiltration barrier remains intact for 50 years after waste placement. For the comparative analysis, we used an infiltration rate equal to 4.0E-04 m/yr, which corresponds to the radon barrier phase rate, for all time periods exceeding 50 years after waste placement.

3.5.3 Volumetric Water Content

Waste material compacted in 12-inch lifts, or soil surrounding oversize debris, is compacted to 90 percent of its maximum density. To achieve this density, the water content would need to be within several percent of the material's optimum moisture content. For a sandy soil with some silt content, typical values of optimum moisture content range from 11 to 16 percent (weight of water to weight of solids). Given the arid nature of the climate, the facility operator is most likely to need to raise the water content to facilitate compaction, and would use the least amount of water necessary. We have assumed a compaction moisture content of 11 percent by weight, a maximum dry density of 1.87 g/cm^3, a compacted dry density of 1.75 g/cm^3, and a solid specific gravity of 2.0. This yields a volumetric water content equal to 0.19, which the comparative analysis uses for the LLW Reference Disposal Facility for all phases.

3.5.4 Thickness

The comparative analysis uses the licensed waste depth of 13.1 meters as the thickness of the LLW Reference Disposal Facility.

3.5.5 Bulk waste density

The bulk density of the solid materials in the LLW Reference Disposal Facility will be a function of the mix of concrete, steel, and trash (or Dry Active Waste) disposed in the cell. Trash will undergo better compaction than in a typical MSW landfill, and will therefore have a higher bulk density than the 0.85 g/cm^3 used for the MSW Reference Landfill. Concrete rubble will have a bulk density near 2.10 g/cm^3. Steel can raise the bulk density significantly, but will probably be surrounded with soil compacted to a bulk density of about 1.94 g/cm^3. For the comparative analysis, we used a bulk density equal to 2.10 g/cm^3.

3.5.6 Distribution Coefficients, K_d

The introduction of trash into the LLW Reference Disposal Facility introduces the possibility of a significant organic component in the leachate. In the comparative analysis, we have selected the median values of K_d reported in SC&A 2003 Table 9.33, and adjusted them in accordance with Equation J.13. We conservatively used the median TOC value of 377 ppm derived from municipal landfill leachate, and explicitly set the fraction of non-complexing material to zero.

The radionuclide specific mean values of the distribution coefficients used in the comparative analysis for the LLW Reference Disposal Facility equal those used for the MSW Reference Landfill and appear in Table J-9.

4.0 COMPARATIVE ANALYSIS

In the comparative analysis, each disposal facility type receives an amount of each radionuclide representing one unit of activity[14]. For the different disposal facility types, if the inventory, timing, and activity levels of disposed radionuclides is held constant, the ratio of the total activity released from each disposal facility type compared to the total activity released from the SC&A Reference Landfill is a function of the leach rate constant L_n and equals:

$$\frac{\sum_{i=0}^{k} R_n(j+i)}{\left[\sum_{i=0}^{k} R_n(j+i)\right]_{REF}} = \frac{f(L_n)}{f(L_n)_{REF}} \quad \text{(J.15)}$$

$$L_n = \frac{I}{\theta^{cz} T_0 R_{dn}^{cz}} \quad \text{(J.16)}$$

$$R_{dn} = 1 + \frac{\rho_b K_{dn}}{\theta^{cz}} \quad \text{(J.17)}$$

Combining the Equations J.16 and J.17 yields:

$$L_n = \frac{I}{\theta^{cz} T_0 \left(1 + \frac{\rho_b K_{dn}}{\theta^{cz}}\right)} \quad \text{(J.18)}$$

Table J-16 summarizes the input parameters for the comparative analysis.

It is worth reiterating that the K_d values can vary by several orders of magnitude. Figure J-1 show the range of K_d values for each radionuclide reported in the literature. The shaded sections of each horizontal bar represent the K_d values that correspond to plus or minus one standard deviation (from Table 9.33 in SC&A 2003) of log(K_d), as measured from the median value of K_d at the boundary between the colored bars. The ends of the white bars represent the minimum and maximum K_d values. Note that the horizontal scale is logarithmic.

[14] This corresponds to $\beta_1 = \beta_2 = ... = \beta_n$ in Equation J.1. In practice, $\beta_1 \neq \beta_2 \neq ... \neq \beta_n$ and the radionuclide-specific activity released would be recalculated from the unit activity results.

The mobilization and movement of radionuclides are dependent on their chemical forms, pH of the leachate, nature of the organic constituents, presence of other chemical agents, porosity of the soils and waste mixture, water saturation of the soil and waste mixture, water infiltration rates, and age of the landfill. As a result, the analysis considered whether coefficient distributions (K_d) of radionuclides contained in a mixture of released materials and other wastes should be modified, given that such an environment may have different retention or sorption properties than natural soils. The presence of highly heterogenous wastes with widely different physical and chemical properties may result in conditions that are less than ideal in maintaining an efficient ion exchange process between dissimilar materials. For example, coefficient distributions are reduced when organic materials are kept in solution, i.e., making radionuclides more mobile in such conditions. Conversely, coefficients increase when organic materials are bound in solid phase, thereby, making radionuclides less mobile. Given that it is not feasible to develop landfill-specific K_d values, a simplified and realistically conservative approach was used in this analysis. Since K_d values are normally defined for soils or materials with soil-like properties, the analysis assumed that coefficient distributions typically developed for soils are unlikely to apply to a mixture of released materials and landfill wastes containing organic constituents. An Argonne National Laboratory report was used to make specific adjustments to radionuclide distribution coefficients originally defined for soils (ANL 2001). The adjustment considers the presence of organic constituents as total organic carbon (TOC) and a correction factor based on K_d values.

Table J-16: Input Parameters for the Comparative Analysis

		Type of Disposal Facility					
Parameter	Symbol	SC&A Reference	Municipal Solid Waste	Industrial, low permeability waste	Industrial, high permeability waste	Construction &	NRC LLW
Infiltration rate, years 0-3 (m/yr)	I	0.0432	0.2	0.113	0.342	0.536	0
Infiltration rate, years 3-5 (m/yr)	I	0.0432	0.2	0.113	0.342	0.536	0
Infiltration rate, years 5-10 (m/yr)	I	0.0432	0.2	0.113	0.342	0.109	0
Infiltration rate, years 10-20 (m/yr)	I	0.0432	0.109	0.113	0.342	0.109	0
Infiltration rate, years 20-50 (m/yr)	I	0.0432	0.0445	0.0761	0.0761	0.109	0
Infiltration rate, years > 50 (m/yr)	I	0.109	0.109	0.109	0.109	0.109	0
Volumetric water content of the contaminated zone, years 0-50 (dimensionless)	$\theta^{(cz)}$	0.13	0.35	0.187	0.055	0.03	0.19
Volumetric water content of the contaminated zone, years > 50 (dimensionless)	$\theta^{(cz)}$	0.14	0.35	0.187	0.125	0.03	0.19
Thickness of the contaminated zone (m)	T_0	2.57	13.4	2.57	2.57	5.3	13.1
Bulk waste density (g/cm3)	ρ_b	0.89	0.85	1.47	1.21	2.1	2.1
Distribution coefficient (cm^3/g)	K_d						
C-14		1	1	11	11	11	1
Fe-55		2.6	2.6	209	209	209	2.6
Mn-54		2	2	158	158	158	2
Co-58		2.9	2.9	235	235	235	2.9
Co-60		2.9	2.9	235	235	235	2.9
Ni-63		5.3	5.3	424	424	424	5.3
Sr-90		3	3	32	32	32	3
Nb-95		4.7	4.7	380	380	380	4.7
Zr-95		17.1	17.1	1,380	1,380	1,380	17.1
Ru-106		19.7	19.7	1,588	1,588	1,588	19.7
Ag-110m		2.7	2.7	217	217	217	2.7
Sb-125		4.7	4.7	380	380	380	4.7
I-129		0.43	0.43	4.6	4.6	4.6	0.43
Cs-134		5.5	5.5	446	446	446	5.5
Cs-137		5.5	5.5	446	446	446	5.5
Pu-238		11.8	11.8	953	953	953	11.8
Pu-239		11.8	11.8	953	953	953	11.8
Pu-240		11.8	11.8	953	953	953	11.8

5.0 ANALYTICAL RESULTS

The next 6 graphs present the cumulative leaching of activity from the waste versus time for each radionuclide as a fraction of the activity placed in the landfill or disposal facility. The leveling of each curve signifies either that all of the activity from that radionuclide has leached from the waste to the environment, or that the radionuclide has decayed beyond the point of any consequential release.

Figures J-2 through J-7 indicate the radionuclide-specific release for 6 disposal facilities, which are respectively:

- the SC&A Reference Landfill
- the MSW Reference Landfill
- the Industrial Reference Landfill with high permeability waste
- the Industrial Reference Landfill with low permeability waste
- the C&D Reference Landfill
- the LLW Reference Disposal Facility

Note that the release from the LLW Reference Disposal Facility is much lower than in any of the other disposal facilities, and that less than 1 percent of the activity of any radionuclide is released within 1,000 years. In the other 5 graphs, two radionuclides, C-14 and I-129, dominate the early and sometimes the total release of radioactivity, with between 70 and 100 percent of the activity of C-14 and I-129 released within 1,000 years. In the SC&A Reference Landfill (Figure J-2) and the MSW Reference Landfill (Figure J-3), Pu-239 and Pu-240 make important contributions to the total activity released but at a rate which is approximately 10 percent of the C-14 and I-129 release rates. The differences in the activity amounts for each radionuclide are assumed to be equal. For example, in Figure J-2, 100 percent of the C-14 activity but only 0.1 percent of the Zr-95 activity is ultimately released from the SC&A Reference Landfill.

In Figures J-8 through J-17, the curves apply only when the activity amounts for each radionuclide are equal.

Figure J-8 shows the total activity released for all radionuclides for each of the disposal facility types. Each curve equals the sum of the 18 radionuclide-specific curves for the corresponding disposal facility type. The graph allows a direct comparison of the predicted release history for each disposal facility, but the position of each curve is dependent on the specific input parameters selected for the reference landfill. Other combinations of parameters could cause curves to rise or fall relative to the results for other disposal facility types. For the combination of parameters and activities analyzed, the SC&A Reference Landfill and the MSW Reference Landfill allow the greatest release of activity and the LLW Reference Disposal Facility allows the least. The releases from the Industrial Reference Landfills and the C&D Reference Landfill fall about midway in between.

Figure J-9 compares the cumulative release from each disposal facility up to the indicated time (i.e. its curve in Figure J-8) to the cumulative release at the same time from the SC&A Reference Landfill. Note that the relative benefits of the disposal facility types vary over time.

The dips generally reflect the influence of reduced infiltration due to the placement of a low permeability cap, and the subsequent rises reflect eventual deterioration of the cap and breakthrough of leachate-contaminated groundwater to a well or surface water body.

Figure J-10 shows the cumulative release from each disposal facility up to the indicated time compared to the ultimate cumulative release from the same disposal facility. The curves show the percentage of the activity that has been released at any point in time compared to the amount that will ultimately be released. For example, in the first 100 years following disposal, 66 percent of the ultimately released activity is released from the SC&A Reference Landfill, 38 percent from the MSW Reference Landfill, and less than 1 percent from the LLW Reference Disposal Facility.

A sensitivity analysis was also performed of the effect of each input parameter to the cumulative release rate. The MSW Reference Landfill was chosen as the control. For each part of the sensitivity analysis, one input parameter was changed in an unfavorable and in a favorable direction, and the results graphed against the MSW Reference Landfill control. Figures J-11 through J-16 present the results of the sensitivity analysis for the individual parameter variation.

Figure J-11 shows the effect of varying K_d. Lowering all of the radionuclide-specific K_d values by the equivalent of one standard deviation of $\log(K_d)$ increased and accelerated the release of radioactivity approximately by a factor of 10. Raising the K_d values by the same amount reduced the release to a small fraction of the control. ANL 2001a concludes that "given the fact that the effective Kd values of radionuclides in ... disposal units can either increase or decrease as the result of many factors, ... whenever they are available, actual (measured) Kd values rather than modeled values should be used."

Figure J-12 shows the influence of infiltration. Doubling the infiltration increases the release about the same amount as reducing the infiltration by half decreases the release. This is to be expected by the proportionality of the leach rate constant and infiltration in Equation J.18. The infiltration rate depends primarily on the amount of precipitation, the percentage of runoff and the permeability of the cap or surface waste layer. Disposal facilities with sloping, low permeability caps in arid climates will have lower infiltration values and release rates than other facilities, if all other parameters are the same.

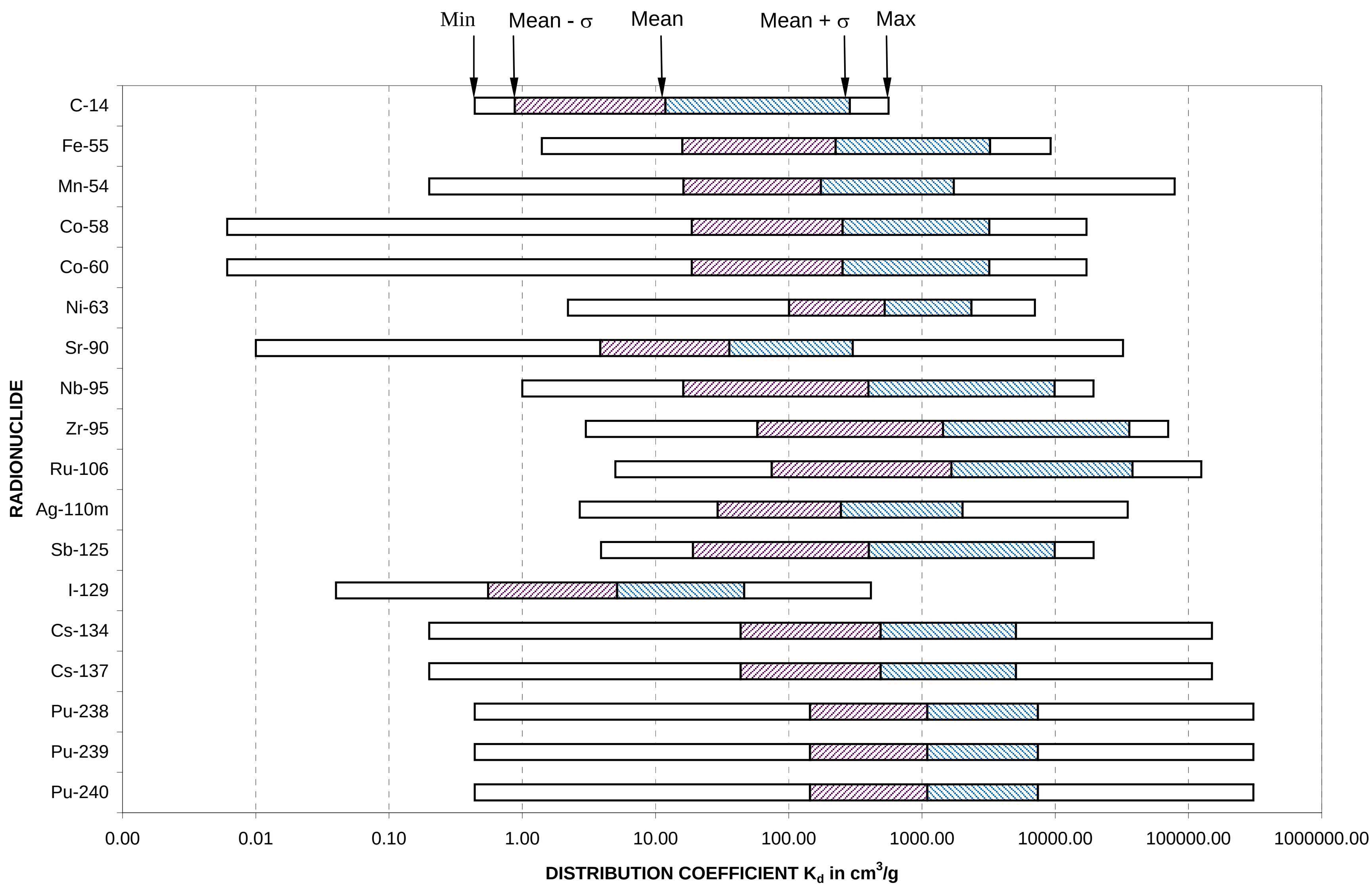
Figure J-13 shows the relative insensitivity of the cumulative release and the release rate to the volumetric water content. The range of volumetric water contents chosen, 0.12 to 0.55, represent all but extreme conditions in MSW landfills.

Figure J-14 shows the effect of varying the landfill thickness. Reducing the landfill thickness by half increases the release about the same amount that doubling the landfill thickness reduces the release. This is to be expected by the inverse proportionality of the leach rate constant and thickness in Equation J.18. Thicker landfills increase the retention time of the radionuclides in the landfill itself, slowing the rate of release. The increased retention time also allows more complete radioactive decay and lower cumulative releases.

Figure J-15 shows the effect of varying the density. The density has an effect because the K_d values are partitioning ratios between the volume of liquid and mass of solids, and the density input parameter establishes the mass. Varying the MSW bulk density from 0.57 t/m^3 to 1.28 t/m^3, about the maximum range for MSW landfills, shows moderate variation in the cumulative release curves.

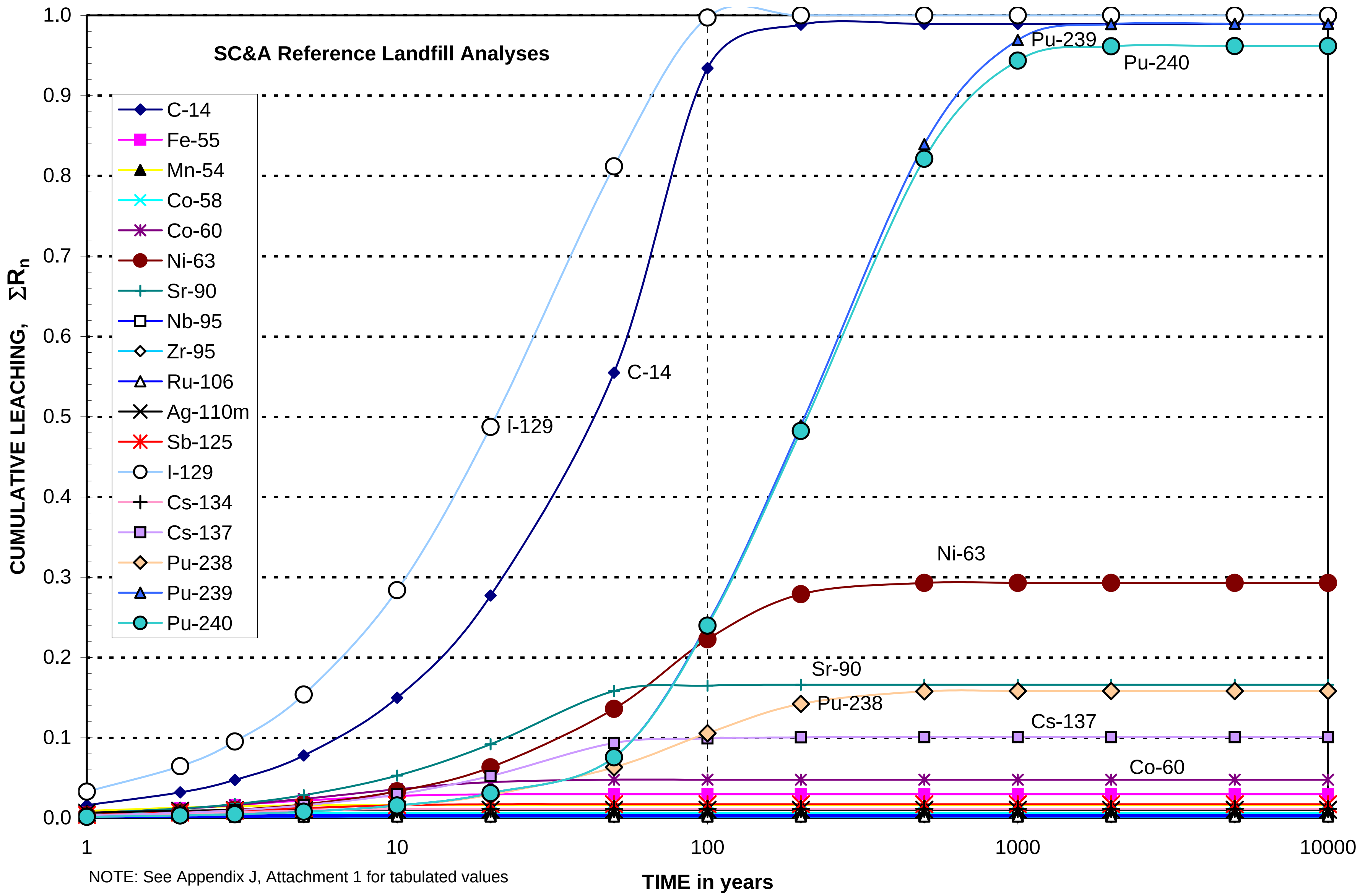
Figure J-16 shows the effect of varying the groundwater travel time from 0 years to 500 years before it potentially reaches a biological receptor. The additional decay time has a minimal effect on the cumulative release. Note that the curves only begin to diverge when the leachate collection system is shut down 50 years after waste placement. Also note that the 0 year curve is equivalent to a landfill where the leachate collection system functions forever. Shutting down the leachate collection system reduces the radioactivity released to the environment, but releases the activity in a less controlled manner.

Figure J-17 summarizes the results from Figures J-11 through J-16, and shows only the unfavorable curves compared to the MSW Reference Landfill control curve. Note that due to the proportionality of infiltration and the inverse proportionality of thickness to the leach rate constant, that the 200 percent infiltration and 50 percent thickness curves are exactly the same. Also note that the curves for volumetric water content, groundwater travel time, and density are graphed at or near has the most unfavorable possible values. It is important to recognize that K_d the most pronounced effect, and also has the widest range of potential values.



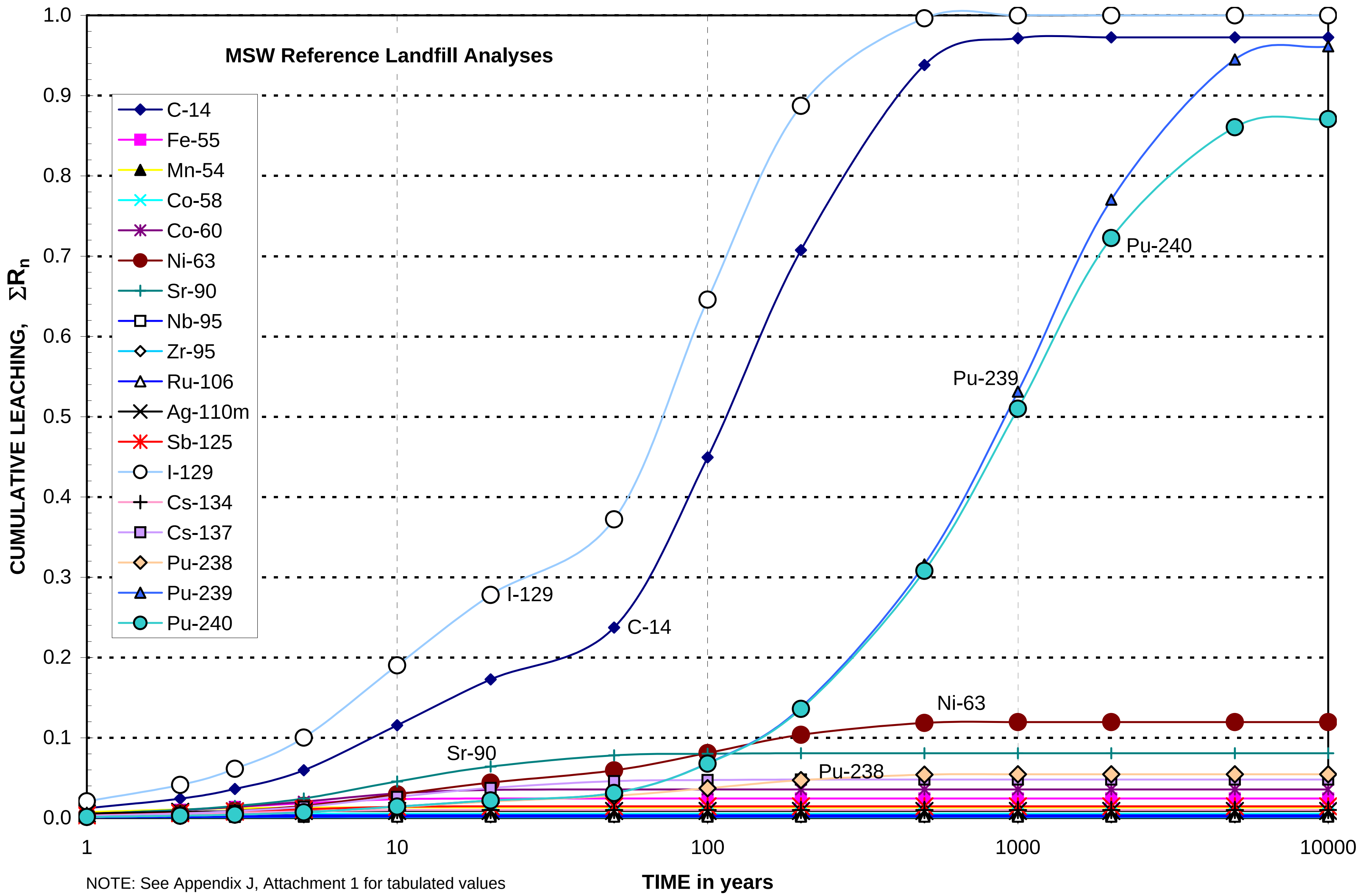
Min
Mean - σ
Mean
Mean + σ
Max
RADIONUCLIDE
C-14
Fe-55
Mn-54
Co-58
Co-60
Ni-63
Sr-90
Nb-95
Zr-95
Ru-106
Ag-110m
Sb-125
I-129
Cs-134
Cs-137
Pu-238
Pu-239
Pu-240
0.00
0.01
0.10
1.00
10.00
100.00
1000.00
10000.00
100000.00
1000000.00
DISTRIBUTION COEFFICIENT K_d in cm^3/g

Figure J-1



SC&A Reference Landfill Analyses
CUMULATIVE LEACHING, ΣR_n
TIME in years
C-14
Fe-55
Mn-54
Co-58
Co-60
Ni-63
Sr-90
Nb-95
Zr-95
Ru-106
Ag-110m
Sb-125
I-129
Cs-134
Cs-137
Pu-238
Pu-239
Pu-240
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-2



NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-3

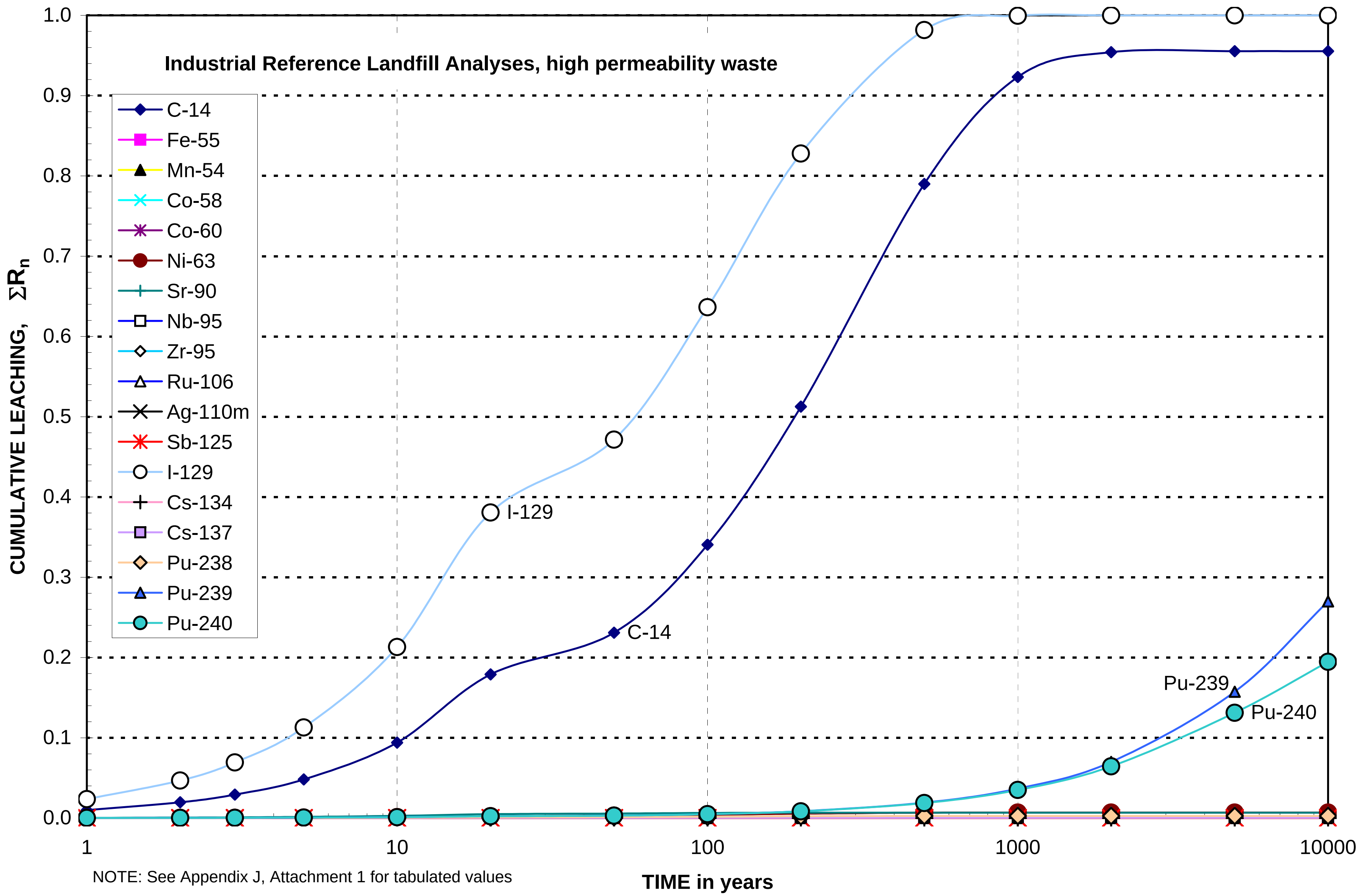
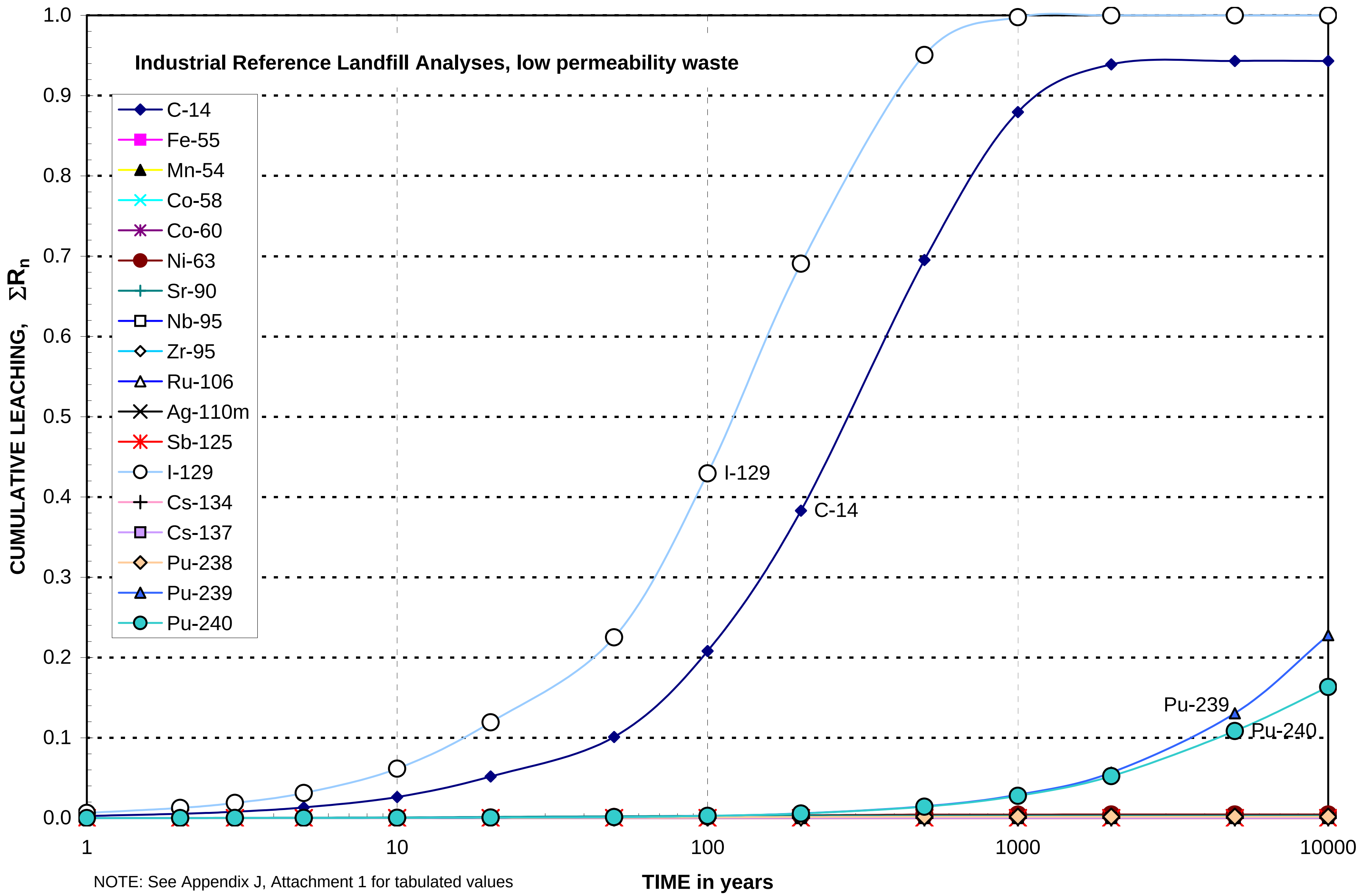

Industrial Reference Landfill Analyses, high permeability waste
C-14
Fe-55
Mn-54
Co-58
Co-60
Ni-63
Sr-90
Nb-95
Zr-95
Ru-106
Ag-110m
Sb-125
I-129
Cs-134
Cs-137
Pu-238
Pu-239
Pu-240
I-129
C-14
Pu-239
Pu-240
CUMULATIVE LEACHING, ΣR_n
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
10
100
1000
10000
TIME in years
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-4



NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-5

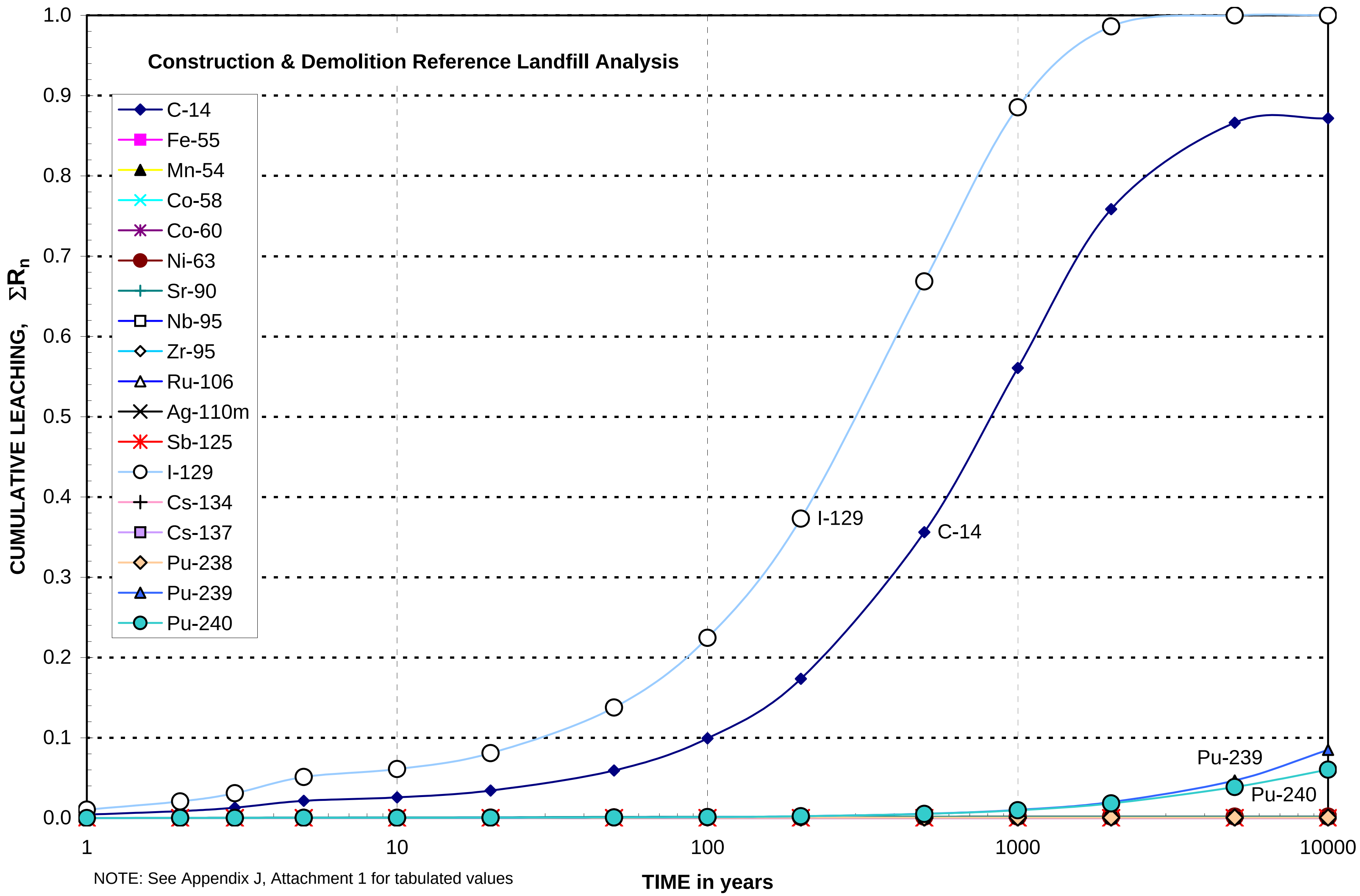
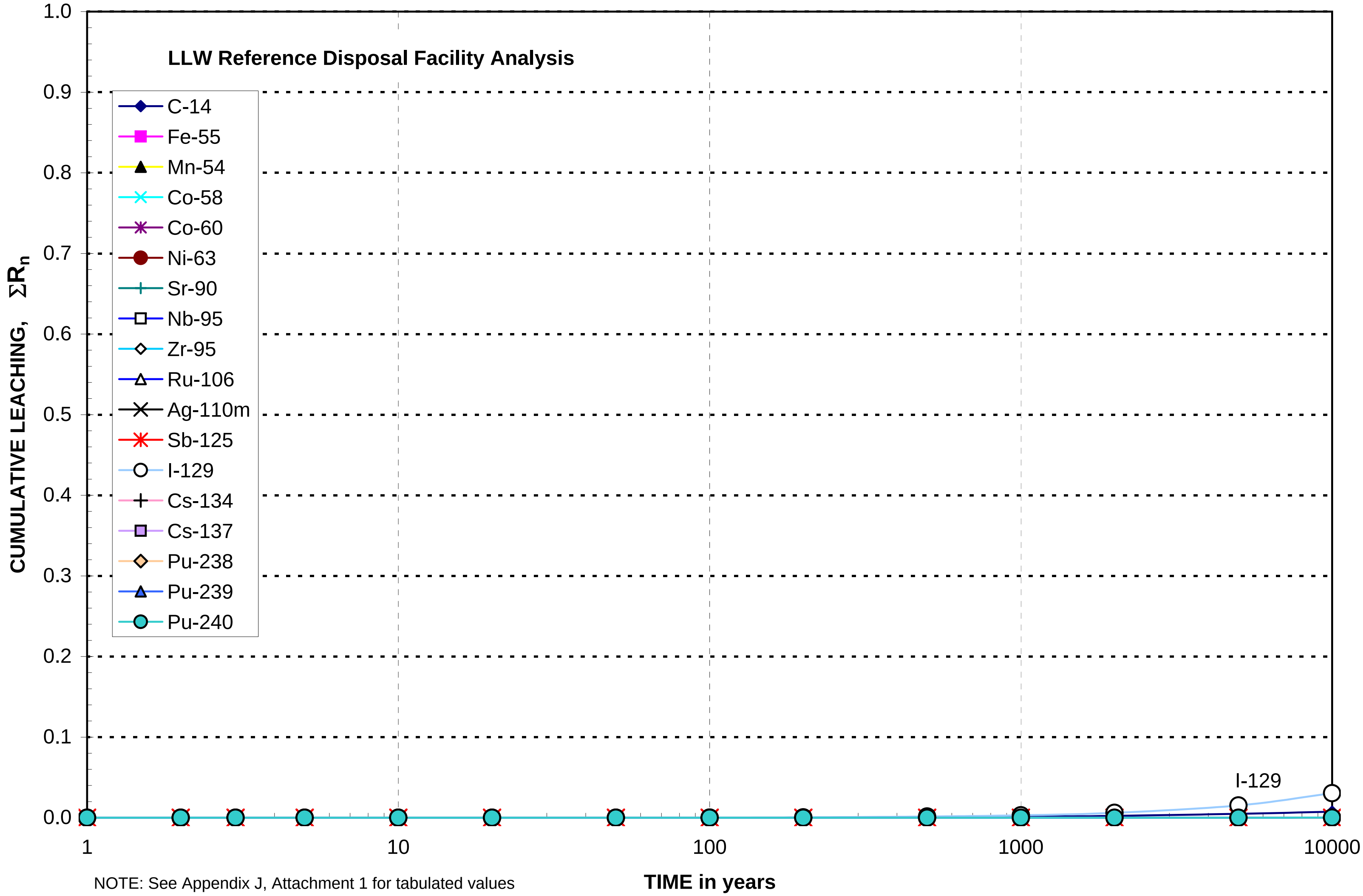
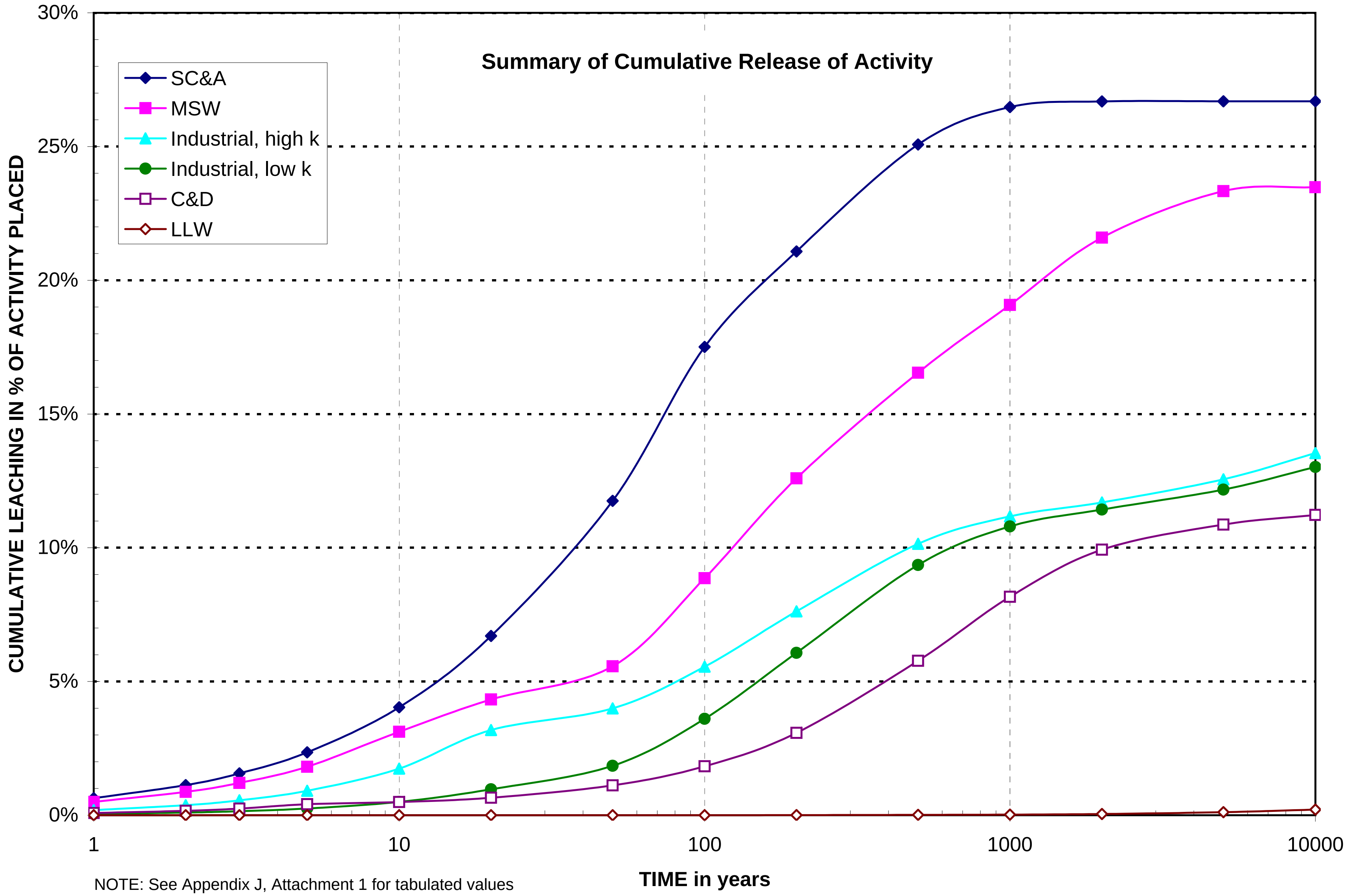

Construction & Demolition Reference Landfill Analysis
C-14
Fe-55
Mn-54
Co-58
Co-60
Ni-63
Sr-90
Nb-95
Zr-95
Ru-106
Ag-110m
Sb-125
I-129
Cs-134
Cs-137
Pu-238
Pu-239
Pu-240
CUMULATIVE LEACHING, ΣRn
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
10
100
1000
10000
I-129
C-14
Pu-239
Pu-240
NOTE: See Appendix J, Attachment 1 for tabulated values
TIME in years

Figure J-6



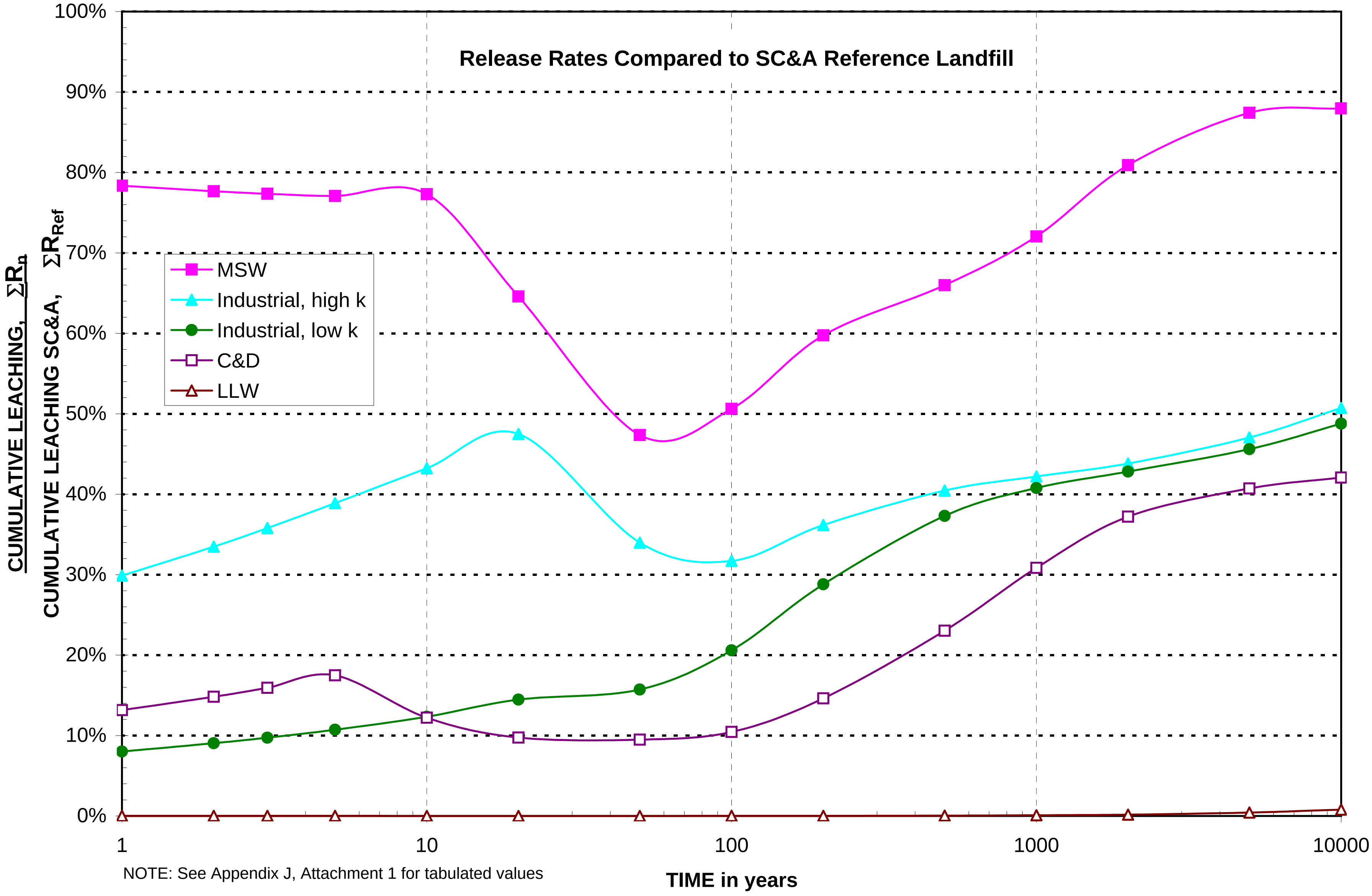
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-7



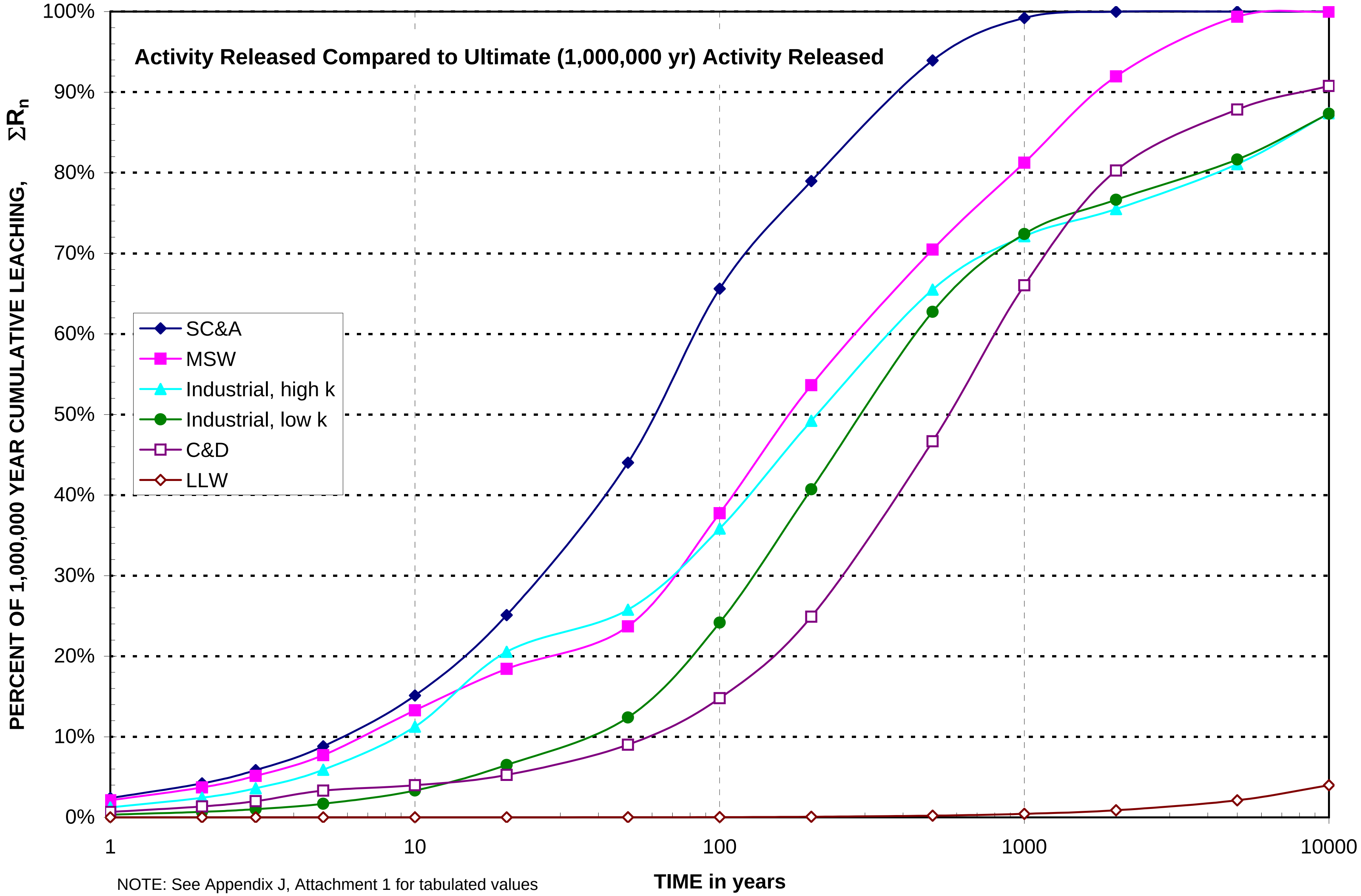
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-8



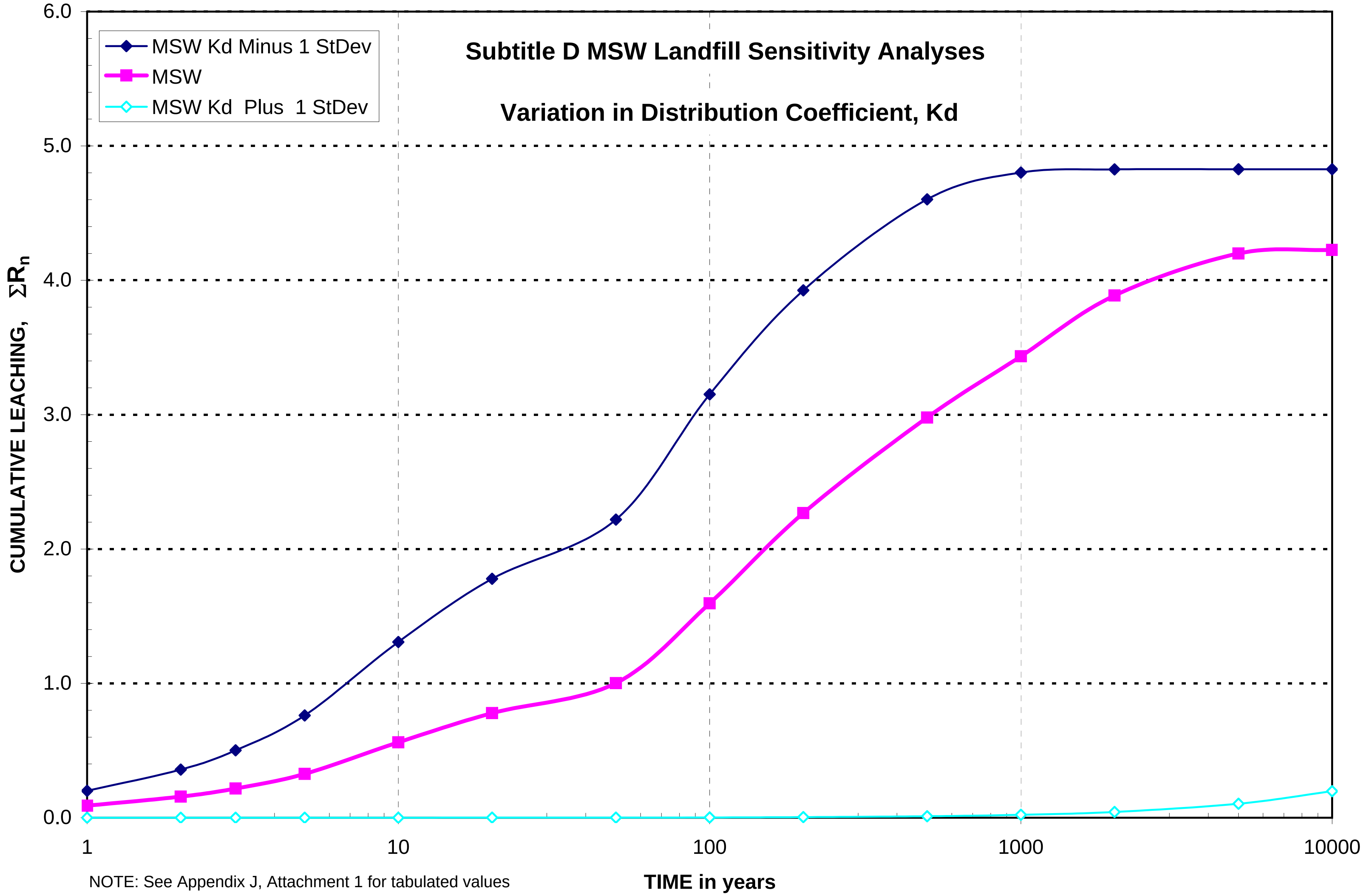
Release Rates Compared to SC&A Reference Landfill
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
1
10
100
1000
10000
TIME in years
CUMULATIVE LEACHING, ΣRn
CUMULATIVE LEACHING SC&A, ΣRRef
MSW
Industrial, high k
Industrial, low k
C&D
LLW
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-9



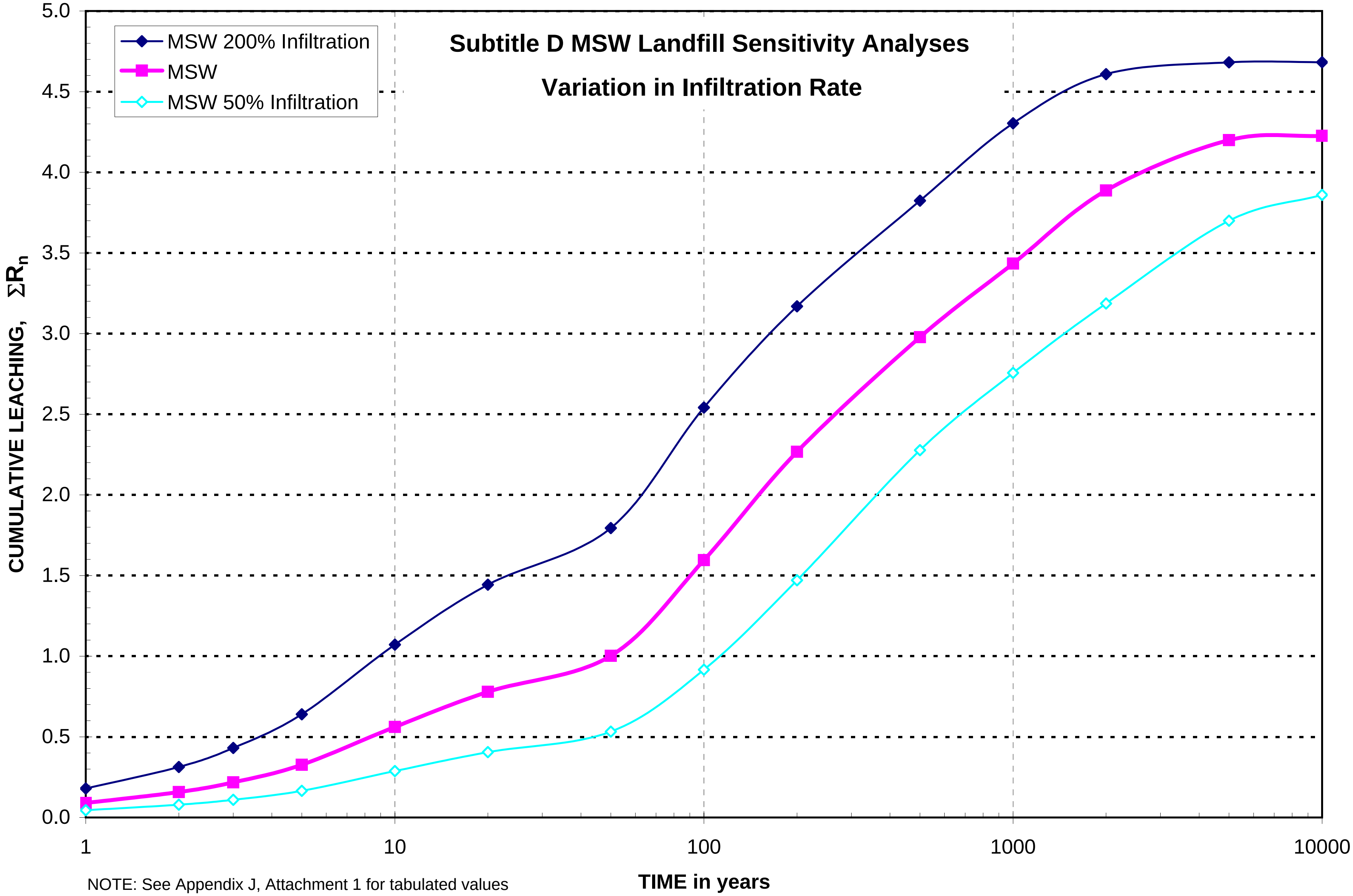
Activity Released Compared to Ultimate (1,000,000 yr) Activity Released
PERCENT OF 1,000,000 YEAR CUMULATIVE LEACHING, ΣR_n
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
SC&A
MSW
Industrial, high k
Industrial, low k
C&D
LLW
1
10
100
1000
10000
TIME in years
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-10



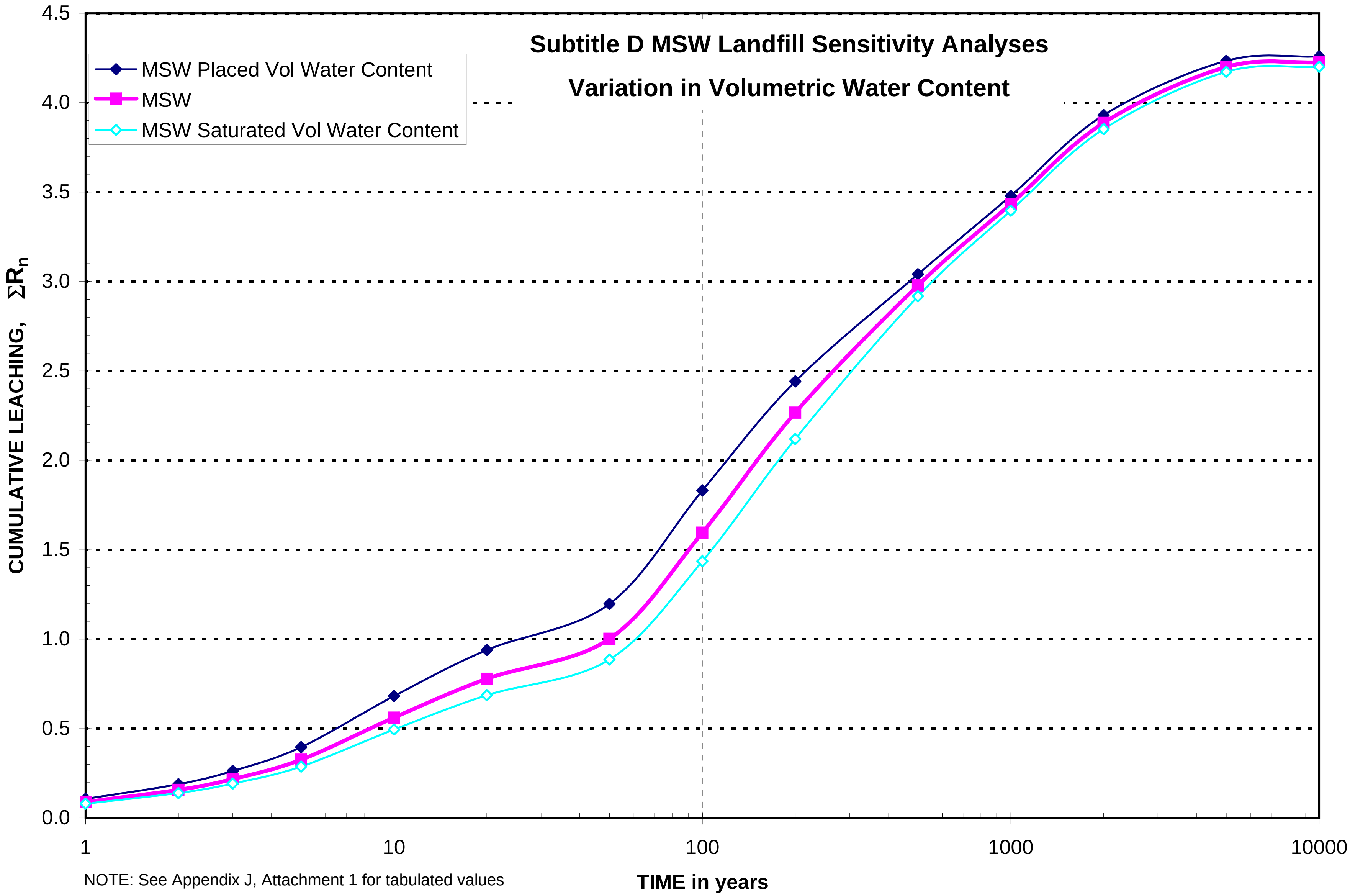
Subtitle D MSW Landfill Sensitivity Analyses
Variation in Distribution Coefficient, Kd
MSW Kd Minus 1 StDev
MSW
MSW Kd Plus 1 StDev
CUMULATIVE LEACHING, ΣRn
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1
10
100
1000
10000
TIME in years
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-11



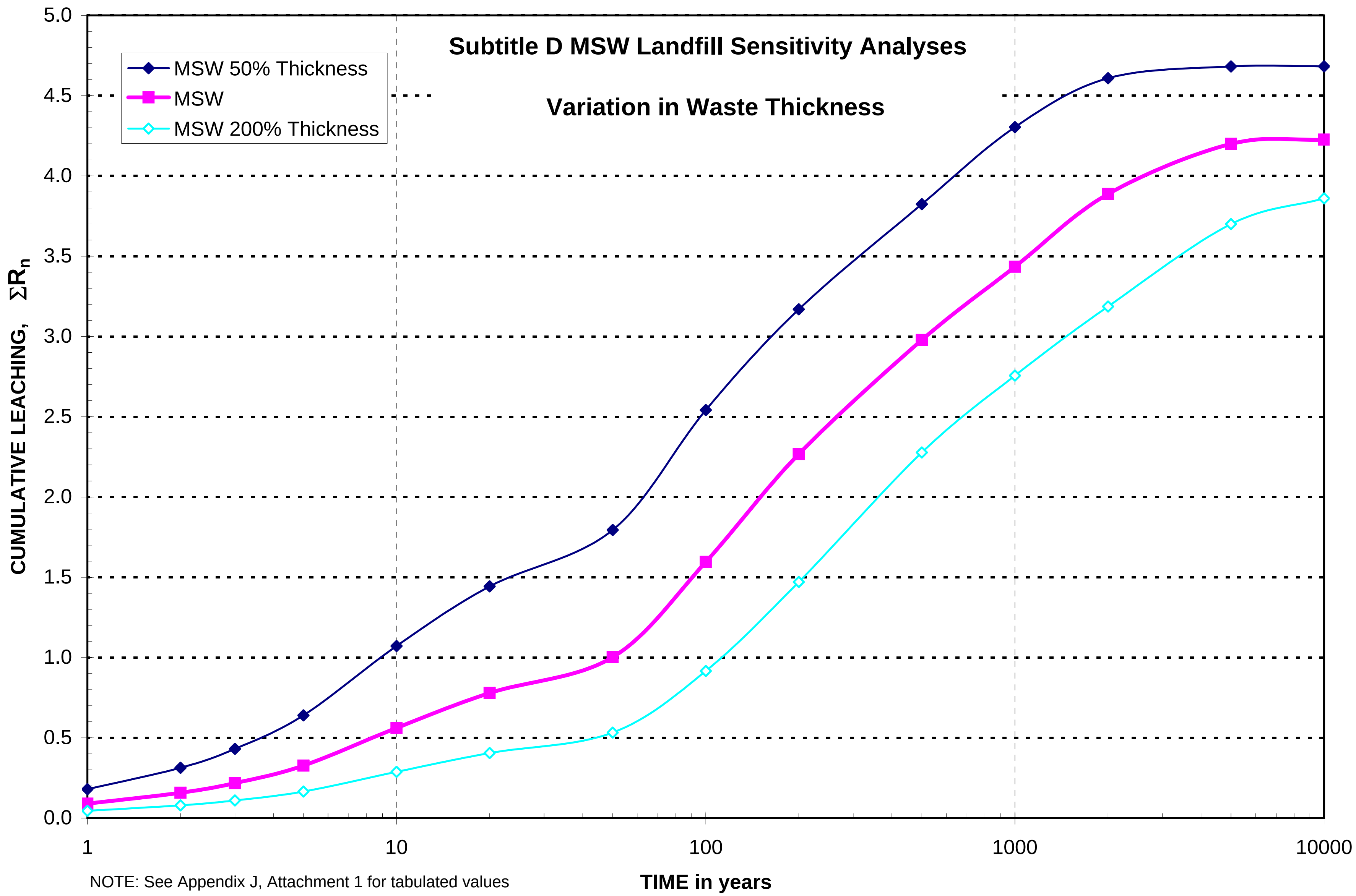
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-12



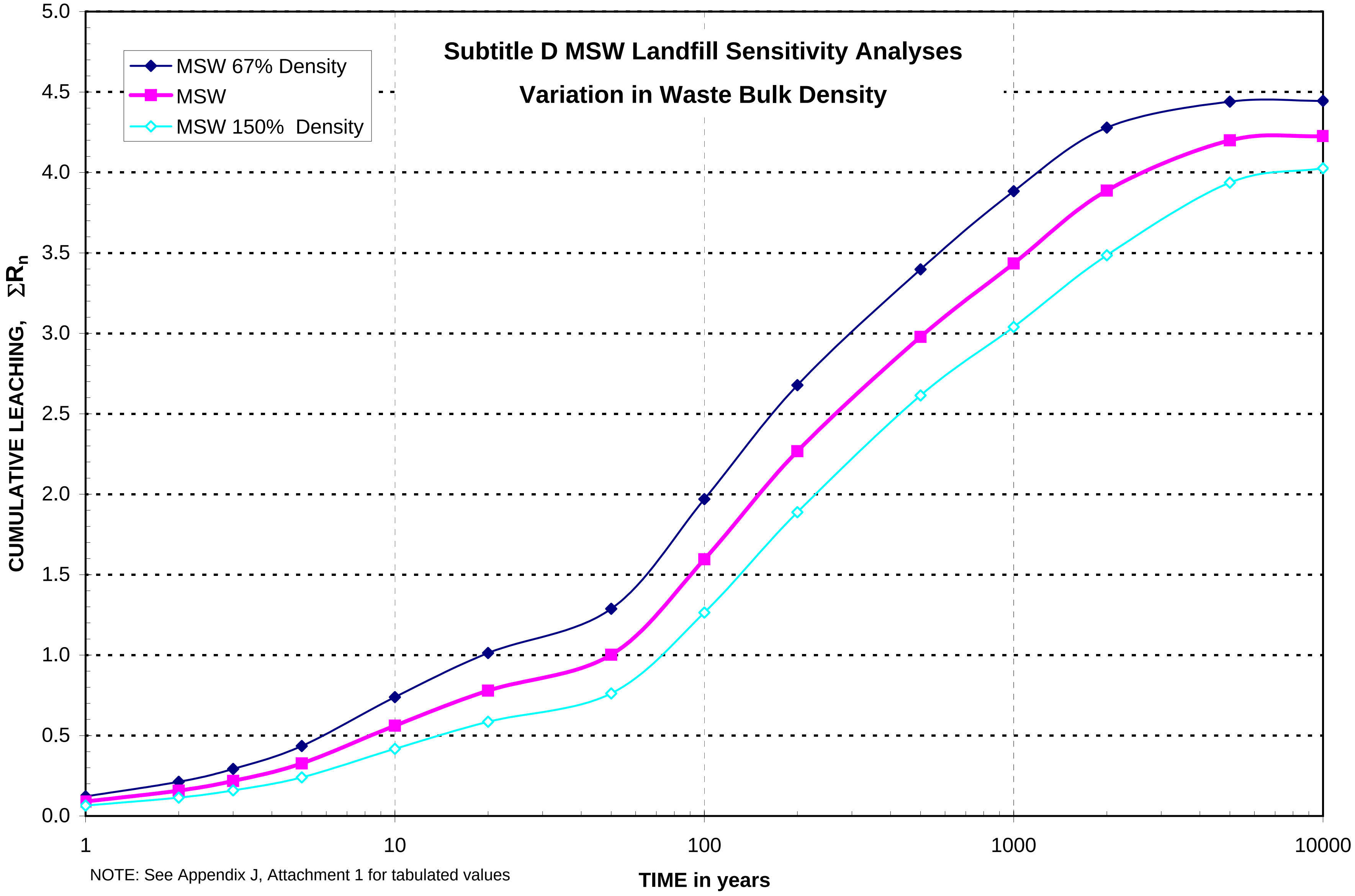
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-13



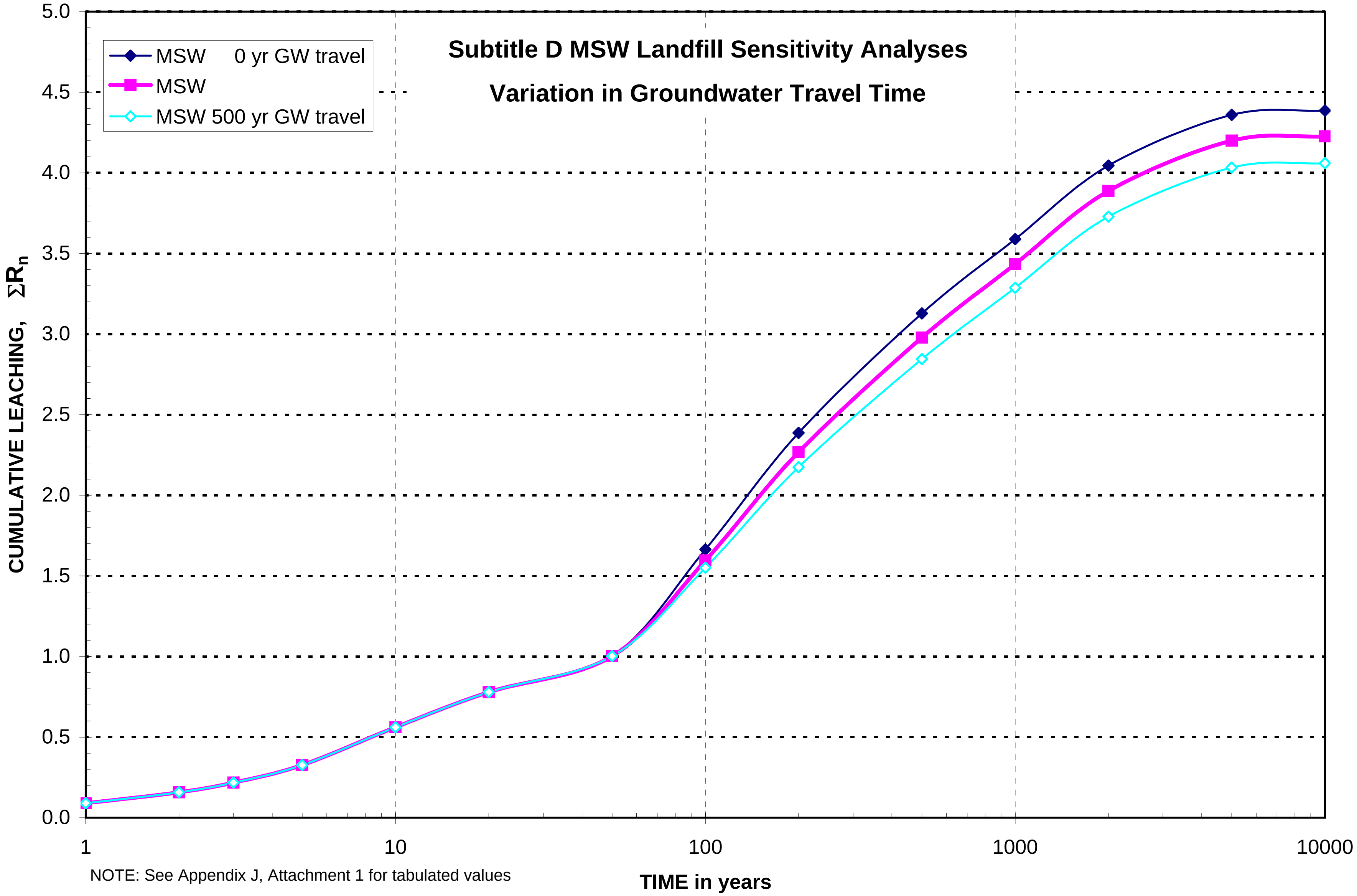
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-14



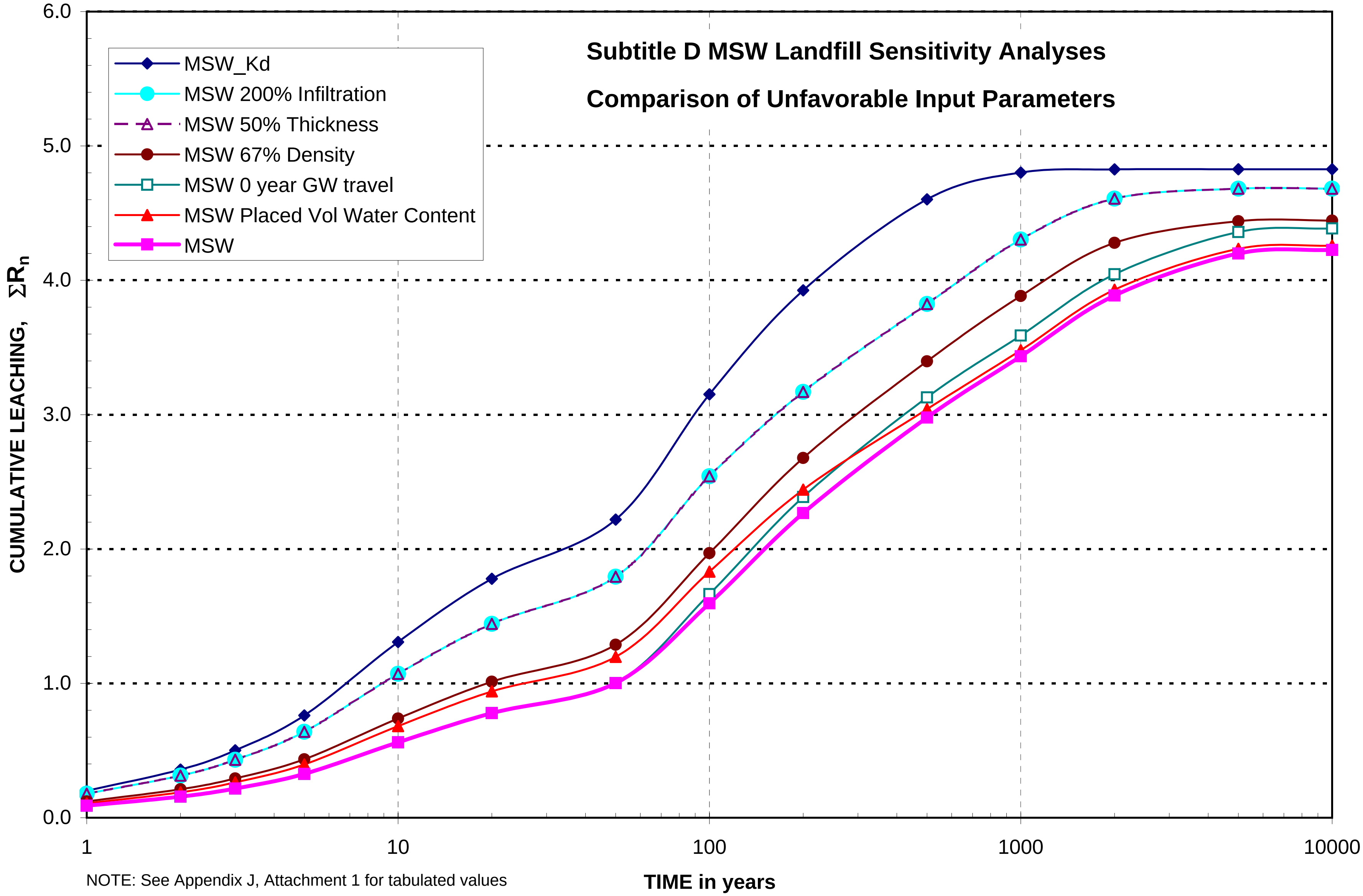
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-15



Subtitle D MSW Landfill Sensitivity Analyses
Variation in Groundwater Travel Time
MSW 0 yr GW travel
MSW
MSW 500 yr GW travel
CUMULATIVE LEACHING, ΣR_n
TIME in years
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
1
10
100
1000
10000
NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-16



NOTE: See Appendix J, Attachment 1 for tabulated values

Figure J-17

Attachment 1

Analytical Support Files for the Comparison of Disposal Facilities

SC&A Reference Landfill Analyses

Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

		Start Year					
		0	3	5	10	20	50
Infiltration rate (m/yr)	$I =$	0.0432	0.0432	0.0432	0.0432	0.0432	0.1090
Volumetric water content	$\theta =$	0.13	0.13	0.13	0.13	0.13	0.14
Thickness (m)	$T_0 =$	2.57	2.57	2.57	2.57	2.57	2.57
Bulk density, unsaturated waste (g/cm^3)	$\rho_b =$	0.89	0.89	0.89	0.89	0.89	0.89

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.61E-02	1.61E-02	1.61E-02	1.61E-02	1.61E-02	4.03E-02
Fe-55	2.57E-01	7.73E-01	2.59	6.90E-03	6.90E-03	6.90E-03	6.90E-03	6.90E-03	1.73E-02
Mn-54	8.10E-01	4.45E-01	1.96	8.97E-03	8.97E-03	8.97E-03	8.97E-03	8.97E-03	2.25E-02
Co-58	3.58E+00	2.79E-02	2.91	6.17E-03	6.17E-03	6.17E-03	6.17E-03	6.17E-03	1.55E-02
Co-60	1.32E-01	8.76E-01	2.91	6.17E-03	6.17E-03	6.17E-03	6.17E-03	6.17E-03	1.55E-02
Ni-63	7.22E-03	9.93E-01	5.26	3.49E-03	3.49E-03	3.49E-03	3.49E-03	3.49E-03	8.80E-03
Sr-90	2.41E-02	9.76E-01	2.98	6.04E-03	6.04E-03	6.04E-03	6.04E-03	6.04E-03	1.52E-02
Nb-95	7.24E+00	7.17E-04	4.71	3.89E-03	3.89E-03	3.89E-03	3.89E-03	3.89E-03	9.78E-03
Zr-95	3.95E+00	1.93E-02	17.12	1.09E-03	1.09E-03	1.09E-03	1.09E-03	1.09E-03	2.76E-03
Ru-106	6.78E-01	5.08E-01	19.70	9.52E-04	9.52E-04	9.52E-04	9.52E-04	9.52E-04	2.40E-03
Ag-110m	1.01E+00	3.64E-01	2.69	6.66E-03	6.66E-03	6.66E-03	6.66E-03	6.66E-03	1.67E-02
Sb-125	2.51E-01	7.78E-01	4.71	3.89E-03	3.89E-03	3.89E-03	3.89E-03	3.89E-03	9.78E-03
I-129	4.41E-08	1.00E+00	0.43	3.29E-02	3.29E-02	3.29E-02	3.29E-02	3.29E-02	8.13E-02
Cs-134	3.36E-01	7.15E-01	5.53	3.33E-03	3.33E-03	3.33E-03	3.33E-03	3.33E-03	8.38E-03
Cs-137	2.31E-02	9.77E-01	5.53	3.33E-03	3.33E-03	3.33E-03	3.33E-03	3.33E-03	8.38E-03
Pu-238	7.90E-03	9.92E-01	11.82	1.58E-03	1.58E-03	1.58E-03	1.58E-03	1.58E-03	3.98E-03
Pu-239	2.87E-05	1.00E+00	11.82	1.58E-03	1.58E-03	1.58E-03	1.58E-03	1.58E-03	3.98E-03
Pu-240	1.06E-04	1.00E+00	11.82	1.58E-03	1.58E-03	1.58E-03	1.58E-03	1.58E-03	3.98E-03

SC&A Reference Landfill Analyses

Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.6%	1.1%	1.6%	2.4%	4.0%	6.7%	11.8%	17.5%	21.1%	25.1%	26.5%	26.7%	26.7%	26.7%	26.7%
Cumulative activity released =	0.11458	0.20259	0.28151	0.42357	0.72652	1.20614	2.11537	3.15182	3.79374	4.51355	4.76624	4.80386	4.80452	4.80452	4.80452
Relative activity released =	2.4%	4.2%	5.9%	8.8%	15.1%	25.1%	44.0%	65.6%	79.0%	93.9%	99.2%	100.0%	100.0%	100.0%	100.0%
Cum. released/SC&A released =	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01612	0.03199	0.04759	0.07804	0.14995	0.27724	0.55494	*0.93412*	*0.98846*	*0.98935*	*0.98935*	*0.98935*	*0.98935*	*0.98935*	*0.98935*
Fe-55	0.00690	0.01220	0.01626	0.02179	0.02761	0.02958	0.02974	*0.02974*	*0.02974*	*0.02974*	*0.02974*	*0.02974*	*0.02974*	*0.02974*	*0.02974*
Mn-54	0.00897	0.01292	0.01467	0.01577	0.01604	0.01604	0.01604	*0.01604*	*0.01604*	*0.01604*	*0.01604*	*0.01604*	*0.01604*	*0.01604*	*0.01604*
Co-58	0.00617	0.00634	0.00635	0.00635	0.00635	0.00635	0.00635	*0.00635*	*0.00635*	*0.00635*	*0.00635*	*0.00635*	*0.00635*	*0.00635*	*0.00635*
Co-60	0.00617	0.01155	0.01623	0.02385	0.03581	0.04480	0.04776	*0.04776*	*0.04776*	*0.04776*	*0.04776*	*0.04776*	*0.04776*	*0.04776*	*0.04776*
Ni-63	0.00349	0.00695	0.01037	0.01710	0.03332	0.06324	0.13598	*0.22263*	*0.27885*	*0.29285*	*0.29297*	*0.29297*	*0.29297*	*0.29297*	*0.29297*
Sr-90	0.00604	0.01189	0.01758	0.02844	0.05290	0.09203	0.15822	*0.16495*	*0.16601*	*0.16604*	*0.16604*	*0.16604*	*0.16604*	*0.16604*	*0.16604*
Nb-95	0.00389	0.00389	0.00389	0.00389	0.00389	0.00389	0.00389	*0.00389*	*0.00389*	*0.00389*	*0.00389*	*0.00389*	*0.00389*	*0.00389*	*0.00389*
Zr-95	0.00109	0.00112	0.00112	0.00112	0.00112	0.00112	0.00112	*0.00112*	*0.00112*	*0.00112*	*0.00112*	*0.00112*	*0.00112*	*0.00112*	*0.00112*
Ru-106	0.00095	0.00143	0.00168	0.00187	0.00193	0.00193	0.00193	*0.00193*	*0.00193*	*0.00193*	*0.00193*	*0.00193*	*0.00193*	*0.00193*	*0.00193*
Ag-110m	0.00666	0.00906	0.00994	0.01037	0.01043	0.01043	0.01043	*0.01043*	*0.01043*	*0.01043*	*0.01043*	*0.01043*	*0.01043*	*0.01043*	*0.01043*
Sb-125	0.00389	0.00690	0.00923	0.01245	0.01593	0.01717	0.01728	*0.01728*	*0.01728*	*0.01728*	*0.01728*	*0.01728*	*0.01728*	*0.01728*	*0.01728*
I-129	0.03286	0.06463	0.09537	0.15383	0.28400	0.48735	0.81183	*0.99729*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*
Cs-134	0.00333	0.00570	0.00738	0.00944	0.01117	0.01155	0.01156	*0.01156*	*0.01156*	*0.01156*	*0.01156*	*0.01156*	*0.01156*	*0.01156*	*0.01156*
Cs-137	0.00333	0.00657	0.00972	0.01579	0.02962	0.05236	0.09351	*0.09918*	*0.10060*	*0.10066*	*0.10066*	*0.10066*	*0.10066*	*0.10066*	*0.10066*
Pu-238	0.00158	0.00314	0.00469	0.00774	0.01513	0.02889	0.06315	*0.10578*	*0.14229*	*0.15783*	*0.15828*	*0.15829*	*0.15829*	*0.15829*	*0.15829*
Pu-239	0.00158	0.00315	0.00473	0.00787	0.01567	0.03109	0.07589	*0.24207*	*0.48923*	*0.83946*	*0.96928*	*0.98905*	*0.98941*	*0.98941*	*0.98941*
Pu-240	0.00158	0.00315	0.00473	0.00787	0.01567	0.03107	0.07575	*0.23971*	*0.48221*	*0.82126*	*0.94357*	*0.96142*	*0.96172*	*0.96172*	*0.96172*
	Cumulative Leaching, ΣR														

MSW Reference Landfill Analyses

Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta^*T_0^*(1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content	θ =	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)	T_0 =	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	0.85	0.85	0.85	0.85	0.85	0.85

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.22E-02	1.22E-02	1.22E-02	6.66E-03	2.72E-03	6.66E-03
Fe-55	2.57E-01	7.73E-01	2.59	5.85E-03	5.85E-03	5.85E-03	3.19E-03	1.30E-03	3.19E-03
Mn-54	8.10E-01	4.45E-01	1.96	7.40E-03	7.40E-03	7.40E-03	4.04E-03	1.65E-03	4.04E-03
Co-58	3.58E+00	2.79E-02	2.91	5.28E-03	5.28E-03	5.28E-03	2.88E-03	1.17E-03	2.88E-03
Co-60	1.32E-01	8.76E-01	2.91	5.28E-03	5.28E-03	5.28E-03	2.88E-03	1.17E-03	2.88E-03
Ni-63	7.22E-03	9.93E-01	5.26	3.10E-03	3.10E-03	3.10E-03	1.69E-03	6.89E-04	1.69E-03
Sr-90	2.41E-02	9.76E-01	2.98	5.17E-03	5.17E-03	5.17E-03	2.82E-03	1.15E-03	2.82E-03
Nb-95	7.24E+00	7.17E-04	4.71	3.43E-03	3.43E-03	3.43E-03	1.87E-03	7.62E-04	1.87E-03
Zr-95	3.95E+00	1.93E-02	17.12	1.00E-03	1.00E-03	1.00E-03	5.46E-04	2.23E-04	5.46E-04
Ru-106	6.78E-01	5.08E-01	19.70	8.73E-04	8.73E-04	8.73E-04	4.76E-04	1.94E-04	4.76E-04
Ag-110m	1.01E+00	3.64E-01	2.69	5.66E-03	5.66E-03	5.66E-03	3.08E-03	1.26E-03	3.08E-03
Sb-125	2.51E-01	7.78E-01	4.71	3.43E-03	3.43E-03	3.43E-03	1.87E-03	7.62E-04	1.87E-03
I-129	4.41E-08	1.00E+00	0.43	2.09E-02	2.09E-02	2.09E-02	1.14E-02	4.65E-03	1.14E-02
Cs-134	3.36E-01	7.15E-01	5.53	2.95E-03	2.95E-03	2.95E-03	1.61E-03	6.57E-04	1.61E-03
Cs-137	2.31E-02	9.77E-01	5.53	2.95E-03	2.95E-03	2.95E-03	1.61E-03	6.57E-04	1.61E-03
Pu-238	7.90E-03	9.92E-01	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04
Pu-239	2.87E-05	1.00E+00	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04
Pu-240	1.06E-04	1.00E+00	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04

MSW Reference Landfill Analyses

Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.5%	0.9%	1.2%	1.8%	3.1%	4.3%	5.6%	8.9%	12.6%	16.5%	19.1%	21.6%	23.3%	23.5%	23.5%
Cumulative activity released =	0.08979	0.15736	0.21773	0.32650	0.56161	0.77892	1.00192	1.59543	2.26704	2.97828	3.43415	3.88711	4.19969	4.22636	4.22677
Relative activity released =	2.1%	3.7%	5.2%	7.7%	13.3%	18.4%	23.7%	37.7%	53.6%	70.5%	81.2%	92.0%	99.4%	100.0%	100.0%
Cum. released/SC&A released =	78.4%	77.7%	77.3%	77.1%	77.3%	64.6%	47.4%	50.6%	59.8%	66.0%	72.1%	80.9%	87.4%	88.0%	88.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01222	0.02429	0.03621	0.05960	0.11562	0.17268	0.23728	*0.44928*	*0.70754*	*0.93815*	*0.97144*	*0.97259*	*0.97259*	*0.97259*	*0.97259*
Fe-55	0.00585	0.01034	0.01380	0.01849	0.02346	0.02439	0.02442	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*
Mn-54	0.00740	0.01067	0.01212	0.01304	0.01326	0.01326	0.01326	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*
Co-58	0.00528	0.00543	0.00543	0.00543	0.00543	0.00543	0.00543	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*
Co-60	0.00528	0.00988	0.01389	0.02044	0.03072	0.03500	0.03561	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*
Ni-63	0.00310	0.00616	0.00919	0.01517	0.02957	0.04420	0.05944	*0.08107*	*0.10379*	*0.11851*	*0.11959*	*0.11960*	*0.11960*	*0.11960*	*0.11960*
Sr-90	0.00517	0.01020	0.01508	0.02441	0.04550	0.06419	0.07817	*0.08005*	*0.08067*	*0.08072*	*0.08072*	*0.08072*	*0.08072*	*0.08072*	*0.08072*
Nb-95	0.00343	0.00343	0.00343	0.00343	0.00343	0.00343	0.00343	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*
Zr-95	0.00100	0.00102	0.00102	0.00102	0.00102	0.00102	0.00102	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*
Ru-106	0.00087	0.00132	0.00154	0.00171	0.00177	0.00177	0.00177	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*
Ag-110m	0.00566	0.00771	0.00845	0.00882	0.00887	0.00887	0.00887	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*
Sb-125	0.00343	0.00608	0.00814	0.01098	0.01405	0.01466	0.01468	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*
I-129	0.02089	0.04134	0.06137	0.10018	0.19032	0.27793	0.37211	*0.64581*	*0.88729*	*0.99636*	*0.99998*	*0.99999*	*0.99999*	*0.99999*	*0.99999*
Cs-134	0.00295	0.00506	0.00656	0.00839	0.00993	0.01011	0.01012	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*
Cs-137	0.00295	0.00583	0.00864	0.01403	0.02635	0.03748	0.04607	*0.04744*	*0.04795*	*0.04800*	*0.04800*	*0.04800*	*0.04800*	*0.04800*	*0.04800*
Pu-238	0.00144	0.00286	0.00427	0.00705	0.01377	0.02063	0.02775	*0.03719*	*0.04726*	*0.05401*	*0.05455*	*0.05455*	*0.05455*	*0.05455*	*0.05455*
Pu-239	0.00144	0.00287	0.00430	0.00716	0.01426	0.02194	0.03126	*0.06826*	*0.13789*	*0.31589*	*0.53127*	*0.77050*	*0.94496*	*0.96143*	*0.96172*
Pu-240	0.00144	0.00287	0.00430	0.00716	0.01426	0.02193	0.03123	*0.06772*	*0.13603*	*0.30803*	*0.51000*	*0.72256*	*0.86067*	*0.87087*	*0.87099*
	Cumulative Leaching, ΣR														

Industrial Reference Landfill Analyses, high permeability waste

Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	$I =$	0.3420	0.3420	0.3420	0.3420	0.0761	0.1090
Volumetric water content	$\theta =$	0.055	0.055	0.055	0.055	0.055	0.125
Thickness (m)	$T_0 =$	2.57	2.57	2.57	2.57	2.57	2.57
Bulk density, unsaturated waste (g/cm^3)	$\rho_b =$	1.21	1.21	1.21	1.21	1.21	1.21

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	11.00	9.96E-03	9.96E-03	9.96E-03	9.96E-03	2.22E-03	3.16E-03
Fe-55	2.57E-01	7.73E-01	209.00	5.26E-04	5.26E-04	5.26E-04	5.26E-04	1.17E-04	1.68E-04
Mn-54	8.10E-01	4.45E-01	158.00	6.96E-04	6.96E-04	6.96E-04	6.96E-04	1.55E-04	2.22E-04
Co-58	3.58E+00	2.79E-02	235.00	4.68E-04	4.68E-04	4.68E-04	4.68E-04	1.04E-04	1.49E-04
Co-60	1.32E-01	8.76E-01	235.00	4.68E-04	4.68E-04	4.68E-04	4.68E-04	1.04E-04	1.49E-04
Ni-63	7.22E-03	9.93E-01	424.00	2.59E-04	2.59E-04	2.59E-04	2.59E-04	5.77E-05	8.26E-05
Sr-90	2.41E-02	9.76E-01	32.00	3.43E-03	3.43E-03	3.43E-03	3.43E-03	7.64E-04	1.09E-03
Nb-95	7.24E+00	7.17E-04	380.00	2.89E-04	2.89E-04	2.89E-04	2.89E-04	6.44E-05	9.22E-05
Zr-95	3.95E+00	1.93E-02	1,380.00	7.97E-05	7.97E-05	7.97E-05	7.97E-05	1.77E-05	2.54E-05
Ru-106	6.78E-01	5.08E-01	1,588.00	6.93E-05	6.93E-05	6.93E-05	6.93E-05	1.54E-05	2.21E-05
Ag-110m	1.01E+00	3.64E-01	217.00	5.07E-04	5.07E-04	5.07E-04	5.07E-04	1.13E-04	1.61E-04
Sb-125	2.51E-01	7.78E-01	380.00	2.89E-04	2.89E-04	2.89E-04	2.89E-04	6.44E-05	9.22E-05
I-129	4.41E-08	1.00E+00	4.60	2.37E-02	2.37E-02	2.37E-02	2.37E-02	5.27E-03	7.45E-03
Cs-134	3.36E-01	7.15E-01	446.00	2.47E-04	2.47E-04	2.47E-04	2.47E-04	5.49E-05	7.86E-05
Cs-137	2.31E-02	9.77E-01	446.00	2.47E-04	2.47E-04	2.47E-04	2.47E-04	5.49E-05	7.86E-05
Pu-238	7.90E-03	9.92E-01	953.00	1.15E-04	1.15E-04	1.15E-04	1.15E-04	2.57E-05	3.68E-05
Pu-239	2.87E-05	1.00E+00	953.00	1.15E-04	1.15E-04	1.15E-04	1.15E-04	2.57E-05	3.68E-05
Pu-240	1.06E-04	1.00E+00	953.00	1.15E-04	1.15E-04	1.15E-04	1.15E-04	2.57E-05	3.68E-05

Industrial Reference Landfill Analyses, high permeability waste

Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.2%	0.4%	0.6%	0.9%	1.7%	3.2%	4.0%	5.6%	7.6%	10.1%	11.2%	11.7%	12.6%	13.5%	15.5%
Cumulative activity released =	0.03425	0.06783	0.10076	0.16470	0.31405	0.57281	0.71877	0.99946	1.37242	1.82632	2.01141	2.10524	2.26062	2.43681	2.78850
Relative activity released =	1.2%	2.4%	3.6%	5.9%	11.3%	20.5%	25.8%	35.8%	49.2%	65.5%	72.1%	75.5%	81.1%	87.4%	100.0%
Cum. released/SC&A released =	29.9%	33.5%	35.8%	38.9%	43.2%	47.5%	34.0%	31.7%	36.2%	40.5%	42.2%	43.8%	47.1%	50.7%	58.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	*0.00984*	*0.01958*	*0.02922*	*0.04820*	*0.09403*	*0.17900*	*0.23085*	*0.34052*	*0.51256*	*0.78995*	*0.92328*	*0.95411*	*0.95532*	*0.95532*	*0.95532*
Fe-55	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Mn-54	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-58	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-60	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ni-63	*0.00013*	*0.00025*	*0.00038*	*0.00062*	*0.00122*	*0.00235*	*0.00300*	*0.00417*	*0.00554*	*0.00668*	*0.00682*	*0.00682*	*0.00682*	*0.00682*	*0.00682*
Sr-90	*0.00031*	*0.00061*	*0.00090*	*0.00146*	*0.00273*	*0.00481*	*0.00565*	*0.00642*	*0.00671*	*0.00673*	*0.00673*	*0.00673*	*0.00673*	*0.00673*	*0.00673*
Nb-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Zr-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ru-106	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ag-110m	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Sb-125	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
I-129	*0.02367*	*0.04679*	*0.06935*	*0.11290*	*0.21305*	*0.38071*	*0.47146*	*0.63638*	*0.82790*	*0.98175*	*0.99956*	*0.99999*	*0.99999*	*0.99999*	*0.99999*
Cs-134	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Cs-137	*0.00002*	*0.00005*	*0.00007*	*0.00012*	*0.00022*	*0.00040*	*0.00047*	*0.00054*	*0.00057*	*0.00058*	*0.00058*	*0.00058*	*0.00058*	*0.00058*	*0.00058*
Pu-238	*0.00005*	*0.00010*	*0.00016*	*0.00026*	*0.00051*	*0.00097*	*0.00124*	*0.00170*	*0.00222*	*0.00262*	*0.00266*	*0.00266*	*0.00266*	*0.00266*	*0.00266*
Pu-239	*0.00012*	*0.00023*	*0.00035*	*0.00058*	*0.00115*	*0.00230*	*0.00306*	*0.00489*	*0.00851*	*0.01925*	*0.03669*	*0.06989*	*0.15741*	*0.26998*	*0.56062*
Pu-240	*0.00011*	*0.00023*	*0.00034*	*0.00057*	*0.00114*	*0.00228*	*0.00304*	*0.00483*	*0.00839*	*0.01876*	*0.03510*	*0.06446*	*0.13112*	*0.19473*	*0.25579*
	Cumulative Leaching, ΣR														

Industrial Reference Landfill Analyses, low permeability waste

Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.1130	0.1130	0.1130	0.1130	0.0761	0.1090
Volumetric water content	θ =	0.187	0.187	0.187	0.187	0.187	0.187
Thickness (m)	T_0 =	2.57	2.57	2.57	2.57	2.57	2.57
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	1.47	1.47	1.47	1.47	1.47	1.47

				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	11.00	2.69E-03	2.69E-03	2.69E-03	2.69E-03	1.81E-03	2.59E-03
Fe-55	2.57E-01	7.73E-01	209.00	1.43E-04	1.43E-04	1.43E-04	1.43E-04	9.63E-05	1.38E-04
Mn-54	8.10E-01	4.45E-01	158.00	1.89E-04	1.89E-04	1.89E-04	1.89E-04	1.27E-04	1.82E-04
Co-58	3.58E+00	2.79E-02	235.00	1.27E-04	1.27E-04	1.27E-04	1.27E-04	8.57E-05	1.23E-04
Co-60	1.32E-01	8.76E-01	235.00	1.27E-04	1.27E-04	1.27E-04	1.27E-04	8.57E-05	1.23E-04
Ni-63	7.22E-03	9.93E-01	424.00	7.05E-05	7.05E-05	7.05E-05	7.05E-05	4.75E-05	6.80E-05
Sr-90	2.41E-02	9.76E-01	32.00	9.31E-04	9.31E-04	9.31E-04	9.31E-04	6.27E-04	8.98E-04
Nb-95	7.24E+00	7.17E-04	380.00	7.87E-05	7.87E-05	7.87E-05	7.87E-05	5.30E-05	7.59E-05
Zr-95	3.95E+00	1.93E-02	1,380.00	2.17E-05	2.17E-05	2.17E-05	2.17E-05	1.46E-05	2.09E-05
Ru-106	6.78E-01	5.08E-01	1,588.00	1.88E-05	1.88E-05	1.88E-05	1.88E-05	1.27E-05	1.82E-05
Ag-110m	1.01E+00	3.64E-01	217.00	1.38E-04	1.38E-04	1.38E-04	1.38E-04	9.28E-05	1.33E-04
Sb-125	2.51E-01	7.78E-01	380.00	7.87E-05	7.87E-05	7.87E-05	7.87E-05	5.30E-05	7.59E-05
I-129	4.41E-08	1.00E+00	4.60	6.33E-03	6.33E-03	6.33E-03	6.33E-03	4.26E-03	6.10E-03
Cs-134	3.36E-01	7.15E-01	446.00	6.70E-05	6.70E-05	6.70E-05	6.70E-05	4.52E-05	6.47E-05
Cs-137	2.31E-02	9.77E-01	446.00	6.70E-05	6.70E-05	6.70E-05	6.70E-05	4.52E-05	6.47E-05
Pu-238	7.90E-03	9.92E-01	953.00	3.14E-05	3.14E-05	3.14E-05	3.14E-05	2.11E-05	3.03E-05
Pu-239	2.87E-05	1.00E+00	953.00	3.14E-05	3.14E-05	3.14E-05	3.14E-05	2.11E-05	3.03E-05
Pu-240	1.06E-04	1.00E+00	953.00	3.14E-05	3.14E-05	3.14E-05	3.14E-05	2.11E-05	3.03E-05

Industrial Reference Landfill Analyses, low permeability waste

Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.1%	0.1%	0.2%	0.3%	0.5%	1.0%	1.8%	3.6%	6.1%	9.4%	10.8%	11.4%	12.2%	13.0%	14.9%
Cumulative activity released =	0.00918	0.01832	0.02740	0.04542	0.08963	0.17453	0.33257	0.64895	1.09285	1.68390	1.94321	2.05711	2.19129	2.34360	2.68377
Relative activity released =	0.3%	0.7%	1.0%	1.7%	3.3%	6.5%	12.4%	24.2%	40.7%	62.7%	72.4%	76.7%	81.6%	87.3%	100.0%
Cum. released/SC&A released =	8.0%	9.0%	9.7%	10.7%	12.3%	14.5%	15.7%	20.6%	28.8%	37.3%	40.8%	42.8%	45.6%	48.8%	55.9%

100 Groundwater travel time (years)

Radionuclide	No. of Years														
	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	*0.00266*	*0.00530*	*0.00794*	*0.01320*	*0.02622*	*0.05172*	*0.10105*	*0.20803*	*0.38295*	*0.69524*	*0.87945*	*0.93896*	*0.94317*	*0.94317*	*0.94317*
Fe-55	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Mn-54	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-58	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-60	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ni-63	*0.00003*	*0.00007*	*0.00010*	*0.00017*	*0.00033*	*0.00064*	*0.00118*	*0.00215*	*0.00328*	*0.00422*	*0.00434*	*0.00434*	*0.00434*	*0.00434*	*0.00434*
Sr-90	*0.00008*	*0.00017*	*0.00024*	*0.00040*	*0.00075*	*0.00133*	*0.00206*	*0.00274*	*0.00299*	*0.00301*	*0.00301*	*0.00301*	*0.00301*	*0.00301*	*0.00301*
Nb-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Zr-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ru-106	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ag-110m	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Sb-125	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
I-129	*0.00633*	*0.01261*	*0.01886*	*0.03124*	*0.06150*	*0.11922*	*0.22513*	*0.42945*	*0.69067*	*0.95070*	*0.99768*	*0.99998*	*0.99999*	*0.99999*	*0.99999*
Cs-134	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Cs-137	*0.00001*	*0.00001*	*0.00002*	*0.00003*	*0.00006*	*0.00011*	*0.00017*	*0.00023*	*0.00025*	*0.00026*	*0.00026*	*0.00026*	*0.00026*	*0.00026*	*0.00026*
Pu-238	*0.00001*	*0.00003*	*0.00004*	*0.00007*	*0.00014*	*0.00026*	*0.00048*	*0.00087*	*0.00130*	*0.00162*	*0.00165*	*0.00165*	*0.00165*	*0.00165*	*0.00165*
Pu-239	*0.00003*	*0.00006*	*0.00009*	*0.00016*	*0.00031*	*0.00063*	*0.00126*	*0.00276*	*0.00575*	*0.01462*	*0.02907*	*0.05671*	*0.13049*	*0.22785*	*0.51174*
Pu-240	*0.00003*	*0.00006*	*0.00009*	*0.00016*	*0.00031*	*0.00062*	*0.00124*	*0.00273*	*0.00566*	*0.01423*	*0.02776*	*0.05220*	*0.10838*	*0.16334*	*0.21962*
	Cumulative Leaching, ΣR														

Construction & Demolition Reference Landfill Analysis

Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

		0	3	5	10	20	50
	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.5360	0.5360	0.1090	0.1090	0.1090	0.1090
Volumetric water content	θ =	0.03	0.03	0.03	0.03	0.03	0.03
Thickness (m)	T_0 =	5.30	5.30	5.30	5.30	5.30	5.30
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	2.10	2.10	2.10	2.10	2.10	2.10

				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	11.00	4.37E-03	4.37E-03	8.89E-04	8.89E-04	8.89E-04	8.89E-04
Fe-55	2.57E-01	7.73E-01	209.00	2.30E-04	2.30E-04	4.69E-05	4.69E-05	4.69E-05	4.69E-05
Mn-54	8.10E-01	4.45E-01	158.00	3.05E-04	3.05E-04	6.20E-05	6.20E-05	6.20E-05	6.20E-05
Co-58	3.58E+00	2.79E-02	235.00	2.05E-04	2.05E-04	4.17E-05	4.17E-05	4.17E-05	4.17E-05
Co-60	1.32E-01	8.76E-01	235.00	2.05E-04	2.05E-04	4.17E-05	4.17E-05	4.17E-05	4.17E-05
Ni-63	7.22E-03	9.93E-01	424.00	1.14E-04	1.14E-04	2.31E-05	2.31E-05	2.31E-05	2.31E-05
Sr-90	2.41E-02	9.76E-01	32.00	1.50E-03	1.50E-03	3.06E-04	3.06E-04	3.06E-04	3.06E-04
Nb-95	7.24E+00	7.17E-04	380.00	1.27E-04	1.27E-04	2.58E-05	2.58E-05	2.58E-05	2.58E-05
Zr-95	3.95E+00	1.93E-02	1,380.00	3.49E-05	3.49E-05	7.10E-06	7.10E-06	7.10E-06	7.10E-06
Ru-106	6.78E-01	5.08E-01	1,588.00	3.03E-05	3.03E-05	6.17E-06	6.17E-06	6.17E-06	6.17E-06
Ag-110m	1.01E+00	3.64E-01	217.00	2.22E-04	2.22E-04	4.51E-05	4.51E-05	4.51E-05	4.51E-05
Sb-125	2.51E-01	7.78E-01	380.00	1.27E-04	1.27E-04	2.58E-05	2.58E-05	2.58E-05	2.58E-05
I-129	4.41E-08	1.00E+00	4.60	1.04E-02	1.04E-02	2.12E-03	2.12E-03	2.12E-03	2.12E-03
Cs-134	3.36E-01	7.15E-01	446.00	1.08E-04	1.08E-04	2.20E-05	2.20E-05	2.20E-05	2.20E-05
Cs-137	2.31E-02	9.77E-01	446.00	1.08E-04	1.08E-04	2.20E-05	2.20E-05	2.20E-05	2.20E-05
Pu-238	7.90E-03	9.92E-01	953.00	5.05E-05	5.05E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05
Pu-239	2.87E-05	1.00E+00	953.00	5.05E-05	5.05E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05
Pu-240	1.06E-04	1.00E+00	953.00	5.05E-05	5.05E-05	1.03E-05	1.03E-05	1.03E-05	1.03E-05

Construction & Demolition Reference Landfill Analysis

Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.1%	0.2%	0.2%	0.4%	0.5%	0.7%	1.1%	1.8%	3.1%	5.8%	8.2%	9.9%	10.9%	11.2%	12.4%
Cumulative activity released =	0.01508	0.03003	0.04485	0.07409	0.08871	0.11750	0.20064	0.32932	0.55466	1.03921	1.47033	1.78729	1.95598	2.02129	2.22666
Relative activity released =	0.7%	1.3%	2.0%	3.3%	4.0%	5.3%	9.0%	14.8%	24.9%	46.7%	66.0%	80.3%	87.8%	90.8%	100.0%
Cum. released/SC&A released =	13.2%	14.8%	15.9%	17.5%	12.2%	9.7%	9.5%	10.4%	14.6%	23.0%	30.8%	37.2%	40.7%	42.1%	46.3%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	*0.00432*	*0.00862*	*0.01290*	*0.02141*	*0.02569*	*0.03420*	*0.05921*	*0.09925*	*0.17350*	*0.35611*	*0.56065*	*0.75852*	*0.86631*	*0.87174*	*0.87177*
Fe-55	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Mn-54	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-58	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-60	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ni-63	*0.00006*	*0.00011*	*0.00016*	*0.00027*	*0.00033*	*0.00043*	*0.00069*	*0.00102*	*0.00141*	*0.00173*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*
Sr-90	*0.00014*	*0.00027*	*0.00040*	*0.00064*	*0.00076*	*0.00095*	*0.00131*	*0.00155*	*0.00164*	*0.00164*	*0.00164*	*0.00164*	*0.00164*	*0.00164*	*0.00164*
Nb-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Zr-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ru-106	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ag-110m	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Sb-125	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
I-129	*0.01044*	*0.02076*	*0.03098*	*0.05111*	*0.06113*	*0.08087*	*0.13763*	*0.22454*	*0.37297*	*0.66850*	*0.88540*	*0.98629*	*0.99995*	*0.99998*	*0.99998*
Cs-134	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Cs-137	*0.00001*	*0.00002*	*0.00003*	*0.00005*	*0.00006*	*0.00008*	*0.00011*	*0.00013*	*0.00014*	*0.00014*	*0.00014*	*0.00014*	*0.00014*	*0.00014*	*0.00014*
Pu-238	*0.00002*	*0.00005*	*0.00007*	*0.00011*	*0.00013*	*0.00018*	*0.00028*	*0.00041*	*0.00056*	*0.00067*	*0.00068*	*0.00068*	*0.00068*	*0.00068*	*0.00068*
Pu-239	*0.00005*	*0.00010*	*0.00015*	*0.00025*	*0.00030*	*0.00041*	*0.00071*	*0.00122*	*0.00224*	*0.00527*	*0.01025*	*0.01991*	*0.04674*	*0.08504*	*0.26305*
Pu-240	*0.00005*	*0.00010*	*0.00015*	*0.00025*	*0.00030*	*0.00040*	*0.00071*	*0.00121*	*0.00221*	*0.00514*	*0.00980*	*0.01834*	*0.03875*	*0.06030*	*0.08763*
	Cumulative Leaching, ΣR														

LLW Reference Disposal Facility Analysis

Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.0008	0.0004	0.0001	0.0001	0.0001	0.0004
Volumetric water content	θ =	0.19	0.19	0.19	0.19	0.19	0.19
Thickness (m)	T_0 =	13.10	13.10	13.10	13.10	13.10	13.10
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	2.10	2.10	2.10	2.10	2.10	2.10

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	11.00	2.62E-06	1.31E-06	3.28E-07	3.28E-07	3.28E-07	1.31E-06
Fe-55	2.57E-01	7.73E-01	209.00	1.39E-07	6.95E-08	1.74E-08	1.74E-08	1.74E-08	6.95E-08
Mn-54	8.10E-01	4.45E-01	158.00	1.84E-07	9.20E-08	2.30E-08	2.30E-08	2.30E-08	9.20E-08
Co-58	3.58E+00	2.79E-02	235.00	1.24E-07	6.18E-08	1.55E-08	1.55E-08	1.55E-08	6.18E-08
Co-60	1.32E-01	8.76E-01	235.00	1.24E-07	6.18E-08	1.55E-08	1.55E-08	1.55E-08	6.18E-08
Ni-63	7.22E-03	9.93E-01	424.00	6.86E-08	3.43E-08	8.57E-09	8.57E-09	8.57E-09	3.43E-08
Sr-90	2.41E-02	9.76E-01	32.00	9.06E-07	4.53E-07	1.13E-07	1.13E-07	1.13E-07	4.53E-07
Nb-95	7.24E+00	7.17E-04	380.00	7.65E-08	3.83E-08	9.56E-09	9.56E-09	9.56E-09	3.83E-08
Zr-95	3.95E+00	1.93E-02	1,380.00	2.11E-08	1.05E-08	2.63E-09	2.63E-09	2.63E-09	1.05E-08
Ru-106	6.78E-01	5.08E-01	1,588.00	1.83E-08	9.16E-09	2.29E-09	2.29E-09	2.29E-09	9.16E-09
Ag-110m	1.01E+00	3.64E-01	217.00	1.34E-07	6.70E-08	1.67E-08	1.67E-08	1.67E-08	6.70E-08
Sb-125	2.51E-01	7.78E-01	380.00	7.65E-08	3.83E-08	9.56E-09	9.56E-09	9.56E-09	3.83E-08
I-129	4.41E-08	1.00E+00	4.60	6.20E-06	3.10E-06	7.75E-07	7.75E-07	7.75E-07	3.10E-06
Cs-134	3.36E-01	7.15E-01	446.00	6.52E-08	3.26E-08	8.15E-09	8.15E-09	8.15E-09	3.26E-08
Cs-137	2.31E-02	9.77E-01	446.00	6.52E-08	3.26E-08	8.15E-09	8.15E-09	8.15E-09	3.26E-08
Pu-238	7.90E-03	9.92E-01	953.00	3.05E-08	1.53E-08	3.81E-09	3.81E-09	3.81E-09	1.53E-08
Pu-239	2.87E-05	1.00E+00	953.00	3.05E-08	1.53E-08	3.81E-09	3.81E-09	3.81E-09	1.53E-08
Pu-240	1.06E-04	1.00E+00	953.00	3.05E-08	1.53E-08	3.81E-09	3.81E-09	3.81E-09	1.53E-08

LLW Reference Disposal Facility Analysis

Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	5.3%
Cumulative activity released =	0.00001	0.00002	0.00003	0.00004	0.00004	0.00005	0.00009	0.00031	0.00075	0.00206	0.00421	0.00840	0.02022	0.03809	0.95469
Relative activity released =	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.9%	2.1%	4.0%	100.0%
Cum. released/SC&A released =	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.8%	19.9%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	*0.00000*	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00002*	*0.00002*	*0.00009*	*0.00022*	*0.00059*	*0.00118*	*0.00226*	*0.00481*	*0.00743*	*0.01055*
Fe-55	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Mn-54	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-58	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-60	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ni-63	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Sr-90	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Nb-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Zr-95	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ru-106	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ag-110m	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Sb-125	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
I-129	*0.00001*	*0.00001*	*0.00002*	*0.00002*	*0.00003*	*0.00004*	*0.00006*	*0.00021*	*0.00052*	*0.00145*	*0.00300*	*0.00609*	*0.01528*	*0.03042*	*0.94346*
Cs-134	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Cs-137	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Pu-238	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Pu-239	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00001*	*0.00001*	*0.00003*	*0.00007*	*0.00013*	*0.00053*
Pu-240	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00001*	*0.00001*	*0.00003*	*0.00006*	*0.00009*	*0.00014*
	Cumulative Leaching, ΣR														

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Distribution Coefficient, K_d
Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content	θ =	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)	T_0 =	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	0.85	0.85	0.85	0.85	0.85	0.85

				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	4.10E-02	3.88E-02	3.88E-02	3.88E-02	2.11E-02	8.63E-03	2.11E-02
Fe-55	2.57E-01	7.73E-01	1.35E+00	9.97E-03	9.97E-03	9.97E-03	5.43E-03	2.22E-03	5.43E-03
Mn-54	8.10E-01	4.45E-01	1.49E+00	9.23E-03	9.23E-03	9.23E-03	5.03E-03	2.05E-03	5.03E-03
Co-58	3.58E+00	2.79E-02	1.74E+00	8.14E-03	8.14E-03	8.14E-03	4.44E-03	1.81E-03	4.44E-03
Co-60	1.32E-01	8.76E-01	1.74E+00	8.14E-03	8.14E-03	8.14E-03	4.44E-03	1.81E-03	4.44E-03
Ni-63	7.22E-03	9.93E-01	9.18E+00	1.83E-03	1.83E-03	1.83E-03	9.98E-04	4.07E-04	9.98E-04
Sr-90	2.41E-02	9.76E-01	3.58E-01	2.28E-02	2.28E-02	2.28E-02	1.24E-02	5.08E-03	1.24E-02
Nb-95	7.24E+00	7.17E-04	1.42E+00	9.61E-03	9.61E-03	9.61E-03	5.24E-03	2.14E-03	5.24E-03
Zr-95	3.95E+00	1.93E-02	5.14E+00	3.16E-03	3.16E-03	3.16E-03	1.72E-03	7.04E-04	1.72E-03
Ru-106	6.78E-01	5.08E-01	6.47E+00	2.55E-03	2.55E-03	2.55E-03	1.39E-03	5.68E-04	1.39E-03
Ag-110m	1.01E+00	3.64E-01	2.48E+00	6.08E-03	6.08E-03	6.08E-03	3.31E-03	1.35E-03	3.31E-03
Sb-125	2.51E-01	7.78E-01	1.42E+00	9.61E-03	9.61E-03	9.61E-03	5.24E-03	2.14E-03	5.24E-03
I-129	4.41E-08	1.00E+00	4.80E-02	3.82E-02	3.82E-02	3.82E-02	2.08E-02	8.50E-03	2.08E-02
Cs-134	3.36E-01	7.15E-01	4.04E+00	3.94E-03	3.94E-03	3.94E-03	2.15E-03	8.77E-04	2.15E-03
Cs-137	2.31E-02	9.77E-01	4.04E+00	3.94E-03	3.94E-03	3.94E-03	2.15E-03	8.77E-04	2.15E-03
Pu-238	7.90E-03	9.92E-01	1.79E+00	7.99E-03	7.99E-03	7.99E-03	4.36E-03	1.78E-03	4.36E-03
Pu-239	2.87E-05	1.00E+00	1.79E+00	7.99E-03	7.99E-03	7.99E-03	4.36E-03	1.78E-03	4.36E-03
Pu-240	1.06E-04	1.00E+00	1.79E+00	7.99E-03	7.99E-03	7.99E-03	4.36E-03	1.78E-03	4.36E-03

				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	2.22E+04	7.91E-07	7.91E-07	7.91E-07	4.31E-07	1.76E-07	4.31E-07
Fe-55	2.57E-01	7.73E-01	2.43E+05	7.22E-08	7.22E-08	7.22E-08	3.93E-08	1.61E-08	3.93E-08
Mn-54	8.10E-01	4.45E-01	1.26E+05	1.40E-07	1.40E-07	1.40E-07	7.61E-08	3.11E-08	7.61E-08
Co-58	3.58E+00	2.79E-02	2.38E+05	7.38E-08	7.38E-08	7.38E-08	4.02E-08	1.64E-08	4.02E-08
Co-60	1.32E-01	8.76E-01	2.38E+05	7.38E-08	7.38E-08	7.38E-08	4.02E-08	1.64E-08	4.02E-08
Ni-63	7.22E-03	9.93E-01	1.47E+05	1.19E-07	1.19E-07	1.19E-07	6.50E-08	2.65E-08	6.50E-08
Sr-90	2.41E-02	9.76E-01	2.15E+04	8.17E-07	8.17E-07	8.17E-07	4.45E-07	1.82E-07	4.45E-07
Nb-95	7.24E+00	7.17E-04	7.67E+05	2.29E-08	2.29E-08	2.29E-08	1.25E-08	5.09E-09	1.25E-08
Zr-95	3.95E+00	1.93E-02	2.78E+06	6.31E-09	6.31E-09	6.31E-09	3.44E-09	1.40E-09	3.44E-09
Ru-106	6.78E-01	5.08E-01	2.93E+06	6.00E-09	6.00E-09	6.00E-09	3.27E-09	1.33E-09	3.27E-09
Ag-110m	1.01E+00	3.64E-01	1.43E+05	1.23E-07	1.23E-07	1.23E-07	6.70E-08	2.73E-08	6.70E-08
Sb-125	2.51E-01	7.78E-01	7.67E+05	2.29E-08	2.29E-08	2.29E-08	1.25E-08	5.09E-09	1.25E-08
I-129	4.41E-08	1.00E+00	4.41E+02	3.98E-05	3.98E-05	3.98E-05	2.17E-05	8.85E-06	2.17E-05
Cs-134	3.36E-01	7.15E-01	3.70E+05	4.75E-08	4.75E-08	4.75E-08	2.59E-08	1.06E-08	2.59E-08
Cs-137	2.31E-02	9.77E-01	3.70E+05	4.75E-08	4.75E-08	4.75E-08	2.59E-08	1.06E-08	2.59E-08
Pu-238	7.90E-03	9.92E-01	5.09E+05	3.45E-08	3.45E-08	3.45E-08	1.88E-08	7.68E-09	1.88E-08
Pu-239	2.87E-05	1.00E+00	5.09E+05	3.45E-08	3.45E-08	3.45E-08	1.88E-08	7.68E-09	1.88E-08
Pu-240	1.06E-04	1.00E+00	5.09E+05	3.45E-08	3.45E-08	3.45E-08	1.88E-08	7.68E-09	1.88E-08

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Distribution Coefficient, Kd
Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	1.1%	2.0%	2.8%	4.2%	7.3%	9.9%	12.3%	17.5%	21.8%	25.6%	26.7%	26.8%	26.8%	26.8%	26.8%
Cumulative activity released =	0.19997	0.35788	0.50174	0.76167	1.30739	1.77843	2.21917	3.15165	3.92527	4.60232	4.80183	4.82582	4.82611	4.82611	4.82611
Relative activity released =	4.1%	7.4%	10.4%	15.8%	27.1%	36.9%	46.0%	65.3%	81.3%	95.4%	99.5%	100.0%	100.0%	100.0%	100.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.03879	0.07606	0.11189	0.17941	0.32654	0.45584	0.57983	*0.84943*	*0.97295*	*0.98924*	*0.98927*	*0.98927*	*0.98927*	*0.98927*	*0.98927*
Fe-55	0.00997	0.01761	0.02345	0.03136	0.03961	0.04112	0.04117	*0.04117*	*0.04117*	*0.04117*	*0.04117*	*0.04117*	*0.04117*	*0.04117*	*0.04117*
Mn-54	0.00923	0.01329	0.01509	0.01622	0.01649	0.01650	0.01650	*0.01650*	*0.01650*	*0.01650*	*0.01650*	*0.01650*	*0.01650*	*0.01650*	*0.01650*
Co-58	0.00814	0.00837	0.00837	0.00837	0.00837	0.00837	0.00837	*0.00837*	*0.00837*	*0.00837*	*0.00837*	*0.00837*	*0.00837*	*0.00837*	*0.00837*
Co-60	0.00814	0.01522	0.02137	0.03136	0.04693	0.05330	0.05420	*0.05420*	*0.05420*	*0.05420*	*0.05420*	*0.05420*	*0.05420*	*0.05420*	*0.05420*
Ni-63	0.00183	0.00365	0.00544	0.00899	0.01759	0.02637	0.03560	*0.04896*	*0.06368*	*0.07426*	*0.07522*	*0.07524*	*0.07524*	*0.07524*	*0.07524*
Sr-90	0.02281	0.04457	0.06533	0.10402	0.18617	0.25232	0.29685	*0.30155*	*0.30243*	*0.30245*	*0.30245*	*0.30245*	*0.30245*	*0.30245*	*0.30245*
Nb-95	0.00961	0.00962	0.00962	0.00962	0.00962	0.00962	0.00962	*0.00962*	*0.00962*	*0.00962*	*0.00962*	*0.00962*	*0.00962*	*0.00962*	*0.00962*
Zr-95	0.00316	0.00322	0.00323	0.00323	0.00323	0.00323	0.00323	*0.00323*	*0.00323*	*0.00323*	*0.00323*	*0.00323*	*0.00323*	*0.00323*	*0.00323*
Ru-106	0.00255	0.00384	0.00450	0.00500	0.00516	0.00517	0.00517	*0.00517*	*0.00517*	*0.00517*	*0.00517*	*0.00517*	*0.00517*	*0.00517*	*0.00517*
Ag-110m	0.00608	0.00828	0.00908	0.00947	0.00953	0.00953	0.00953	*0.00953*	*0.00953*	*0.00953*	*0.00953*	*0.00953*	*0.00953*	*0.00953*	*0.00953*
Sb-125	0.00961	0.01702	0.02272	0.03051	0.03880	0.04037	0.04043	*0.04043*	*0.04043*	*0.04043*	*0.04043*	*0.04043*	*0.04043*	*0.04043*	*0.04043*
I-129	0.03819	0.07493	0.11026	0.17692	0.32255	0.45106	0.57505	*0.85155*	*0.98188*	*0.99996*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*
Cs-134	0.00394	0.00674	0.00874	0.01117	0.01322	0.01346	0.01346	*0.01346*	*0.01346*	*0.01346*	*0.01346*	*0.01346*	*0.01346*	*0.01346*	*0.01346*
Cs-137	0.00394	0.00778	0.01151	0.01868	0.03499	0.04965	0.06090	*0.06267*	*0.06332*	*0.06337*	*0.06337*	*0.06337*	*0.06337*	*0.06337*	*0.06337*
Pu-238	0.00799	0.01586	0.02360	0.03871	0.07446	0.10963	0.14472	*0.18666*	*0.22168*	*0.23585*	*0.23621*	*0.23621*	*0.23621*	*0.23621*	*0.23621*
Pu-239	0.00799	0.01592	0.02378	0.03932	0.07709	0.11649	0.16237	*0.32577*	*0.56224*	*0.87616*	*0.97814*	*0.99074*	*0.99089*	*0.99089*	*0.99089*
Pu-240	0.00799	0.01592	0.02378	0.03931	0.07706	0.11642	0.16218	*0.32340*	*0.55542*	*0.85937*	*0.95551*	*0.96689*	*0.96702*	*0.96702*	*0.96702*
	Cumulative Leaching, ΣR														

Percent of activity leached =	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.1%	0.2%	0.6%	1.1%	5.6%
Cumulative activity leached =	0.00004	0.00008	0.00013	0.00021	0.00042	0.00064	0.00092	0.00202	0.00423	0.01082	0.02170	0.04309	0.10432	0.19748	1.00232
Relative activity leached =	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.4%	0.9%	2.2%	4.1%	20.8%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.00000	0.00000	0.00000	0.00000	0.00001	0.00001	0.00002	*0.00004*	*0.00008*	*0.00020*	*0.00040*	*0.00075*	*0.00159*	*0.00246*	*0.00350*
Fe-55	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Mn-54	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-58	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Co-60	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ni-63	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00001*
Sr-90	0.00000	0.00000	0.00000	0.00000	0.00001	0.00001	0.00001	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00001*	*0.00001*
Nb-95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Zr-95	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ru-106	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Ag-110m	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Sb-125	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
I-129	0.00004	0.00008	0.00012	0.00020	0.00040	0.00061	0.00088	*0.00196*	*0.00412*	*0.01058*	*0.02125*	*0.04224*	*0.10255*	*0.19472*	*0.99797*
Cs-134	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Cs-137	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Pu-238	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*	*0.00000*
Pu-239	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00001*	*0.00002*	*0.00004*	*0.00009*	*0.00016*	*0.00065*
Pu-240	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	*0.00000*	*0.00000*	*0.00001*	*0.00002*	*0.00003*	*0.00007*	*0.00011*	*0.00018*
	Cumulative Leaching, ΣR														

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Infiltration Rate
Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content	θ =	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)	T_0 =	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	0.85	0.85	0.85	0.85	0.85	0.85

I = 200%: 0.400, 0.400, 0.400, 0.218, 0.089, 0.218

				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	2.44E-02	2.44E-02	2.44E-02	1.33E-02	5.44E-03	1.33E-02
Fe-55	2.57E-01	7.73E-01	2.59	1.17E-02	1.17E-02	1.17E-02	6.37E-03	2.60E-03	6.37E-03
Mn-54	8.10E-01	4.45E-01	1.96	1.48E-02	1.48E-02	1.48E-02	8.07E-03	3.30E-03	8.07E-03
Co-58	3.58E+00	2.79E-02	2.91	1.06E-02	1.06E-02	1.06E-02	5.75E-03	2.35E-03	5.75E-03
Co-60	1.32E-01	8.76E-01	2.91	1.06E-02	1.06E-02	1.06E-02	5.75E-03	2.35E-03	5.75E-03
Ni-63	7.22E-03	9.93E-01	5.26	6.19E-03	6.19E-03	6.19E-03	3.38E-03	1.38E-03	3.38E-03
Sr-90	2.41E-02	9.76E-01	2.98	1.03E-02	1.03E-02	1.03E-02	5.64E-03	2.30E-03	5.64E-03
Nb-95	7.24E+00	7.17E-04	4.71	6.85E-03	6.85E-03	6.85E-03	3.73E-03	1.52E-03	3.73E-03
Zr-95	3.95E+00	1.93E-02	17.12	2.00E-03	2.00E-03	2.00E-03	1.09E-03	4.46E-04	1.09E-03
Ru-106	6.78E-01	5.08E-01	19.70	1.75E-03	1.75E-03	1.75E-03	9.52E-04	3.89E-04	9.52E-04
Ag-110m	1.01E+00	3.64E-01	2.69	1.13E-02	1.13E-02	1.13E-02	6.17E-03	2.52E-03	6.17E-03
Sb-125	2.51E-01	7.78E-01	4.71	6.85E-03	6.85E-03	6.85E-03	3.73E-03	1.52E-03	3.73E-03
I-129	4.41E-08	1.00E+00	0.43	4.18E-02	4.18E-02	4.18E-02	2.28E-02	9.30E-03	2.28E-02
Cs-134	3.36E-01	7.15E-01	5.53	5.91E-03	5.91E-03	5.91E-03	3.22E-03	1.31E-03	3.22E-03
Cs-137	2.31E-02	9.77E-01	5.53	5.91E-03	5.91E-03	5.91E-03	3.22E-03	1.31E-03	3.22E-03
Pu-238	7.90E-03	9.92E-01	11.82	2.87E-03	2.87E-03	2.87E-03	1.56E-03	6.39E-04	1.56E-03
Pu-239	2.87E-05	1.00E+00	11.82	2.87E-03	2.87E-03	2.87E-03	1.56E-03	6.39E-04	1.56E-03
Pu-240	1.06E-04	1.00E+00	11.82	2.87E-03	2.87E-03	2.87E-03	1.56E-03	6.39E-04	1.56E-03

I = 50%: 0.100, 0.100, 0.100, 0.055, 0.022, 0.055

				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	6.11E-03	6.11E-03	6.11E-03	3.33E-03	1.36E-03	3.33E-03
Fe-55	2.57E-01	7.73E-01	2.59	2.92E-03	2.92E-03	2.92E-03	1.59E-03	6.50E-04	1.59E-03
Mn-54	8.10E-01	4.45E-01	1.96	3.70E-03	3.70E-03	3.70E-03	2.02E-03	8.24E-04	2.02E-03
Co-58	3.58E+00	2.79E-02	2.91	2.64E-03	2.64E-03	2.64E-03	1.44E-03	5.87E-04	1.44E-03
Co-60	1.32E-01	8.76E-01	2.91	2.64E-03	2.64E-03	2.64E-03	1.44E-03	5.87E-04	1.44E-03
Ni-63	7.22E-03	9.93E-01	5.26	1.55E-03	1.55E-03	1.55E-03	8.44E-04	3.45E-04	8.44E-04
Sr-90	2.41E-02	9.76E-01	2.98	2.59E-03	2.59E-03	2.59E-03	1.41E-03	5.75E-04	1.41E-03
Nb-95	7.24E+00	7.17E-04	4.71	1.71E-03	1.71E-03	1.71E-03	9.34E-04	3.81E-04	9.34E-04
Zr-95	3.95E+00	1.93E-02	17.12	5.01E-04	5.01E-04	5.01E-04	2.73E-04	1.11E-04	2.73E-04
Ru-106	6.78E-01	5.08E-01	19.70	4.37E-04	4.37E-04	4.37E-04	2.38E-04	9.72E-05	2.38E-04
Ag-110m	1.01E+00	3.64E-01	2.69	2.83E-03	2.83E-03	2.83E-03	1.54E-03	6.30E-04	1.54E-03
Sb-125	2.51E-01	7.78E-01	4.71	1.71E-03	1.71E-03	1.71E-03	9.34E-04	3.81E-04	9.34E-04
I-129	4.41E-08	1.00E+00	0.43	1.04E-02	1.04E-02	1.04E-02	5.69E-03	2.32E-03	5.69E-03
Cs-134	3.36E-01	7.15E-01	5.53	1.48E-03	1.48E-03	1.48E-03	8.05E-04	3.29E-04	8.05E-04
Cs-137	2.31E-02	9.77E-01	5.53	1.48E-03	1.48E-03	1.48E-03	8.05E-04	3.29E-04	8.05E-04
Pu-238	7.90E-03	9.92E-01	11.82	7.18E-04	7.18E-04	7.18E-04	3.91E-04	1.60E-04	3.91E-04
Pu-239	2.87E-05	1.00E+00	11.82	7.18E-04	7.18E-04	7.18E-04	3.91E-04	1.60E-04	3.91E-04
Pu-240	1.06E-04	1.00E+00	11.82	7.18E-04	7.18E-04	7.18E-04	3.91E-04	1.60E-04	3.91E-04

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Infiltration Rate
Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	1.0%	1.7%	2.4%	3.6%	6.0%	8.0%	10.0%	14.1%	17.6%	21.2%	23.9%	25.6%	26.0%	26.0%	26.0%
Cumulative activity released =	0.17958	0.31323	0.43124	0.63990	1.07141	1.44308	1.79414	2.54163	3.16945	3.82432	4.30403	4.60829	4.68186	4.68242	4.68242
Relative activity released =	3.8%	6.7%	9.2%	13.7%	22.9%	30.8%	38.3%	54.3%	67.7%	81.7%	91.9%	98.4%	100.0%	100.0%	100.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.02444	0.04827	0.07153	0.11633	0.21907	0.31687	0.41948	*0.69689*	*0.90964*	*0.98252*	*0.98380*	*0.98380*	*0.98380*	*0.98380*	*0.98380*
Fe-55	0.01169	0.02063	0.02746	0.03667	0.04623	0.04797	0.04803	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*
Mn-54	0.01481	0.02130	0.02414	0.02594	0.02636	0.02636	0.02636	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*
Co-58	0.01056	0.01085	0.01086	0.01086	0.01086	0.01086	0.01086	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*
Co-60	0.01056	0.01971	0.02765	0.04050	0.06035	0.06838	0.06950	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*
Ni-63	0.00619	0.01230	0.01833	0.03015	0.05834	0.08649	0.11527	*0.15414*	*0.19048*	*0.20894*	*0.20974*	*0.20974*	*0.20974*	*0.20974*	*0.20974*
Sr-90	0.01035	0.02034	0.03000	0.04834	0.08902	0.12407	0.14949	*0.15268*	*0.15356*	*0.15361*	*0.15361*	*0.15361*	*0.15361*	*0.15361*	*0.15361*
Nb-95	0.00685	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*
Zr-95	0.00200	0.00204	0.00204	0.00204	0.00204	0.00204	0.00204	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*
Ru-106	0.00175	0.00263	0.00308	0.00342	0.00354	0.00354	0.00354	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*
Ag-110m	0.01132	0.01539	0.01686	0.01758	0.01769	0.01769	0.01769	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*
Sb-125	0.00685	0.01215	0.01624	0.02184	0.02786	0.02902	0.02906	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*
I-129	0.04178	0.08182	0.12018	0.19216	0.34740	0.48166	0.60833	*0.87619*	*0.98763*	*0.99998*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*
Cs-134	0.00591	0.01011	0.01309	0.01671	0.01974	0.02009	0.02010	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*
Cs-137	0.00591	0.01165	0.01722	0.02790	0.05203	0.07350	0.08977	*0.09226*	*0.09310*	*0.09317*	*0.09317*	*0.09317*	*0.09317*	*0.09317*	*0.09317*
Pu-238	0.00287	0.00571	0.00852	0.01405	0.02737	0.04083	0.05470	*0.07267*	*0.09084*	*0.10168*	*0.10235*	*0.10236*	*0.10236*	*0.10236*	*0.10236*
Pu-239	0.00287	0.00573	0.00859	0.01427	0.02834	0.04343	0.06158	*0.13190*	*0.25679*	*0.53145*	*0.77745*	*0.93820*	*0.97880*	*0.97914*	*0.97914*
Pu-240	0.00287	0.00573	0.00859	0.01427	0.02833	0.04341	0.06150	*0.13088*	*0.25340*	*0.51894*	*0.74990*	*0.89339*	*0.92637*	*0.92659*	*0.92659*
	Cumulative Leaching, ΣR														

Percent of activity leached =	0.2%	0.4%	0.6%	0.9%	1.6%	2.3%	3.0%	5.1%	8.2%	12.7%	15.3%	17.7%	20.6%	21.4%	21.6%
Cumulative activity leached =	0.04489	0.07886	0.10940	0.16493	0.28773	0.40556	0.53208	0.91604	1.47031	2.27716	2.75666	3.18655	3.69993	3.85976	3.87915
Relative activity leached =	1.0%	1.7%	2.3%	3.5%	6.1%	8.7%	11.4%	19.6%	31.4%	48.6%	58.9%	68.1%	79.0%	82.4%	82.8%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.00611	0.01218	0.01821	0.03017	0.05941	0.09021	0.12643	*0.25778*	*0.46125*	*0.77934*	*0.92304*	*0.95310*	*0.95408*	*0.95408*	*0.95408*
Fe-55	0.00292	0.00518	0.00691	0.00929	0.01182	0.01230	0.01232	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*
Mn-54	0.00370	0.00534	0.00607	0.00654	0.00665	0.00665	0.00665	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*
Co-58	0.00264	0.00271	0.00271	0.00271	0.00271	0.00271	0.00271	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*
Co-60	0.00264	0.00495	0.00696	0.01027	0.01550	0.01771	0.01803	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*
Ni-63	0.00155	0.00308	0.00460	0.00761	0.01489	0.02235	0.03019	*0.04159*	*0.05431*	*0.06365*	*0.06455*	*0.06456*	*0.06456*	*0.06456*	*0.06456*
Sr-90	0.00259	0.00510	0.00756	0.01227	0.02300	0.03265	0.03998	*0.04101*	*0.04137*	*0.04140*	*0.04140*	*0.04140*	*0.04140*	*0.04140*	*0.04140*
Nb-95	0.00171	0.00171	0.00171	0.00171	0.00171	0.00171	0.00171	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*
Zr-95	0.00050	0.00051	0.00051	0.00051	0.00051	0.00051	0.00051	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*
Ru-106	0.00044	0.00066	0.00077	0.00086	0.00089	0.00089	0.00089	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*
Ag-110m	0.00283	0.00386	0.00423	0.00441	0.00444	0.00444	0.00444	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*
Sb-125	0.00171	0.00304	0.00408	0.00550	0.00706	0.00737	0.00738	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*
I-129	0.01045	0.02078	0.03101	0.05115	0.09968	0.14964	0.20697	*0.40390*	*0.66319*	*0.93924*	*0.99649*	*0.99998*	*0.99999*	*0.99999*	*0.99999*
Cs-134	0.00148	0.00253	0.00328	0.00420	0.00498	0.00507	0.00508	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*
Cs-137	0.00148	0.00292	0.00433	0.00704	0.01326	0.01893	0.02334	*0.02406*	*0.02434*	*0.02437*	*0.02437*	*0.02437*	*0.02437*	*0.02437*	*0.02437*
Pu-238	0.00072	0.00143	0.00213	0.00353	0.00691	0.01037	0.01397	*0.01881*	*0.02412*	*0.02789*	*0.02823*	*0.02823*	*0.02823*	*0.02823*	*0.02823*
Pu-239	0.00072	0.00144	0.00215	0.00358	0.00715	0.01103	0.01575	*0.03473*	*0.07150*	*0.17299*	*0.31614*	*0.52625*	*0.81461*	*0.91482*	*0.92881*
Pu-240	0.00072	0.00144	0.00215	0.00358	0.00715	0.01102	0.01573	*0.03445*	*0.07052*	*0.16857*	*0.30273*	*0.48895*	*0.71297*	*0.77259*	*0.77800*
	Cumulative Leaching, ΣR														

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Volumetric Water Content
Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content	θ =	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)	T_0 =	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	0.85	0.85	0.85	0.85	0.85	0.85

θ = Placed: 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.51E-02	1.51E-02	1.51E-02	8.20E-03	3.35E-03	8.20E-03
Fe-55	2.57E-01	7.73E-01	2.59	6.42E-03	6.42E-03	6.42E-03	3.50E-03	1.43E-03	3.50E-03
Mn-54	8.10E-01	4.45E-01	1.96	8.36E-03	8.36E-03	8.36E-03	4.56E-03	1.86E-03	4.56E-03
Co-58	3.58E+00	2.79E-02	2.91	5.75E-03	5.75E-03	5.75E-03	3.13E-03	1.28E-03	3.13E-03
Co-60	1.32E-01	8.76E-01	2.91	5.75E-03	5.75E-03	5.75E-03	3.13E-03	1.28E-03	3.13E-03
Ni-63	7.22E-03	9.93E-01	5.26	3.25E-03	3.25E-03	3.25E-03	1.77E-03	7.24E-04	1.77E-03
Sr-90	2.41E-02	9.76E-01	2.98	5.62E-03	5.62E-03	5.62E-03	3.06E-03	1.25E-03	3.06E-03
Nb-95	7.24E+00	7.17E-04	4.71	3.62E-03	3.62E-03	3.62E-03	1.97E-03	8.05E-04	1.97E-03
Zr-95	3.95E+00	1.93E-02	17.12	1.02E-03	1.02E-03	1.02E-03	5.55E-04	2.26E-04	5.55E-04
Ru-106	6.78E-01	5.08E-01	19.70	8.85E-04	8.85E-04	8.85E-04	4.82E-04	1.97E-04	4.82E-04
Ag-110m	1.01E+00	3.64E-01	2.69	6.20E-03	6.20E-03	6.20E-03	3.38E-03	1.38E-03	3.38E-03
Sb-125	2.51E-01	7.78E-01	4.71	3.62E-03	3.62E-03	3.62E-03	1.97E-03	8.05E-04	1.97E-03
I-129	4.41E-08	1.00E+00	0.43	3.08E-02	3.08E-02	3.08E-02	1.68E-02	6.85E-03	1.68E-02
Cs-134	3.36E-01	7.15E-01	5.53	3.10E-03	3.10E-03	3.10E-03	1.69E-03	6.89E-04	1.69E-03
Cs-137	2.31E-02	9.77E-01	5.53	3.10E-03	3.10E-03	3.10E-03	1.69E-03	6.89E-04	1.69E-03
Pu-238	7.90E-03	9.92E-01	11.82	1.47E-03	1.47E-03	1.47E-03	8.00E-04	3.27E-04	8.00E-04
Pu-239	2.87E-05	1.00E+00	11.82	1.47E-03	1.47E-03	1.47E-03	8.00E-04	3.27E-04	8.00E-04
Pu-240	1.06E-04	1.00E+00	11.82	1.47E-03	1.47E-03	1.47E-03	8.00E-04	3.27E-04	8.00E-04

θ = Saturated: 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.05E-02	1.05E-02	1.05E-02	5.72E-03	2.34E-03	5.72E-03
Fe-55	2.57E-01	7.73E-01	2.59	5.42E-03	5.42E-03	5.42E-03	2.95E-03	1.21E-03	2.95E-03
Mn-54	8.10E-01	4.45E-01	1.96	6.74E-03	6.74E-03	6.74E-03	3.67E-03	1.50E-03	3.67E-03
Co-58	3.58E+00	2.79E-02	2.91	4.93E-03	4.93E-03	4.93E-03	2.69E-03	1.10E-03	2.69E-03
Co-60	1.32E-01	8.76E-01	2.91	4.93E-03	4.93E-03	4.93E-03	2.69E-03	1.10E-03	2.69E-03
Ni-63	7.22E-03	9.93E-01	5.26	2.97E-03	2.97E-03	2.97E-03	1.62E-03	6.62E-04	1.62E-03
Sr-90	2.41E-02	9.76E-01	2.98	4.84E-03	4.84E-03	4.84E-03	2.64E-03	1.08E-03	2.64E-03
Nb-95	7.24E+00	7.17E-04	4.71	3.28E-03	3.28E-03	3.28E-03	1.79E-03	7.29E-04	1.79E-03
Zr-95	3.95E+00	1.93E-02	17.12	9.89E-04	9.89E-04	9.89E-04	5.39E-04	2.20E-04	5.39E-04
Ru-106	6.78E-01	5.08E-01	19.70	8.63E-04	8.63E-04	8.63E-04	4.70E-04	1.92E-04	4.70E-04
Ag-110m	1.01E+00	3.64E-01	2.69	5.26E-03	5.26E-03	5.26E-03	2.87E-03	1.17E-03	2.87E-03
Sb-125	2.51E-01	7.78E-01	4.71	3.28E-03	3.28E-03	3.28E-03	1.79E-03	7.29E-04	1.79E-03
I-129	4.41E-08	1.00E+00	0.43	1.63E-02	1.63E-02	1.63E-02	8.90E-03	3.63E-03	8.90E-03
Cs-134	3.36E-01	7.15E-01	5.53	2.84E-03	2.84E-03	2.84E-03	1.55E-03	6.32E-04	1.55E-03
Cs-137	2.31E-02	9.77E-01	5.53	2.84E-03	2.84E-03	2.84E-03	1.55E-03	6.32E-04	1.55E-03
Pu-238	7.90E-03	9.92E-01	11.82	1.41E-03	1.41E-03	1.41E-03	7.68E-04	3.13E-04	7.68E-04
Pu-239	2.87E-05	1.00E+00	11.82	1.41E-03	1.41E-03	1.41E-03	7.68E-04	3.13E-04	7.68E-04
Pu-240	1.06E-04	1.00E+00	11.82	1.41E-03	1.41E-03	1.41E-03	7.68E-04	3.13E-04	7.68E-04

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Volumetric Water Content
Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.6%	1.1%	1.5%	2.2%	3.8%	5.2%	6.7%	10.2%	13.6%	16.9%	19.3%	21.8%	23.5%	23.7%	23.7%
Cumulative activity released =	0.10694	0.18922	0.26311	0.39640	0.68197	0.94007	1.19765	1.83184	2.44171	3.04050	3.47958	3.93038	4.23396	4.25845	4.25879
Relative activity released =	2.5%	4.4%	6.2%	9.3%	16.0%	22.1%	28.1%	43.0%	57.3%	71.4%	81.7%	92.3%	99.4%	100.0%	100.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01505	0.02988	0.04448	0.07302	0.14066	0.20849	0.28394	*0.52052*	*0.77883*	*0.96039*	*0.97625*	*0.97649*	*0.97649*	*0.97649*	*0.97649*
Fe-55	0.00642	0.01136	0.01515	0.02031	0.02575	0.02676	0.02680	*0.02680*	*0.02680*	*0.02680*	*0.02680*	*0.02680*	*0.02680*	*0.02680*	*0.02680*
Mn-54	0.00836	0.01205	0.01367	0.01471	0.01495	0.01495	0.01495	*0.01495*	*0.01495*	*0.01495*	*0.01495*	*0.01495*	*0.01495*	*0.01495*	*0.01495*
Co-58	0.00575	0.00591	0.00591	0.00591	0.00591	0.00591	0.00591	*0.00591*	*0.00591*	*0.00591*	*0.00591*	*0.00591*	*0.00591*	*0.00591*	*0.00591*
Co-60	0.00575	0.01075	0.01512	0.02223	0.03339	0.03802	0.03868	*0.03868*	*0.03868*	*0.03868*	*0.03868*	*0.03868*	*0.03868*	*0.03868*	*0.03868*
Ni-63	0.00325	0.00647	0.00965	0.01592	0.03103	0.04637	0.06233	*0.08491*	*0.10851*	*0.12360*	*0.12467*	*0.12469*	*0.12469*	*0.12469*	*0.12469*
Sr-90	0.00562	0.01108	0.01637	0.02651	0.04935	0.06955	0.08461	*0.08663*	*0.08728*	*0.08732*	*0.08732*	*0.08732*	*0.08732*	*0.08732*	*0.08732*
Nb-95	0.00362	0.00362	0.00362	0.00362	0.00362	0.00362	0.00362	*0.00362*	*0.00362*	*0.00362*	*0.00362*	*0.00362*	*0.00362*	*0.00362*	*0.00362*
Zr-95	0.00102	0.00104	0.00104	0.00104	0.00104	0.00104	0.00104	*0.00104*	*0.00104*	*0.00104*	*0.00104*	*0.00104*	*0.00104*	*0.00104*	*0.00104*
Ru-106	0.00089	0.00133	0.00156	0.00174	0.00179	0.00180	0.00180	*0.00180*	*0.00180*	*0.00180*	*0.00180*	*0.00180*	*0.00180*	*0.00180*	*0.00180*
Ag-110m	0.00620	0.00844	0.00926	0.00966	0.00972	0.00972	0.00972	*0.00972*	*0.00972*	*0.00972*	*0.00972*	*0.00972*	*0.00972*	*0.00972*	*0.00972*
Sb-125	0.00362	0.00642	0.00860	0.01159	0.01483	0.01547	0.01549	*0.01549*	*0.01549*	*0.01549*	*0.01549*	*0.01549*	*0.01549*	*0.01549*	*0.01549*
I-129	0.03081	0.06067	0.08961	0.14484	0.26870	0.38262	0.49773	*0.78460*	*0.96038*	*0.99975*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*
Cs-134	0.00310	0.00530	0.00687	0.00879	0.01040	0.01059	0.01060	*0.01060*	*0.01060*	*0.01060*	*0.01060*	*0.01060*	*0.01060*	*0.01060*	*0.01060*
Cs-137	0.00310	0.00611	0.00905	0.01470	0.02759	0.03923	0.04821	*0.04964*	*0.05017*	*0.05022*	*0.05022*	*0.05022*	*0.05022*	*0.05022*	*0.05022*
Pu-238	0.00147	0.00292	0.00436	0.00720	0.01408	0.02109	0.02837	*0.03801*	*0.04829*	*0.05516*	*0.05570*	*0.05570*	*0.05570*	*0.05570*	*0.05570*
Pu-239	0.00147	0.00293	0.00440	0.00732	0.01458	0.02244	0.03196	*0.06975*	*0.14078*	*0.32173*	*0.53918*	*0.77774*	*0.94712*	*0.96223*	*0.96248*
Pu-240	0.00147	0.00293	0.00440	0.00732	0.01458	0.02242	0.03192	*0.06920*	*0.13888*	*0.31374*	*0.51765*	*0.72963*	*0.86383*	*0.87320*	*0.87330*
	Cumulative Leaching, ΣR														

Percent of activity leached =	0.4%	0.8%	1.1%	1.6%	2.7%	3.8%	4.9%	8.0%	11.8%	16.2%	18.9%	21.4%	23.2%	23.3%	23.3%
Cumulative activity leached =	0.08022	0.13980	0.19284	0.28820	0.49466	0.68704	0.88657	1.43605	2.11955	2.91716	3.39659	3.85232	4.17252	4.20117	4.20164
Relative activity leached =	1.9%	3.3%	4.5%	6.8%	11.6%	16.1%	20.8%	33.7%	49.8%	68.5%	79.8%	90.5%	98.0%	98.6%	98.7%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01050	0.02089	0.03117	0.05139	0.10012	0.15022	0.20755	*0.40102*	*0.65304*	*0.91482*	*0.96645*	*0.96935*	*0.96936*	*0.96936*	*0.96936*
Fe-55	0.00542	0.00959	0.01280	0.01716	0.02178	0.02265	0.02268	*0.02268*	*0.02268*	*0.02268*	*0.02268*	*0.02268*	*0.02268*	*0.02268*	*0.02268*
Mn-54	0.00674	0.00971	0.01103	0.01187	0.01207	0.01207	0.01207	*0.01207*	*0.01207*	*0.01207*	*0.01207*	*0.01207*	*0.01207*	*0.01207*	*0.01207*
Co-58	0.00493	0.00507	0.00507	0.00507	0.00507	0.00507	0.00507	*0.00507*	*0.00507*	*0.00507*	*0.00507*	*0.00507*	*0.00507*	*0.00507*	*0.00507*
Co-60	0.00493	0.00923	0.01298	0.01910	0.02873	0.03274	0.03331	*0.03331*	*0.03331*	*0.03331*	*0.03331*	*0.03331*	*0.03331*	*0.03331*	*0.03331*
Ni-63	0.00297	0.00592	0.00883	0.01457	0.02841	0.04248	0.05715	*0.07800*	*0.10001*	*0.11441*	*0.11549*	*0.11550*	*0.11550*	*0.11550*	*0.11550*
Sr-90	0.00484	0.00954	0.01410	0.02285	0.04261	0.06017	0.07332	*0.07510*	*0.07569*	*0.07573*	*0.07573*	*0.07573*	*0.07573*	*0.07573*	*0.07573*
Nb-95	0.00328	0.00328	0.00328	0.00328	0.00328	0.00328	0.00328	*0.00328*	*0.00328*	*0.00328*	*0.00328*	*0.00328*	*0.00328*	*0.00328*	*0.00328*
Zr-95	0.00099	0.00101	0.00101	0.00101	0.00101	0.00101	0.00101	*0.00101*	*0.00101*	*0.00101*	*0.00101*	*0.00101*	*0.00101*	*0.00101*	*0.00101*
Ru-106	0.00086	0.00130	0.00152	0.00169	0.00175	0.00175	0.00175	*0.00175*	*0.00175*	*0.00175*	*0.00175*	*0.00175*	*0.00175*	*0.00175*	*0.00175*
Ag-110m	0.00526	0.00717	0.00786	0.00820	0.00825	0.00825	0.00825	*0.00825*	*0.00825*	*0.00825*	*0.00825*	*0.00825*	*0.00825*	*0.00825*	*0.00825*
Sb-125	0.00328	0.00582	0.00779	0.01050	0.01344	0.01402	0.01404	*0.01404*	*0.01404*	*0.01404*	*0.01404*	*0.01404*	*0.01404*	*0.01404*	*0.01404*
I-129	0.01632	0.03238	0.04817	0.07899	0.15174	0.22424	0.30445	*0.55506*	*0.81792*	*0.98752*	*0.99985*	*0.99999*	*0.99999*	*0.99999*	*0.99999*
Cs-134	0.00284	0.00487	0.00631	0.00807	0.00955	0.00973	0.00973	*0.00973*	*0.00973*	*0.00973*	*0.00973*	*0.00973*	*0.00973*	*0.00973*	*0.00973*
Cs-137	0.00284	0.00561	0.00831	0.01350	0.02536	0.03608	0.04436	*0.04568*	*0.04618*	*0.04623*	*0.04623*	*0.04623*	*0.04623*	*0.04623*	*0.04623*
Pu-238	0.00141	0.00280	0.00419	0.00691	0.01351	0.02024	0.02723	*0.03650*	*0.04641*	*0.05306*	*0.05358*	*0.05359*	*0.05359*	*0.05359*	*0.05359*
Pu-239	0.00141	0.00281	0.00422	0.00702	0.01399	0.02153	0.03068	*0.06701*	*0.13547*	*0.31097*	*0.52456*	*0.76427*	*0.94303*	*0.96073*	*0.96106*
Pu-240	0.00141	0.00281	0.00422	0.00702	0.01399	0.02152	0.03064	*0.06649*	*0.13364*	*0.30323*	*0.50352*	*0.71647*	*0.85791*	*0.86885*	*0.86899*
	Cumulative Leaching, ΣR														

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Waste Thickness
Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

		Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)		$I =$	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content		$\theta =$	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)		$T_0 =$	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)		$\rho_b =$	0.85	0.85	0.85	0.85	0.85	0.85

$T_0 =$			50%	6.70	6.70	6.70	6.70	6.70	6.70
				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	2.44E-02	2.44E-02	2.44E-02	1.33E-02	5.44E-03	1.33E-02
Fe-55	2.57E-01	7.73E-01	2.59	1.17E-02	1.17E-02	1.17E-02	6.37E-03	2.60E-03	6.37E-03
Mn-54	8.10E-01	4.45E-01	1.96	1.48E-02	1.48E-02	1.48E-02	8.07E-03	3.30E-03	8.07E-03
Co-58	3.58E+00	2.79E-02	2.91	1.06E-02	1.06E-02	1.06E-02	5.75E-03	2.35E-03	5.75E-03
Co-60	1.32E-01	8.76E-01	2.91	1.06E-02	1.06E-02	1.06E-02	5.75E-03	2.35E-03	5.75E-03
Ni-63	7.22E-03	9.93E-01	5.26	6.19E-03	6.19E-03	6.19E-03	3.38E-03	1.38E-03	3.38E-03
Sr-90	2.41E-02	9.76E-01	2.98	1.03E-02	1.03E-02	1.03E-02	5.64E-03	2.30E-03	5.64E-03
Nb-95	7.24E+00	7.17E-04	4.71	6.85E-03	6.85E-03	6.85E-03	3.73E-03	1.52E-03	3.73E-03
Zr-95	3.95E+00	1.93E-02	17.12	2.00E-03	2.00E-03	2.00E-03	1.09E-03	4.46E-04	1.09E-03
Ru-106	6.78E-01	5.08E-01	19.70	1.75E-03	1.75E-03	1.75E-03	9.52E-04	3.89E-04	9.52E-04
Ag-110m	1.01E+00	3.64E-01	2.69	1.13E-02	1.13E-02	1.13E-02	6.17E-03	2.52E-03	6.17E-03
Sb-125	2.51E-01	7.78E-01	4.71	6.85E-03	6.85E-03	6.85E-03	3.73E-03	1.52E-03	3.73E-03
I-129	4.41E-08	1.00E+00	0.43	4.18E-02	4.18E-02	4.18E-02	2.28E-02	9.30E-03	2.28E-02
Cs-134	3.36E-01	7.15E-01	5.53	5.91E-03	5.91E-03	5.91E-03	3.22E-03	1.31E-03	3.22E-03
Cs-137	2.31E-02	9.77E-01	5.53	5.91E-03	5.91E-03	5.91E-03	3.22E-03	1.31E-03	3.22E-03
Pu-238	7.90E-03	9.92E-01	11.82	2.87E-03	2.87E-03	2.87E-03	1.56E-03	6.39E-04	1.56E-03
Pu-239	2.87E-05	1.00E+00	11.82	2.87E-03	2.87E-03	2.87E-03	1.56E-03	6.39E-04	1.56E-03
Pu-240	1.06E-04	1.00E+00	11.82	2.87E-03	2.87E-03	2.87E-03	1.56E-03	6.39E-04	1.56E-03

$T_0 =$			200%	26.80	26.80	26.80	26.80	26.80	26.80
				Leach Rate					
Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	6.11E-03	6.11E-03	6.11E-03	3.33E-03	1.36E-03	3.33E-03
Fe-55	2.57E-01	7.73E-01	2.59	2.92E-03	2.92E-03	2.92E-03	1.59E-03	6.50E-04	1.59E-03
Mn-54	8.10E-01	4.45E-01	1.96	3.70E-03	3.70E-03	3.70E-03	2.02E-03	8.24E-04	2.02E-03
Co-58	3.58E+00	2.79E-02	2.91	2.64E-03	2.64E-03	2.64E-03	1.44E-03	5.87E-04	1.44E-03
Co-60	1.32E-01	8.76E-01	2.91	2.64E-03	2.64E-03	2.64E-03	1.44E-03	5.87E-04	1.44E-03
Ni-63	7.22E-03	9.93E-01	5.26	1.55E-03	1.55E-03	1.55E-03	8.44E-04	3.45E-04	8.44E-04
Sr-90	2.41E-02	9.76E-01	2.98	2.59E-03	2.59E-03	2.59E-03	1.41E-03	5.75E-04	1.41E-03
Nb-95	7.24E+00	7.17E-04	4.71	1.71E-03	1.71E-03	1.71E-03	9.34E-04	3.81E-04	9.34E-04
Zr-95	3.95E+00	1.93E-02	17.12	5.01E-04	5.01E-04	5.01E-04	2.73E-04	1.11E-04	2.73E-04
Ru-106	6.78E-01	5.08E-01	19.70	4.37E-04	4.37E-04	4.37E-04	2.38E-04	9.72E-05	2.38E-04
Ag-110m	1.01E+00	3.64E-01	2.69	2.83E-03	2.83E-03	2.83E-03	1.54E-03	6.30E-04	1.54E-03
Sb-125	2.51E-01	7.78E-01	4.71	1.71E-03	1.71E-03	1.71E-03	9.34E-04	3.81E-04	9.34E-04
I-129	4.41E-08	1.00E+00	0.43	1.04E-02	1.04E-02	1.04E-02	5.69E-03	2.32E-03	5.69E-03
Cs-134	3.36E-01	7.15E-01	5.53	1.48E-03	1.48E-03	1.48E-03	8.05E-04	3.29E-04	8.05E-04
Cs-137	2.31E-02	9.77E-01	5.53	1.48E-03	1.48E-03	1.48E-03	8.05E-04	3.29E-04	8.05E-04
Pu-238	7.90E-03	9.92E-01	11.82	7.18E-04	7.18E-04	7.18E-04	3.91E-04	1.60E-04	3.91E-04
Pu-239	2.87E-05	1.00E+00	11.82	7.18E-04	7.18E-04	7.18E-04	3.91E-04	1.60E-04	3.91E-04
Pu-240	1.06E-04	1.00E+00	11.82	7.18E-04	7.18E-04	7.18E-04	3.91E-04	1.60E-04	3.91E-04

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Waste Thickness
Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	1.0%	1.7%	2.4%	3.6%	6.0%	8.0%	10.0%	14.1%	17.6%	21.2%	23.9%	25.6%	26.0%	26.0%	26.0%
Cumulative activity released =	0.17958	0.31323	0.43124	0.63990	1.07141	1.44308	1.79414	2.54163	3.16945	3.82432	4.30403	4.60829	4.68186	4.68242	4.68242
Relative activity released =	3.8%	6.7%	9.2%	13.7%	22.9%	30.8%	38.3%	54.3%	67.7%	81.7%	91.9%	98.4%	100.0%	100.0%	100.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.02444	0.04827	0.07153	0.11633	0.21907	0.31687	0.41948	*0.69689*	*0.90964*	*0.98252*	*0.98380*	*0.98380*	*0.98380*	*0.98380*	*0.98380*
Fe-55	0.01169	0.02063	0.02746	0.03667	0.04623	0.04797	0.04803	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*	*0.04803*
Mn-54	0.01481	0.02130	0.02414	0.02594	0.02636	0.02636	0.02636	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*	*0.02636*
Co-58	0.01056	0.01085	0.01086	0.01086	0.01086	0.01086	0.01086	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*	*0.01086*
Co-60	0.01056	0.01971	0.02765	0.04050	0.06035	0.06838	0.06950	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*	*0.06950*
Ni-63	0.00619	0.01230	0.01833	0.03015	0.05834	0.08649	0.11527	*0.15414*	*0.19048*	*0.20894*	*0.20974*	*0.20974*	*0.20974*	*0.20974*	*0.20974*
Sr-90	0.01035	0.02034	0.03000	0.04834	0.08902	0.12407	0.14949	*0.15268*	*0.15356*	*0.15361*	*0.15361*	*0.15361*	*0.15361*	*0.15361*	*0.15361*
Nb-95	0.00685	0.00686	0.00686	0.00686	0.00686	0.00686	0.00686	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*	*0.00686*
Zr-95	0.00200	0.00204	0.00204	0.00204	0.00204	0.00204	0.00204	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*	*0.00204*
Ru-106	0.00175	0.00263	0.00308	0.00342	0.00354	0.00354	0.00354	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*	*0.00354*
Ag-110m	0.01132	0.01539	0.01686	0.01758	0.01769	0.01769	0.01769	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*	*0.01769*
Sb-125	0.00685	0.01215	0.01624	0.02184	0.02786	0.02902	0.02906	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*	*0.02906*
I-129	0.04178	0.08182	0.12018	0.19216	0.34740	0.48166	0.60833	*0.87619*	*0.98763*	*0.99998*	*1.00000*	*1.00000*	*1.00000*	*1.00000*	*1.00000*
Cs-134	0.00591	0.01011	0.01309	0.01671	0.01974	0.02009	0.02010	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*	*0.02010*
Cs-137	0.00591	0.01165	0.01722	0.02790	0.05203	0.07350	0.08977	*0.09226*	*0.09310*	*0.09317*	*0.09317*	*0.09317*	*0.09317*	*0.09317*	*0.09317*
Pu-238	0.00287	0.00571	0.00852	0.01405	0.02737	0.04083	0.05470	*0.07267*	*0.09084*	*0.10168*	*0.10235*	*0.10236*	*0.10236*	*0.10236*	*0.10236*
Pu-239	0.00287	0.00573	0.00859	0.01427	0.02834	0.04343	0.06158	*0.13190*	*0.25679*	*0.53145*	*0.77745*	*0.93820*	*0.97880*	*0.97914*	*0.97914*
Pu-240	0.00287	0.00573	0.00859	0.01427	0.02833	0.04341	0.06150	*0.13088*	*0.25340*	*0.51894*	*0.74990*	*0.89339*	*0.92637*	*0.92659*	*0.92659*
	Cumulative Leaching, ΣR														

Percent of activity leached =	0.2%	0.4%	0.6%	0.9%	1.6%	2.3%	3.0%	5.1%	8.2%	12.7%	15.3%	17.7%	20.6%	21.4%	21.6%
Cumulative activity leached =	0.04489	0.07886	0.10940	0.16493	0.28773	0.40556	0.53208	0.91604	1.47031	2.27716	2.75666	3.18655	3.69993	3.85976	3.87915
Relative activity leached =	1.0%	1.7%	2.3%	3.5%	6.1%	8.7%	11.4%	19.6%	31.4%	48.6%	58.9%	68.1%	79.0%	82.4%	82.8%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.00611	0.01218	0.01821	0.03017	0.05941	0.09021	0.12643	*0.25778*	*0.46125*	*0.77934*	*0.92304*	*0.95310*	*0.95408*	*0.95408*	*0.95408*
Fe-55	0.00292	0.00518	0.00691	0.00929	0.01182	0.01230	0.01232	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*	*0.01232*
Mn-54	0.00370	0.00534	0.00607	0.00654	0.00665	0.00665	0.00665	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*	*0.00665*
Co-58	0.00264	0.00271	0.00271	0.00271	0.00271	0.00271	0.00271	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*	*0.00271*
Co-60	0.00264	0.00495	0.00696	0.01027	0.01550	0.01771	0.01803	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*	*0.01803*
Ni-63	0.00155	0.00308	0.00460	0.00761	0.01489	0.02235	0.03019	*0.04159*	*0.05431*	*0.06365*	*0.06455*	*0.06456*	*0.06456*	*0.06456*	*0.06456*
Sr-90	0.00259	0.00510	0.00756	0.01227	0.02300	0.03265	0.03998	*0.04101*	*0.04137*	*0.04140*	*0.04140*	*0.04140*	*0.04140*	*0.04140*	*0.04140*
Nb-95	0.00171	0.00171	0.00171	0.00171	0.00171	0.00171	0.00171	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*	*0.00171*
Zr-95	0.00050	0.00051	0.00051	0.00051	0.00051	0.00051	0.00051	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*	*0.00051*
Ru-106	0.00044	0.00066	0.00077	0.00086	0.00089	0.00089	0.00089	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*	*0.00089*
Ag-110m	0.00283	0.00386	0.00423	0.00441	0.00444	0.00444	0.00444	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*	*0.00444*
Sb-125	0.00171	0.00304	0.00408	0.00550	0.00706	0.00737	0.00738	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*	*0.00738*
I-129	0.01045	0.02078	0.03101	0.05115	0.09968	0.14964	0.20697	*0.40390*	*0.66319*	*0.93924*	*0.99649*	*0.99998*	*0.99999*	*0.99999*	*0.99999*
Cs-134	0.00148	0.00253	0.00328	0.00420	0.00498	0.00507	0.00508	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*	*0.00508*
Cs-137	0.00148	0.00292	0.00433	0.00704	0.01326	0.01893	0.02334	*0.02406*	*0.02434*	*0.02437*	*0.02437*	*0.02437*	*0.02437*	*0.02437*	*0.02437*
Pu-238	0.00072	0.00143	0.00213	0.00353	0.00691	0.01037	0.01397	*0.01881*	*0.02412*	*0.02789*	*0.02823*	*0.02823*	*0.02823*	*0.02823*	*0.02823*
Pu-239	0.00072	0.00144	0.00215	0.00358	0.00715	0.01103	0.01575	*0.03473*	*0.07150*	*0.17299*	*0.31614*	*0.52625*	*0.81461*	*0.91482*	*0.92881*
Pu-240	0.00072	0.00144	0.00215	0.00358	0.00715	0.01102	0.01573	*0.03445*	*0.07052*	*0.16857*	*0.30273*	*0.48895*	*0.71297*	*0.77259*	*0.77800*
	Cumulative Leaching, ΣR														

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Waste Bulk Density
Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content	θ =	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)	T_0 =	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	0.85	0.85	0.85	0.85	0.85	0.85

ρ_b = 67%: 0.57 | 0.57 | 0.57 | 0.57 | 0.57 | 0.57

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.60E-02	1.60E-02	1.60E-02	8.74E-03	3.57E-03	8.74E-03
Fe-55	2.57E-01	7.73E-01	2.59	8.21E-03	8.21E-03	8.21E-03	4.47E-03	1.83E-03	4.47E-03
Mn-54	8.10E-01	4.45E-01	1.96	1.02E-02	1.02E-02	1.02E-02	5.57E-03	2.27E-03	5.57E-03
Co-58	3.58E+00	2.79E-02	2.91	7.46E-03	7.46E-03	7.46E-03	4.06E-03	1.66E-03	4.06E-03
Co-60	1.32E-01	8.76E-01	2.91	7.46E-03	7.46E-03	7.46E-03	4.06E-03	1.66E-03	4.06E-03
Ni-63	7.22E-03	9.93E-01	5.26	4.48E-03	4.48E-03	4.48E-03	2.44E-03	9.97E-04	2.44E-03
Sr-90	2.41E-02	9.76E-01	2.98	7.32E-03	7.32E-03	7.32E-03	3.99E-03	1.63E-03	3.99E-03
Nb-95	7.24E+00	7.17E-04	4.71	4.94E-03	4.94E-03	4.94E-03	2.69E-03	1.10E-03	2.69E-03
Zr-95	3.95E+00	1.93E-02	17.12	1.49E-03	1.49E-03	1.49E-03	8.09E-04	3.30E-04	8.09E-04
Ru-106	6.78E-01	5.08E-01	19.70	1.30E-03	1.30E-03	1.30E-03	7.07E-04	2.89E-04	7.07E-04
Ag-110m	1.01E+00	3.64E-01	2.69	7.96E-03	7.96E-03	7.96E-03	4.34E-03	1.77E-03	4.34E-03
Sb-125	2.51E-01	7.78E-01	4.71	4.94E-03	4.94E-03	4.94E-03	2.69E-03	1.10E-03	2.69E-03
I-129	4.41E-08	1.00E+00	0.43	2.52E-02	2.52E-02	2.52E-02	1.37E-02	5.60E-03	1.37E-02
Cs-134	3.36E-01	7.15E-01	5.53	4.28E-03	4.28E-03	4.28E-03	2.33E-03	9.53E-04	2.33E-03
Cs-137	2.31E-02	9.77E-01	5.53	4.28E-03	4.28E-03	4.28E-03	2.33E-03	9.53E-04	2.33E-03
Pu-238	7.90E-03	9.92E-01	11.82	2.12E-03	2.12E-03	2.12E-03	1.15E-03	4.71E-04	1.15E-03
Pu-239	2.87E-05	1.00E+00	11.82	2.12E-03	2.12E-03	2.12E-03	1.15E-03	4.71E-04	1.15E-03
Pu-240	1.06E-04	1.00E+00	11.82	2.12E-03	2.12E-03	2.12E-03	1.15E-03	4.71E-04	1.15E-03

ρ_b = 150%: 1.28 | 1.28 | 1.28 | 1.28 | 1.28 | 1.28

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	9.01E-03	9.01E-03	9.01E-03	4.91E-03	2.00E-03	4.91E-03
Fe-55	2.57E-01	7.73E-01	2.59	4.08E-03	4.08E-03	4.08E-03	2.23E-03	9.09E-04	2.23E-03
Mn-54	8.10E-01	4.45E-01	1.96	5.24E-03	5.24E-03	5.24E-03	2.86E-03	1.17E-03	2.86E-03
Co-58	3.58E+00	2.79E-02	2.91	3.67E-03	3.67E-03	3.67E-03	2.00E-03	8.17E-04	2.00E-03
Co-60	1.32E-01	8.76E-01	2.91	3.67E-03	3.67E-03	3.67E-03	2.00E-03	8.17E-04	2.00E-03
Ni-63	7.22E-03	9.93E-01	5.26	2.12E-03	2.12E-03	2.12E-03	1.15E-03	4.71E-04	1.15E-03
Sr-90	2.41E-02	9.76E-01	2.98	3.59E-03	3.59E-03	3.59E-03	1.96E-03	8.00E-04	1.96E-03
Nb-95	7.24E+00	7.17E-04	4.71	2.35E-03	2.35E-03	2.35E-03	1.28E-03	5.22E-04	1.28E-03
Zr-95	3.95E+00	1.93E-02	17.12	6.73E-04	6.73E-04	6.73E-04	3.67E-04	1.50E-04	3.67E-04
Ru-106	6.78E-01	5.08E-01	19.70	5.86E-04	5.86E-04	5.86E-04	3.19E-04	1.30E-04	3.19E-04
Ag-110m	1.01E+00	3.64E-01	2.69	3.95E-03	3.95E-03	3.95E-03	2.15E-03	8.78E-04	2.15E-03
Sb-125	2.51E-01	7.78E-01	4.71	2.35E-03	2.35E-03	2.35E-03	1.28E-03	5.22E-04	1.28E-03
I-129	4.41E-08	1.00E+00	0.43	1.66E-02	1.66E-02	1.66E-02	9.07E-03	3.70E-03	9.07E-03
Cs-134	3.36E-01	7.15E-01	5.53	2.02E-03	2.02E-03	2.02E-03	1.10E-03	4.49E-04	1.10E-03
Cs-137	2.31E-02	9.77E-01	5.53	2.02E-03	2.02E-03	2.02E-03	1.10E-03	4.49E-04	1.10E-03
Pu-238	7.90E-03	9.92E-01	11.82	9.68E-04	9.68E-04	9.68E-04	5.28E-04	2.15E-04	5.28E-04
Pu-239	2.87E-05	1.00E+00	11.82	9.68E-04	9.68E-04	9.68E-04	5.28E-04	2.15E-04	5.28E-04
Pu-240	1.06E-04	1.00E+00	11.82	9.68E-04	9.68E-04	9.68E-04	5.28E-04	2.15E-04	5.28E-04

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Waste Bulk Density
Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.7%	1.2%	1.6%	2.4%	4.1%	5.6%	7.2%	10.9%	14.9%	18.9%	21.6%	23.8%	24.7%	24.7%	24.7%
Cumulative activity released =	0.12188	0.21213	0.29212	0.43490	0.73850	1.01302	1.28762	1.96923	2.67794	3.39738	3.88357	4.27876	4.44024	4.44456	4.44457
Relative activity released =	2.7%	4.8%	6.6%	9.8%	16.6%	22.8%	29.0%	44.3%	60.3%	76.4%	87.4%	96.3%	99.9%	100.0%	100.0%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01603	0.03180	0.04732	0.07761	0.14915	0.22050	0.29939	*0.54290*	*0.79901*	*0.96519*	*0.97742*	*0.97757*	*0.97757*	*0.97757*	*0.97757*
Fe-55	0.00821	0.01450	0.01933	0.02587	0.03274	0.03401	0.03405	*0.03405*	*0.03405*	*0.03405*	*0.03405*	*0.03405*	*0.03405*	*0.03405*	*0.03405*
Mn-54	0.01022	0.01472	0.01670	0.01796	0.01825	0.01826	0.01826	*0.01826*	*0.01826*	*0.01826*	*0.01826*	*0.01826*	*0.01826*	*0.01826*	*0.01826*
Co-58	0.00746	0.00766	0.00767	0.00767	0.00767	0.00767	0.00767	*0.00767*	*0.00767*	*0.00767*	*0.00767*	*0.00767*	*0.00767*	*0.00767*	*0.00767*
Co-60	0.00746	0.01394	0.01958	0.02876	0.04308	0.04896	0.04979	*0.04979*	*0.04979*	*0.04979*	*0.04979*	*0.04979*	*0.04979*	*0.04979*	*0.04979*
Ni-63	0.00448	0.00891	0.01329	0.02190	0.04255	0.06336	0.08486	*0.11469*	*0.14445*	*0.16171*	*0.16270*	*0.16271*	*0.16271*	*0.16271*	*0.16271*
Sr-90	0.00732	0.01440	0.02127	0.03438	0.06376	0.08950	0.10851	*0.11099*	*0.11175*	*0.11180*	*0.11180*	*0.11180*	*0.11180*	*0.11180*	*0.11180*
Nb-95	0.00494	0.00494	0.00494	0.00494	0.00494	0.00494	0.00494	*0.00494*	*0.00494*	*0.00494*	*0.00494*	*0.00494*	*0.00494*	*0.00494*	*0.00494*
Zr-95	0.00149	0.00151	0.00151	0.00151	0.00151	0.00151	0.00151	*0.00151*	*0.00151*	*0.00151*	*0.00151*	*0.00151*	*0.00151*	*0.00151*	*0.00151*
Ru-106	0.00130	0.00195	0.00229	0.00254	0.00263	0.00263	0.00263	*0.00263*	*0.00263*	*0.00263*	*0.00263*	*0.00263*	*0.00263*	*0.00263*	*0.00263*
Ag-110m	0.00796	0.01084	0.01188	0.01239	0.01246	0.01246	0.01246	*0.01246*	*0.01246*	*0.01246*	*0.01246*	*0.01246*	*0.01246*	*0.01246*	*0.01246*
Sb-125	0.00494	0.00877	0.01173	0.01580	0.02019	0.02104	0.02107	*0.02107*	*0.02107*	*0.02107*	*0.02107*	*0.02107*	*0.02107*	*0.02107*	*0.02107*
I-129	0.02517	0.04971	0.07363	0.11967	0.22503	0.32501	0.42967	*0.71412*	*0.92817*	*0.99885*	*0.99999*	*0.99999*	*0.99999*	*0.99999*	*0.99999*
Cs-134	0.00428	0.00733	0.00950	0.01214	0.01436	0.01462	0.01462	*0.01462*	*0.01462*	*0.01462*	*0.01462*	*0.01462*	*0.01462*	*0.01462*	*0.01462*
Cs-137	0.00428	0.00845	0.01251	0.02029	0.03798	0.05386	0.06601	*0.06791*	*0.06860*	*0.06865*	*0.06865*	*0.06865*	*0.06865*	*0.06865*	*0.06865*
Pu-238	0.00212	0.00421	0.00629	0.01038	0.02025	0.03028	0.04065	*0.05425*	*0.06840*	*0.07737*	*0.07800*	*0.07801*	*0.07801*	*0.07801*	*0.07801*
Pu-239	0.00212	0.00423	0.00634	0.01054	0.02097	0.03221	0.04578	*0.09905*	*0.19659*	*0.42859*	*0.67169*	*0.88064*	*0.97021*	*0.97285*	*0.97285*
Pu-240	0.00212	0.00423	0.00634	0.01054	0.02097	0.03219	0.04573	*0.09829*	*0.19396*	*0.41820*	*0.64629*	*0.83237*	*0.90429*	*0.90596*	*0.90596*
	Cumulative Leaching, ΣR														

Percent of activity leached =	0.4%	0.6%	0.9%	1.3%	2.3%	3.3%	4.2%	7.0%	10.5%	14.5%	16.9%	19.4%	21.9%	22.4%	22.4%
Cumulative activity leached =	0.06486	0.11438	0.15895	0.23995	0.41770	0.58547	0.76190	1.26395	1.88823	2.61372	3.03969	3.48506	3.93694	4.02553	4.03064
Relative activity leached =	1.5%	2.6%	3.6%	5.4%	9.4%	13.2%	17.1%	28.4%	42.5%	58.8%	68.4%	78.4%	88.6%	90.6%	90.7%

100 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.00901	0.01793	0.02677	0.04422	0.08645	0.13023	0.18081	*0.35569*	*0.59723*	*0.88449*	*0.95916*	*0.96564*	*0.96569*	*0.96569*	*0.96569*
Fe-55	0.00408	0.00723	0.00965	0.01295	0.01647	0.01713	0.01715	*0.01715*	*0.01715*	*0.01715*	*0.01715*	*0.01715*	*0.01715*	*0.01715*	*0.01715*
Mn-54	0.00524	0.00756	0.00858	0.00924	0.00940	0.00940	0.00940	*0.00940*	*0.00940*	*0.00940*	*0.00940*	*0.00940*	*0.00940*	*0.00940*	*0.00940*
Co-58	0.00367	0.00377	0.00378	0.00378	0.00378	0.00378	0.00378	*0.00378*	*0.00378*	*0.00378*	*0.00378*	*0.00378*	*0.00378*	*0.00378*	*0.00378*
Co-60	0.00367	0.00688	0.00967	0.01425	0.02148	0.02451	0.02495	*0.02495*	*0.02495*	*0.02495*	*0.02495*	*0.02495*	*0.02495*	*0.02495*	*0.02495*
Ni-63	0.00212	0.00421	0.00629	0.01038	0.02029	0.03041	0.04101	*0.05630*	*0.07297*	*0.08466*	*0.08567*	*0.08569*	*0.08569*	*0.08569*	*0.08569*
Sr-90	0.00359	0.00709	0.01049	0.01701	0.03183	0.04507	0.05506	*0.05644*	*0.05692*	*0.05696*	*0.05696*	*0.05696*	*0.05696*	*0.05696*	*0.05696*
Nb-95	0.00235	0.00235	0.00235	0.00235	0.00235	0.00235	0.00235	*0.00235*	*0.00235*	*0.00235*	*0.00235*	*0.00235*	*0.00235*	*0.00235*	*0.00235*
Zr-95	0.00067	0.00069	0.00069	0.00069	0.00069	0.00069	0.00069	*0.00069*	*0.00069*	*0.00069*	*0.00069*	*0.00069*	*0.00069*	*0.00069*	*0.00069*
Ru-106	0.00059	0.00088	0.00103	0.00115	0.00119	0.00119	0.00119	*0.00119*	*0.00119*	*0.00119*	*0.00119*	*0.00119*	*0.00119*	*0.00119*	*0.00119*
Ag-110m	0.00395	0.00538	0.00590	0.00616	0.00619	0.00619	0.00619	*0.00619*	*0.00619*	*0.00619*	*0.00619*	*0.00619*	*0.00619*	*0.00619*	*0.00619*
Sb-125	0.00235	0.00417	0.00558	0.00753	0.00965	0.01007	0.01009	*0.01009*	*0.01009*	*0.01009*	*0.01009*	*0.01009*	*0.01009*	*0.01009*	*0.01009*
I-129	0.01665	0.03301	0.04911	0.08050	0.15452	0.22816	0.30947	*0.56218*	*0.82399*	*0.98856*	*0.99987*	*0.99999*	*0.99999*	*0.99999*	*0.99999*
Cs-134	0.00202	0.00345	0.00448	0.00573	0.00679	0.00692	0.00692	*0.00692*	*0.00692*	*0.00692*	*0.00692*	*0.00692*	*0.00692*	*0.00692*	*0.00692*
Cs-137	0.00202	0.00398	0.00590	0.00959	0.01805	0.02574	0.03170	*0.03267*	*0.03304*	*0.03308*	*0.03308*	*0.03308*	*0.03308*	*0.03308*	*0.03308*
Pu-238	0.00097	0.00193	0.00288	0.00475	0.00930	0.01395	0.01880	*0.02526*	*0.03229*	*0.03718*	*0.03760*	*0.03761*	*0.03761*	*0.03761*	*0.03761*
Pu-239	0.00097	0.00193	0.00290	0.00483	0.00964	0.01485	0.02118	*0.04654*	*0.09519*	*0.22591*	*0.40066*	*0.63316*	*0.88667*	*0.94188*	*0.94552*
Pu-240	0.00097	0.00193	0.00290	0.00483	0.00963	0.01484	0.02116	*0.04618*	*0.09390*	*0.22020*	*0.38400*	*0.59024*	*0.78857*	*0.82195*	*0.82341*
	Cumulative Leaching, ΣR														

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Groundwater Travel Time
Input Parameters and Leach Rate Constants

Leach Rate $L = I/(\theta * T_0 * (1+\rho_b K_d)/\theta)$

	Start Year	0	3	5	10	20	50
Infiltration rate (m/yr)	I =	0.200	0.200	0.200	0.109	0.045	0.109
Volumetric water content	θ =	0.35	0.35	0.35	0.35	0.35	0.35
Thickness (m)	T_0 =	13.40	13.40	13.40	13.40	13.40	13.40
Bulk density, unsaturated waste (g/cm^3)	ρ_b =	0.85	0.85	0.85	0.85	0.85	0.85

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.22E-02	1.22E-02	1.22E-02	6.66E-03	2.72E-03	6.66E-03
Fe-55	2.57E-01	7.73E-01	2.59	5.85E-03	5.85E-03	5.85E-03	3.19E-03	1.30E-03	3.19E-03
Mn-54	8.10E-01	4.45E-01	1.96	7.40E-03	7.40E-03	7.40E-03	4.04E-03	1.65E-03	4.04E-03
Co-58	3.58E+00	2.79E-02	2.91	5.28E-03	5.28E-03	5.28E-03	2.88E-03	1.17E-03	2.88E-03
Co-60	1.32E-01	8.76E-01	2.91	5.28E-03	5.28E-03	5.28E-03	2.88E-03	1.17E-03	2.88E-03
Ni-63	7.22E-03	9.93E-01	5.26	3.10E-03	3.10E-03	3.10E-03	1.69E-03	6.89E-04	1.69E-03
Sr-90	2.41E-02	9.76E-01	2.98	5.17E-03	5.17E-03	5.17E-03	2.82E-03	1.15E-03	2.82E-03
Nb-95	7.24E+00	7.17E-04	4.71	3.43E-03	3.43E-03	3.43E-03	1.87E-03	7.62E-04	1.87E-03
Zr-95	3.95E+00	1.93E-02	17.12	1.00E-03	1.00E-03	1.00E-03	5.46E-04	2.23E-04	5.46E-04
Ru-106	6.78E-01	5.08E-01	19.70	8.73E-04	8.73E-04	8.73E-04	4.76E-04	1.94E-04	4.76E-04
Ag-110m	1.01E+00	3.64E-01	2.69	5.66E-03	5.66E-03	5.66E-03	3.08E-03	1.26E-03	3.08E-03
Sb-125	2.51E-01	7.78E-01	4.71	3.43E-03	3.43E-03	3.43E-03	1.87E-03	7.62E-04	1.87E-03
I-129	4.41E-08	1.00E+00	0.43	2.09E-02	2.09E-02	2.09E-02	1.14E-02	4.65E-03	1.14E-02
Cs-134	3.36E-01	7.15E-01	5.53	2.95E-03	2.95E-03	2.95E-03	1.61E-03	6.57E-04	1.61E-03
Cs-137	2.31E-02	9.77E-01	5.53	2.95E-03	2.95E-03	2.95E-03	1.61E-03	6.57E-04	1.61E-03
Pu-238	7.90E-03	9.92E-01	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04
Pu-239	2.87E-05	1.00E+00	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04
Pu-240	1.06E-04	1.00E+00	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04

Radionuclide	Decay Constant λ, yr^{-1}	$e^{-\lambda}$	K_d	Leach Rate 0	3	5	10	20	50
C-14	1.21E-04	1.00E+00	1.03	1.22E-02	1.22E-02	1.22E-02	6.66E-03	2.72E-03	6.66E-03
Fe-55	2.57E-01	7.73E-01	2.59	5.85E-03	5.85E-03	5.85E-03	3.19E-03	1.30E-03	3.19E-03
Mn-54	8.10E-01	4.45E-01	1.96	7.40E-03	7.40E-03	7.40E-03	4.04E-03	1.65E-03	4.04E-03
Co-58	3.58E+00	2.79E-02	2.91	5.28E-03	5.28E-03	5.28E-03	2.88E-03	1.17E-03	2.88E-03
Co-60	1.32E-01	8.76E-01	2.91	5.28E-03	5.28E-03	5.28E-03	2.88E-03	1.17E-03	2.88E-03
Ni-63	7.22E-03	9.93E-01	5.26	3.10E-03	3.10E-03	3.10E-03	1.69E-03	6.89E-04	1.69E-03
Sr-90	2.41E-02	9.76E-01	2.98	5.17E-03	5.17E-03	5.17E-03	2.82E-03	1.15E-03	2.82E-03
Nb-95	7.24E+00	7.17E-04	4.71	3.43E-03	3.43E-03	3.43E-03	1.87E-03	7.62E-04	1.87E-03
Zr-95	3.95E+00	1.93E-02	17.12	1.00E-03	1.00E-03	1.00E-03	5.46E-04	2.23E-04	5.46E-04
Ru-106	6.78E-01	5.08E-01	19.70	8.73E-04	8.73E-04	8.73E-04	4.76E-04	1.94E-04	4.76E-04
Ag-110m	1.01E+00	3.64E-01	2.69	5.66E-03	5.66E-03	5.66E-03	3.08E-03	1.26E-03	3.08E-03
Sb-125	2.51E-01	7.78E-01	4.71	3.43E-03	3.43E-03	3.43E-03	1.87E-03	7.62E-04	1.87E-03
I-129	4.41E-08	1.00E+00	0.43	2.09E-02	2.09E-02	2.09E-02	1.14E-02	4.65E-03	1.14E-02
Cs-134	3.36E-01	7.15E-01	5.53	2.95E-03	2.95E-03	2.95E-03	1.61E-03	6.57E-04	1.61E-03
Cs-137	2.31E-02	9.77E-01	5.53	2.95E-03	2.95E-03	2.95E-03	1.61E-03	6.57E-04	1.61E-03
Pu-238	7.90E-03	9.92E-01	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04
Pu-239	2.87E-05	1.00E+00	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04
Pu-240	1.06E-04	1.00E+00	11.82	1.44E-03	1.44E-03	1.44E-03	7.82E-04	3.19E-04	7.82E-04

Subtitle D MSW Landfill Sensitivity Analyses
Variation in Groundwater Travel Time
Radionuclide Activity Released per Unit Activity Placed in Disposal Facility

Percent of activity released =	0.5%	0.9%	1.2%	1.8%	3.1%	4.3%	5.6%	9.2%	13.3%	17.4%	19.9%	22.5%	24.2%	24.4%	24.4%
Cumulative activity released =	0.08979	0.15736	0.21773	0.32650	0.56161	0.77892	1.00192	1.66432	2.38711	3.12809	3.58891	4.04487	4.35941	4.38624	4.38666
Relative activity released =	2.0%	3.6%	5.0%	7.4%	12.8%	17.8%	22.8%	37.9%	54.4%	71.3%	81.8%	92.2%	99.4%	100.0%	100.0%

0 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01222	0.02429	0.03621	0.05960	0.11562	0.17268	0.23728	*0.45186*	*0.71326*	*0.94668*	*0.98038*	*0.98154*	*0.98154*	*0.98154*	*0.98154*
Fe-55	0.00585	0.01034	0.01380	0.01849	0.02346	0.02439	0.02442	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*
Mn-54	0.00740	0.01067	0.01212	0.01304	0.01326	0.01326	0.01326	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*
Co-58	0.00528	0.00543	0.00543	0.00543	0.00543	0.00543	0.00543	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*
Co-60	0.00528	0.00988	0.01389	0.02044	0.03072	0.03500	0.03561	*0.03564*	*0.03564*	*0.03564*	*0.03564*	*0.03564*	*0.03564*	*0.03564*	*0.03564*
Ni-63	0.00310	0.00616	0.00919	0.01517	0.02957	0.04420	0.05944	*0.10396*	*0.15073*	*0.18103*	*0.18325*	*0.18327*	*0.18327*	*0.18327*	*0.18327*
Sr-90	0.00517	0.01020	0.01508	0.02441	0.04550	0.06419	0.07817	*0.09915*	*0.10603*	*0.10653*	*0.10653*	*0.10653*	*0.10653*	*0.10653*	*0.10653*
Nb-95	0.00343	0.00343	0.00343	0.00343	0.00343	0.00343	0.00343	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*
Zr-95	0.00100	0.00102	0.00102	0.00102	0.00102	0.00102	0.00102	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*
Ru-106	0.00087	0.00132	0.00154	0.00171	0.00177	0.00177	0.00177	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*
Ag-110m	0.00566	0.00771	0.00845	0.00882	0.00887	0.00887	0.00887	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*
Sb-125	0.00343	0.00608	0.00814	0.01098	0.01405	0.01466	0.01468	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*
I-129	0.02089	0.04134	0.06137	0.10018	0.19032	0.27793	0.37211	*0.64581*	*0.88730*	*0.99636*	*0.99998*	*1.00000*	*1.00000*	*1.00000*	*1.00000*
Cs-134	0.00295	0.00506	0.00656	0.00839	0.00993	0.01011	0.01012	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*
Cs-137	0.00295	0.00583	0.00864	0.01403	0.02635	0.03748	0.04607	*0.05988*	*0.06506*	*0.06554*	*0.06554*	*0.06554*	*0.06554*	*0.06554*	*0.06554*
Pu-238	0.00144	0.00286	0.00427	0.00705	0.01377	0.02063	0.02775	*0.04855*	*0.07075*	*0.08562*	*0.08679*	*0.08681*	*0.08681*	*0.08681*	*0.08681*
Pu-239	0.00144	0.00287	0.00430	0.00716	0.01426	0.02194	0.03126	*0.06836*	*0.13820*	*0.31671*	*0.53271*	*0.77262*	*0.94758*	*0.96410*	*0.96439*
Pu-240	0.00144	0.00287	0.00430	0.00716	0.01426	0.02193	0.03123	*0.06811*	*0.13715*	*0.31098*	*0.51510*	*0.72992*	*0.86951*	*0.87982*	*0.87994*
	Cumulative Leaching, ΣR														

Percent of activity leached =	0.5%	0.9%	1.2%	1.8%	3.1%	4.3%	5.6%	8.6%	12.1%	15.8%	18.3%	20.7%	22.4%	22.6%	22.6%
Cumulative activity leached =	0.08979	0.15736	0.21773	0.32650	0.56161	0.77892	1.00192	1.55076	2.17429	2.84501	3.28693	3.72827	4.03312	4.05918	4.05958
Relative activity leached =	2.0%	3.6%	5.0%	7.4%	12.8%	17.8%	22.8%	35.4%	49.6%	64.9%	74.9%	85.0%	91.9%	92.5%	92.5%

500 Groundwater travel time (years)

	No. of Years														
Radionuclide	1	2	3	5	10	20	50	100	200	500	1000	2000	5000	10000	1000000
C-14	0.01222	0.02429	0.03621	0.05960	0.11562	0.17268	0.23728	*0.43926*	*0.68532*	*0.90504*	*0.93675*	*0.93785*	*0.93785*	*0.93785*	*0.93785*
Fe-55	0.00585	0.01034	0.01380	0.01849	0.02346	0.02439	0.02442	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*	*0.02442*
Mn-54	0.00740	0.01067	0.01212	0.01304	0.01326	0.01326	0.01326	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*	*0.01326*
Co-58	0.00528	0.00543	0.00543	0.00543	0.00543	0.00543	0.00543	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*	*0.00543*
Co-60	0.00528	0.00988	0.01389	0.02044	0.03072	0.03500	0.03561	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*	*0.03561*
Ni-63	0.00310	0.00616	0.00919	0.01517	0.02957	0.04420	0.05944	*0.06065*	*0.06191*	*0.06273*	*0.06279*	*0.06279*	*0.06279*	*0.06279*	*0.06279*
Sr-90	0.00517	0.01020	0.01508	0.02441	0.04550	0.06419	0.07817	*0.07817*	*0.07817*	*0.07817*	*0.07817*	*0.07817*	*0.07817*	*0.07817*	*0.07817*
Nb-95	0.00343	0.00343	0.00343	0.00343	0.00343	0.00343	0.00343	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*	*0.00343*
Zr-95	0.00100	0.00102	0.00102	0.00102	0.00102	0.00102	0.00102	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*	*0.00102*
Ru-106	0.00087	0.00132	0.00154	0.00171	0.00177	0.00177	0.00177	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*	*0.00177*
Ag-110m	0.00566	0.00771	0.00845	0.00882	0.00887	0.00887	0.00887	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*	*0.00887*
Sb-125	0.00343	0.00608	0.00814	0.01098	0.01405	0.01466	0.01468	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*	*0.01468*
I-129	0.02089	0.04134	0.06137	0.10018	0.19032	0.27793	0.37211	*0.64581*	*0.88728*	*0.99635*	*0.99997*	*0.99998*	*0.99998*	*0.99998*	*0.99998*
Cs-134	0.00295	0.00506	0.00656	0.00839	0.00993	0.01011	0.01012	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*	*0.01012*
Cs-137	0.00295	0.00583	0.00864	0.01403	0.02635	0.03748	0.04607	*0.04607*	*0.04607*	*0.04607*	*0.04607*	*0.04607*	*0.04607*	*0.04607*	*0.04607*
Pu-238	0.00144	0.00286	0.00427	0.00705	0.01377	0.02063	0.02775	*0.02815*	*0.02858*	*0.02886*	*0.02888*	*0.02888*	*0.02888*	*0.02888*	*0.02888*
Pu-239	0.00144	0.00287	0.00430	0.00716	0.01426	0.02194	0.03126	*0.06784*	*0.13667*	*0.31264*	*0.52556*	*0.76206*	*0.93453*	*0.95081*	*0.95110*
Pu-240	0.00144	0.00287	0.00430	0.00716	0.01426	0.02193	0.03123	*0.06621*	*0.13168*	*0.29654*	*0.49013*	*0.69386*	*0.82624*	*0.83601*	*0.83613*
	Cumulative Leaching, ΣR														

Attachment 2
Landfill Capacity Analysis

The amount of material generated from licensee facilities under the Proposed Action could affect the utilization of the current disposal capacity for the existing population of EPA/State-regulated RCRA Subtitle D landfills and the disposal capacity for the existing population of LLW disposal facilities. This section provides estimates of the current disposal capacity for EPA/State-regulated Subtitle D landfills, and LLW disposal facilities, to provide the basis for an analysis of the potential effects of the Alternatives on the utilization of the current capacity, which is presented in Section 3.7.

This section provides estimates based on the existing disposal capacity. NRC assumed that no new landfill facilities or incineration facilities would be constructed.

Subtitle D Landfill Capacity

Capacity data for Subtitle D landfills was obtained from "The State of Garbage in America", a report on municipal solid waste published annually in *Biocycle*. EPA does not collect information on Subtitle D landfill capacity nationally, and uses data from "The State of Garbage in America" for its own analysis and publishes the information on its web page. *Biocycle* bases its report on detailed surveys completed by the States.

Each State reports the remaining landfill capacity of the existing landfills in the State in units of years. In order to convert years to tons of waste, for each State the total amount of waste generated (tons per year) was multiplied by the percent waste generated in each State that is landfilled. Waste imported to the State was then added and waste exported (tons) from the State was subtracted to get the total waste landfilled in each State (tons per year). Finally, waste landfilled per year for each State was multiplied by years of remaining capacity for each State, resulting in total remaining capacity (tons)[15]. Table J-1 summarizes the data for remaining disposal capacity for Subtitle D landfills.

As shown in Table J-1, the remaining capacity increased between 1998 and 2000, as State and local governments have developed additional Subtitle D landfills or expanded the capacity of existing Subtitle D landfills. However, for the purposes of the capacity analysis, NRC has assumed that the amount of remaining capacity would remain equal to the capacity reported in "The State of Garbage in America" in 2001.

[15] Where "percent landfilled" data were not given, a percentage was extrapolated from the previous years' data to estimate a percent landfilled. If only one year of previous data was available, that data point was adjusted by the rise or fall in the national landfill rate average. Where remaining years of capacity was not given or specific, the average of the two years was used if a range was given, or the previous years' data was extrapolated if no information was given. If no information was given on waste imported and exported, imports and exports were assumed to be a net zero.

Table J-1 Remaining Disposal Capacity for Subtitle D Landfills, by Year*

BioCycle Study Year	Landfill Capacity Tons Remaining
1998	4,292,505,695
1999	5,016,256,036
2000	6,985,681,722
2001	6,584,885,975

* "Year" corresponds to the year in which the BioCycle State of Garbage Report was conducted.

Table J-2 Remaining Disposal Capacity for Subtitle D Landfills, 2001

Remaining Capacity in Tons (2001)	Cubic Yards per Ton	Cubic Yards of Remaining Capacity
6,584,885,975	1.66	10,970,420,034
6,584,885,975	4.33	28,512,556,272
6,584,885,975	7	46,094,201,825

The conversion of remaining Subtitle D landfill capacity from tons to cubic yards is dependent on the assumed density of waste and how tightly it is compacted. A wide range of solid waste density conversion factors are used by landfill operators to estimate remaining capacity[16]. Using low, middle, and high end conversion factors produces a wide range of the total volume capacity remaining in Subtitle D landfills as of 2001 (Table J-2).

Subtitle D landfill capacity is not evenly distributed throughout the country, nor is the proportion of landfill space per region to the amount of waste generated per region equal across the country. Table J-3 shows the remaining capacity for each region. The Mountain region has much more capacity than it needs to dispose of waste generated in that region, while the New England and Mid Atlantic regions have a lower amount of disposal capacity. The New England and Mid Atlantic regions export solid waste to other regions for disposal.

[16] Online searches and interviews with randomly chosen landfill operators were used to find standard "tons to cubic yards" conversions. Conversions used in Delaware, Virginia, California, Mississippi, North Carolina, and Colorado ranged from 1.66 cubic yards per ton to 7 cubic yards per ton, depending on the compaction rate for regular solid waste and density of waste. While only two sources cited conversion factors between 4 and 7 cubic yards per ton, the majority cited factors between 1.66 and 3.33 cubic yards per ton. Soil and construction and demolition materials are sometimes deposited in Subtitle D landfills and are more dense than household materials, filling .75 cubic yards to 1 cubic yard per ton.

Table J-3 Remaining Subtitle D Disposal Capacity, by Region

Region	Capacity Remaining (Tons)	Waste Produced in 2000 (Tons)	Years of Capacity Remaining for Waste Generated by the Region*
Great Plains	151,566,300	7,874,000	19.2
Mid Atlantic	579,273,144	72,914,000	7.9
Midwest	1,056,426,519	86,071,000	12.3
Mountain	1,388,043,477	8,946,000	155.2
New England	26,029,658	16,278,000	1.6
South	1,744,757,227	119,647,000	14.6
West	1,605,671,450	94,729,000	17

* Years remaining if waste continued to be generated at 2000 levels, and was landfilled in its region of origin.

Great Plains: Kansas, North Dakota, Oklahoma, South Dakota
Mid Atlantic: Delaware, D.C, Maryland, Pennsylvania, Virginia, West Virginia, New Jersey, New York
Midwest: Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, Wisconsin
Mountain: Wyoming, Idaho, Montana, Colorado
New England: Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont
South: Alabama, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas
West: Arizona, Arkansas, California, Nevada, New Mexico, Oregon, Utah, Washington

Because information was not available for 2003 landfill capacity, total national Subtitle D landfill capacity was estimated for four years using the most recent available "The State of Garbage in America" reports. Trends in the data were used to estimate the data missing from the 2001 report and to estimate current remaining capacity. In 2001, three States reported their Subtitle D landfill capacities in tons, which was used for QA/QC. California's capacity estimated using the methods described in the section above, is 665,280,000 tons, while the State reported its capacity is 677 million tons. Massachusetts' estimated capacity is 1,883,320 tons and its reported capacity is 1,808,669. New York's estimated capacity is 64,074,500 tons and its reported capacity is 68 million tons.

Solid Waste Incinerator Capacity

As reported in BioCycle 2004, there were 106 waste-to-energy plants or MSW incinerators (hereinafter referred to collectively as incinerators) in the continental United States[17] in 2002. The incinerators are distributed throughout the country, but are much more prevalent east of the Mississippi River. The regional distribution as of 2002 appears in Table J-4.

[17] No data was reported for Alabama.

Table J-4 Existing MSW Incinerators by Region, 2002

Region	Facility Location(s)	Number of MSW Incinerators
New England	CT, MA, NH, ME	19
Mid-Atlantic	NY, NJ, PA, MD	24
South	VA, KY, TN, NC, SC, GA, FL	26
Great Lakes	MN, WI, IN, MI	22
Mid-west	IA, OK, AR, TX	6
Rocky Mountain	UT	1
West	CA, OR, WA	8

For solid waste incinerator capacity, States reported daily capacity. Per *Biocycle*'s methodology, incinerator capacity (tons per day) was multiplied by 300 operating days per year for total capacity (tons per year)[18]. This capacity, shown in Table J-5, only applies to trash, not to the other materials, which would not be incinerated under any of the Alternatives.

Table J-5 Existing Solid Waste Incineration Capacity, by Year

BioCycle Study Year	Incinerator Capacity (tons/year)
1998	29,982,296
1999	34,282,200
2000	35,322,058
2001	33,791,899

As shown, the existing solid waste incineration capacity increased between 1998 and 2000, as State and local governments have developed additional facilities or expanded the capacity of existing facilities. However, for the purposes of the capacity analysis in Section 3.7, NRC has assumed that the incineration capacity would remain equal to the capacity reported in "The State of Garbage in America" in 2001.

To make sure the estimated solid waste incinerator capacities were reasonable, the estimated capacity was compared to percent of solid waste incinerated each year. As reported in BioCycle Data from the 1998 report, incinerators were running at around 100 percent capacity. Data from the 1999 report showed that incinerators were running at 82 percent capacity, which reflects a decline in the percent of waste incinerated nationally in those years from 9 percent to 7.5 percent. The data from the 2000 and 2001 reports show incinerators operating at 75 percent and 84 percent capacity, respectively. In those years, the percent of waste incinerated remained steady at 7 percent, while the total waste stream increased. The drop from incinerators operating at 82 percent to 75 percent capacity, derived from the 1999 and 2000 reports, also corresponds to a drop in percent of waste incinerated from 7.5 percent to 7 percent.

[18] Where daily capacity was not given, the national average daily capacity per incinerator for that year was multiplied by the number of incinerators maintained by the State.

Low level Radioactive Waste (LLW) Disposal Facility Capacity

Three facilities in the country are currently licensed by States to accept LLW for disposal. Their total remaining capacity is roughly 10.4 million cubic yards, as summarized in Table J-6.

Table J-6 LLW Disposal Facility Capacity, 2002

Facility	Remaining Volume (million cubic yards)	Notes
Envirocare - Clive, UT	2.7	Remaining capacity as of 12/02.
Barnwell Disposal Facility - Barnwell, SC	0.008	Reported as 230,000 cubic feet. This only accounts for non-regional* waste. Barnwell will stop accepting non-regional waste in 2008.
Hanford Off-Site LLW Disposal Facility - Hanford, WA	7.7	Excluding facilities for wastes generated at the Hanford Site.
Total	10.4	Not including Barnwell.

* Non-regional waste is anything generated outside the Atlantic Compact, which includes South Carolina, New Jersey, and Connecticut.

Attachment 3

Regulatory Comparison of EPA Regulated Disposal Facilities

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• **Wastes received**: Construction and demolition wastes only, meaning uncontaminated solid waste resulting from the construction, remodeling, repair and demolition of utilities, structures and roads; and uncontaminated solid waste resulting from land clearing. Wastes received vary slightly according to the categories below: 1. C&D debris landfills three acres or less: C&D debris landfills three acres or less in area may receive C&D debris, other than pulverized C&D debris, provided no more than 200 tons of C&D debris is received per week. All other C&D debris landfills not specifically exempt or registered under this category must comply with the requirements of "C&D debris landfills greater than three acres" (section 360-7.4 NYCRR), described below. 2. **C&D debris landfills greater than three acres**: C&D debris landfills greater than three acres in area, C&D debris landfills that accept any pulverized C&D debris from a permitted C&D debris processing facility, or C&D debris landfills that receive more than 200 tons of C&D debris per week.	• **Wastes received**: Construction and demolition wastes and inert debris only, meaning the waste building materials, packaging and rubble resulting from construction, remodeling, repair and demolition operations on pavements, houses, commercial buildings and other structures. Construction, demolition and inert (CDI) waste includes the following that meet the above criteria: 2. Components of the building or structure that is the subject of the construction work including, (e.g., lumber, gypsum, glass, metal, roofing material, brick, slag, ceramics, plaster, clay and clay products, tile, carpeting, fully cured asphalt, HVAC systems, lighting fixtures, appliances, and furnishings) 3. Tools and building materials consumed or partially consumed in the course of the construction work (may include blueprints, plans, etc.); 4. Packaging derived from materials installed in the structure or from tools and equipment used in the course of the construction work; 5. Plant materials resulting from construction work when commingled with dirt, rock, inert debris or C&D debris; and	• **Wastes received**: Construction and demolition wastes as defined by 3745-400-01 of the Administrative Code, and some types of solid waste as specified below: 1. Packaging which results from the use of construction materials incidental to the load; 2. Tree stumps, trunks and clean (i.e., without leaves and smaller branches attached) branches exceeding 4 inches (25 cm) in diameter; and 3. Asbestos materials subject to NESHAP, 40 CFR Part 61, Subpart M, may be disposed of only if the necessary air pollution control permits have been issued.

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	6. Solid waste that is specifically determined to be inert by the applicable Regional Water Quality Control Board, such as treated industrial wastes and de-watered bentonite-based drilling mud.	
• **Waste restrictions:** Solid waste (including what otherwise would be construction and demolition debris) resulting from any processing technique, other than that employed at a department-approved C&D debris processing facility, that renders individual waste components unrecognizable, such as pulverizing or shredding. • Non-commercial facilities which accept only recognizable, uncontaminated[(a)] concrete and concrete products (including steel or fiberglass reinforcing rods that are embedded in the concrete), asphalt pavement, brick, glass, soil and rock, or landfills for the disposal of trees, stumps, yard waste and wood chips generated from these materials when origin and disposal of such waste occur on properties under the same ownership or control are exempt from the provisions listed below. • [(a)] Uncontaminated means C&D debris that is not mixed or commingled with other solid waste at the point of generation, processing or disposal, and that is not contaminated with spills of a petroleum product, hazardous waste or industrial waste. Contamination from spills of a petroleum	• **Waste restrictions:** C&D debris excludes commingled office recyclables and, except as provided above, commingled commercial solid waste, and commingled industrial solid waste as they are defined in Title 27, CCR section 20164. • It also excludes wastes not separated for reuse solid waste, recyclable materials that are not hazardous, and may not contain more than 1% purtrescible wastes by volume. • It must not contain soluble pollutants at concentrations in excess of applicable water quality objectives, and may not contain significant quantities of decomposable waste.	• **Waste restrictions:** C&D waste may not have been pulverized, shredded, or otherwise rendered to the extent that the debris is not readily identifiable. Facilities may not accept any hazardous wastes, infectious wastes, or containerized or bulk liquids.

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product does not include asphalt or concrete pavement that has come into contact with petroleum products through normal vehicle use of the roadway.		
• **Location restrictions**: Restrictions exist for siting on, over, or near agricultural land; floodplains; regulated wetlands; critical habitat for threatened or endangered species; areas located hydraulically upgradient from reservoirs, reservoir stems or controlled lakes, or located in watersheds which are managed pursuant to the Safe Water Drinking Act; primary water supply and principal aquifers; airports; unstable areas; areas with geological characteristics subject to rapid or unpredictable groundwater flow; or unmonitorable or unremediable areas. • **C&D debris landfills three acres or less** must meet adhere to all these restrictions with the exception that these landfills may be sited over principal aquifers, but may not be sited over primary water supply aquifers or within public water supply stabilized cone of depression areas.	• **Location restrictions:** Facilities within 10,000 feet of any airport runway end used by turbojet aircraft or within 5,000 feet of any airport runway end used by only piston-type aircraft must be designed and operated so that the facility does not pose a bird hazard to aircraft. • Facilities located within a five-mile radius of any airport runway end used by turbojet or piston-type aircraft must notify the affected airport and the FAA. • Facilities must be sited where soil characteristics, distance from waste to ground water, and of water beneath or adjacent to the landfill will ensure no impairment of beneficial uses of surface water or of ground. • Facilities shall not be located on a known Holocene fault and are subject to floodplain restrictions.	• **Location restrictions:** Facilities located within five hundred feet of an occupied building which is not owned by the owner or operator shall establish a barrier to minimize visibility of the facility operations. Also, facilities may not be located within the boundaries of the one-hundred-year flood plain of a watercourse unless the owner or operator has obtained an exemption from the licensing authority in accordance with paragraph (C)(2) of rule 3745-400-15 of the Administrative Code, or within the boundaries of a sole source aquifer designated by the Administrator of the United States Environmental Protection Agency under the "Safe Drinking Water Act," 88 Stat. 1660 , 42 U.S.C.A. 300F, as amended.

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• **Operating and design criteria:** 1. Base or liner system **For C&D debris landfills three acres or less:** A base system of at least two feet of soils having a coefficient of permeability of 1 x 10-5 centimeters per second or less is required. **For C&D debris landfills greater than three acres:** A minimum liner system of a single composite liner and a leachate collection system where the composite liner must consist of geomembrane having a minimum thickness of 60 mils that directly overlays a soil layer is required. A secondary composite liner where the soil component of the secondary composite liner must be at least 24 inches in compacted thickness and must have a maximum remolded coefficient of permeability of 1 x 10-7 centimeters per second throughout its thickness and must be directly overlain by and in contact with a geomembrane is also required. The soil material particles must be able to pass a one inch screen. Geomembrane liners used to control fluid migration from landfills are also required. (360-2.13 (j)(k) except (j)(1)(i).) 2. Leachate collection system **For C&D debris landfills three acres or less:** No leachate collection system is required. **For C&D debris landfills greater than three acres:** A leachate collection and removal system	• **Operating and design criteria:** **Regulations are as or more stringent than 40 CFR Part 258. Some criteria include:** Facilities are required to have containment structures which are capable of preventing degradation of waters of the State as a result of waste discharges to the landfills. Liners must be installed to cover all natural geologic materials that are likely to be in contact with waste (including landfill gas or leachate). 1. Liners shall be designed and constructed to contain fluid, including landfill gas, waste, and leachate. Clay liners, if used, must be a minimum of 1 foot thick and be installed at a relative compaction of at least 90 percent. 2. A leachate collection system may need to be installed directly above underlying containment features for landfills and waste piles, and installed between the liners for surface impoundments (20340. [C15: Section 2543 // T14: Section 17781(b)(2) (d)(1)]). • It must be installed immediately above the liner (except in the case of a surface impoundment), and between the inner and outer liner of a double liner system, and be designed, constructed, maintained, and operated to collect and remove twice the maximum anticipated daily volume of leachate from the Unit.	• **Operating and design criteria** 1. Recompacted soil liner is required except for facilities where the conditions in paragraph (A) of rule 3745-400-09 of the Administrative Code are met; where the facility was filled with debris as of September 30, 1996; or where the facility was filled with debris prior to an approved modification to enlarge the facility. 2. A leachate collection system is required that • Can collect leachate within the limits of debris placement • Is capable of maintaining less than a one foot depth of leachate over the in situ and/or added geologic material or constructed liner, excluding the leachate sump collection point(s). • Is constructed on a prepared smooth surface that shall include the following: (a) Have a minimum slope of two per cent. (b) Be able to bear the weight of the facility and its construction and operations without causing or allowing a failure of the leachate collection system to occur through settling. (c) Be free of debris, foreign material, deleterious material; and • Is constructed of a drainage medium that shall provide a permeability no less than 1 x 10-3 cm/sec. The medium may consist of suitable select debris or other suitable

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above the liner system must be designed, constructed, maintained and operated to collect and remove leachate from the landfill and ensure that the leachate head on the liner system does not exceed one foot at the expected flow, except during storm events. The leachate collection and removal system must be designed and constructed to operate without clogging throughout the effective facility life and post-closure maintenance period. The leachate collection and removal pipe network must be designed to be accessible for routine cleaning and maintenance (360-2.13(h), (l), (m) except 360-2.13(l)(2)(ii).) 3. Final cover system **For C&D debris landfills three acres or less:** Final landfill slopes must not be less than 4 percent, or greater than 25 percent and must be stable when subjected to the peak discharge from a rainfall intensity of a 24-hour duration, 25-year storm. A surface water drainage system may be necessary to provide such protection. The final cover system must consist of: • A barrier soil cover is a soil layer of low permeability constructed to minimize precipitation migration into the landfill. • A protection layer of soil not less than 24 inches thick must be installed on top of the barrier soil cover. Material specifications,	• It should be designed and operated to function without clogging through the scheduled closure of the Unit and during the post closure maintenance period. • It should consist of a permeable subdrain layer which covers the bottom of the Unit and extends as far up the sides as possible. 3. A final cover must function with minimum maintenance and provide waste containment to protect public health and safety by controlling at a minimum, vectors, fire, odor, litter and landfill gas migration. The final cover shall also be compatible with postclosure land use. Thickness, quality, and type of final cover may depend on the following: a need to control landfill gas emissions and fires; the future reuse of the site; and provide access to all areas of the site as needed for inspection of monitoring and control facilities, etc.	waste materials and shall be at least one foot thick. • Is designed to prevent crushing of, or damage to, any of its components. • Is designed to function without clogging. • If a pipe network is proposed, is designed with access for cleaning and inspection devices and with pipe lengths not exceeding the capabilities of the cleaning and inspection devices. • Is designed to provide access for obtaining leachate samples for testing of leachate quality and for determining the leachate head. • Is designed to be capable of conveying leachate outside the limits of debris placement for treatment and discharge in accordance with Chapter 6111. (water pollution control) of the Revised Code. • If storage of leachate outside of the limits of debris placement is proposed, include a storage containment designed to be no less protective of the environment than the facility. • Is constructed and certified in phases, if necessary, so as to stay immediately ahead of the working face. This is true except for areas containing debris as of September 30, 1996, or areas

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installation methods and compaction specifications must be adequate to protect the barrier soil cover from desiccation cracking, frost action, and root penetration, promote stability and resist erosion at the final design slopes of the landfill. • A topsoil layer or alternative soil material of not less than six inches thick in-place must be installed on top of the protection layer. The topsoil or alternative soil material must be sufficient to maintain vegetative growth. • Gas venting system. A gas venting system below the barrier soil layer may be required by the department. **For C&D debris landfills greater than three acres:** The final cover system must also consist of a layered system (gas venting layer, barrier soil or geomembrane layer, barrier protection layer and top soil layer – see above and 360-2.15(d)). Final landfill slopes must not be less than 4 percent, nor greater than 33 percent and must be stable when subjected to the peak discharge from a rainfall intensity of a 24-hour, 25-year storm event. A surface water drainage system may be necessary to provide such protection. Landfill gas control systems must be designed to prevent the migration of concentrated amounts of landfill gases off-site. (360-2.15(e).)		containing debris placed without a recompacted soil liner prior to January 1, 1999. 3. The facility shall use a standard cap system over any area of a facility that receives debris after September 30, 1996 that meets the construction and performance specifications of a standard cap system as follows: • First, a soil layer of well compacted, cohesive soil with a minimum recompacted thickness of eighteen inches. The soil shall meet the following criteria: (a) The maximum soil particle size shall be six inches. (b) At least ninety five percent of the soil particles, by volume, shall pass the three inch sieve. (c) At least seventy five percent of the soil particles, by volume, shall pass the number four sieve. (d) At least fifty percent of the soil particles, by weight, shall pass the number two hundred sieve. (e) The soil shall meet either of the following specifications: (i) Possess plasticity properties lying above the A-line in the "Unified Soil Classification System" described in ASTM D 2487. (ii) Consist of 0.002 inch or finer clay particles

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4. <u>Access</u> **For both types of C&D debris landfills:** An attendant must be on duty during all operating hours of the landfill. The landfill must only be operated between the hours of sunrise and sunset. 5. <u>Specific waste placement requirements</u> **For both types of C&D debris landfills:** ▪ C&D debris must be spread in layers not exceeding five feet in uncompacted thickness. ▪ The first layer of waste placed in contact with any leachate management structures must be at least five feet in compacted thickness, of a select nature and placed in a manner that will not impact or impede the operation of these structures. ▪ No slope may be greater than 33 percent.		as determined in ASTM D 422 such that these clay particles shall comprise at least fifteen percent of the total soil dry mass. (f) The soil may be an alternative soil type acceptable to the licensing authority. (g) The soil shall not be comprised of solid waste or construction and demolition debris. (h) The soil shall be compacted using loose lifts twelve inches thick or less and meet a compaction standard described in paragraph (C)(5) of rule 3745-400-08 of the Administrative Code. • Second, a soil layer with minimum thickness of six inches and of sufficient fertility to support dense vegetation. • Third, a complete and dense perennial vegetative cover of healthy grasses or other vegetation shall be established and maintained on all exposed final cover. • The standard cap system shall have a minimum slope of three per cent and a maximum slope of twenty-five per cent and shall be graded to eliminate ponding, promote drainage, and minimize erosion. • Comparable materials and/or thicknesses for the standard cap system may be utilized by the owner or operator if the final cap system specified in this rule is not compatible with the end use.

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		4. The facility shall construct a vegetative cap system where an area of an existing facility is filled with debris to final grade as of September 30, 1996, and where no dense vegetation has been established in the area and the area remains an inactive licensed disposal area for the remaining life of the facility as follows. (a) Consist of a soil layer with a thickness of six inches and of sufficient fertility to support dense vegetation. (b) Consist of a complete and dense perennial vegetative cover of healthy grasses or other vegetation shall be established and maintained on all exposed final cap. (c) Be graded to eliminate ponding, promote drainage, and minimize erosion. (d) Utilize comparable materials and/or thicknesses for the vegetative cap system if the final cap system specified in this rule is not compatible with the end use. The facility shall not be required to construct any cap system where an area of an existing facility is filled with debris to final grade but where dense vegetation has been established in the area as of September 30, 1996, and the area remains an inactive licensed disposal area for the remaining life of the facility. 5. Access will

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		• Be limited to authorized personnel only, except when operating personnel are present during operating hours. • Exclude live domestic and live farm animals from the facility except those used for security or vector control. • Not be denied to the licensing authority and its authorized representatives, who upon proper identification, may enter the facility at reasonable times to determine compliance with Chapter 3714 of the Revised Code and rules adopted thereunder. • Owner/Operators (O/O) must maintain access roads to allow passage of loaded vehicles with minimum dust generation or erosion during inclement weather. • O/Os must employ measures necessary to minimize the incidence of mud, dirt, and dust on public roads before vehicles leave the facility. • O/Os must post clear instructions for using the facility at the entrance. Instructions shall include a listing of wastes the disposal of which is prohibited as outlined in paragraph (F) of this rule and of telephone numbers of emergency personnel including the local fire department, the board of health, and the appropriate district office of Ohio EPA. The instructions shall be readable from vehicles

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		arriving to deposit debris.
• **Recordkeeping and reporting:** The landfill operator must have in his possession during all hours of operation, a copy of the permit issued pursuant to this Part, including conditions, a copy of the operation and maintenance manual and the most recent annual report for both types of C&D debris landfills.	• **Recordkeeping and reporting:** Regulations are as or more stringent than 40 CFR Part 258.	• **Recordkeeping and reporting:** O/Os must keep a daily log of operations of the facility that contains all the information specified on forms prescribed by the director. O/Os must keep records of all material prohibited for disposal that was accepted by the facility, including material removed from the working face in accordance with paragraph (F)(3) of 3745-400-11. For prohibited materials removed by the owner or operator, dated records of volumes and destinations for proper disposal shall be kept. For prohibited materials removed by others or for rejected loads, the O/Os must list the responsible entity, including companies maintaining transfer containers at the facility for the purpose of collecting prohibited materials. • O/Os must obtain an approved and valid license as required by Chapter 3745-37 of Administrative Code. The owner or operator shall retain at the facility during operational hours, the license application which contains the facility's construction and monitoring plans. • O/Os must maintain all applicable permits and authorizations required by Chapters 3704. (air pollution control) and 6111. (water pollution

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		control) of the Revised Code.
• **Groundwater monitoring:** **For both C&D debris landfills:** A minimum separation of five-feet must be maintained between the base system and the seasonal high groundwater table. The nature of the materials making up this separation, whether natural or backfilled, shall be subject to department approval. A minimum of ten-feet separation must be maintained between the base system and bedrock. The nature of the materials making up this separation, whether natural or backfilled, shall be subject to department approval. The groundwater monitoring system must be comprised of monitoring wells and piezometers able to define the three-dimensional groundwater flow system. Monitoring wells must be capable of detecting landfill-derived groundwater contamination within the critical stratigraphic section. Horizontal well spacing and well screen placement as well as the rest of the groundwater monitoring system must comply with 360-2.11.	• **Groundwater monitoring:** Regulations are as or more stringent than 40 CFR Part 258.	• **Groundwater monitoring:** O/Os of any facility disposing of debris on or after September 30, 1996, shall have a ground water monitoring well system unless the limits of debris placement meet the criteria in paragraph (B) of rule 3745-400-09 of the Administrative Code. The monitoring well system is not required to be capable of determining the impact of the facility on the quality of the ground water beneath the facility. • The ground water monitoring well system shall include a sufficient number of background and downgradient monitoring wells that yield ground water samples from the first continuous significant zone of saturation underlying the facility. • All monitoring wells must allow the collection of ground water samples that are representative of ground water quality in the geologic unit being monitored and at a minimum include the following: (1) Monitoring wells shall be cased in a manner that maintains the integrity of the monitoring well boreholes. (2) The annular space, i.e., the space between the borehole and the well casing, above the sampling depth shall be sealed to prevent the contamination of the samples and the ground water.

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		(3) The casing shall be screened or perforated and surrounded by sand or gravel in such a way that allows for the minimization of the passage of formation materials into the well. • Upon the installation of ground water monitoring wells, a construction certification report shall be submitted in accordance with rule 3745-400-08 of the Administrative Code.
• **Detection monitoring** **For both C&D debris landfills:** Operational water quality monitoring must be conducted during the operation, closure, and post-closure periods of the facility. The operational water quality monitoring plan must be able to distinguish landfill-derived contamination from the existing water quality at the site. The plan must also describe trigger mechanisms for initiating contingency water quality monitoring. The minimum requirements for operational water quality monitoring include: • Sampling and analysis must be performed at least quarterly, once for baseline parameters and three times for routine parameters. • Operational water quality analysis must include at least those parameters specified in the Water Quality Analysis Tables for routine and baseline parameters. • Within 90 days of completing the quarterly field sampling activities, the facility O/O must determine whether or not there is a	• **Detection monitoring:** Regulations are as or more stringent than 40 CFR Part 258.	• **Detection monitoring:** O/Os must determine the concentration or value of the parameters listed in the appendix of 3745-400-10 in ground water and leachate in accordance with the following schedule: (1) The owner or operator shall, whenever ground water samples are drawn from a monitoring well, field analyze the samples for parameters 1, 2, and 3 listed in the appendix . (2) During the initial year of ground water monitoring, O/Os must: • At least quarterly, determine the initial background concentration or value in ground water samples from all monitoring wells for parameters 1 to 19 listed in the appendix of this rule. • During the first quarterly analysis of ground water quality, also determine the concentration or value for parameters 20 to 64 listed in the appendix of this rule. • At least once, determine the

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significant increase from existing water quality levels established for each parameter.		concentrations or values in the leachate for parameters 1 to 19 listed in the appendix of this rule. • After the initial year, O/Os must at least annually sample all monitoring wells and the leachate collection system and analyze the samples for the parameters 1 to 19 listed in the appendix.
• **Compliance/assessment monitoring For both C&D debris landfills:** The O/O must compare the groundwater quality of each parameter at each monitoring well to the existing water quality value of that parameter. A significant increase has occurred if: • the groundwater quality for any parameter at any monitoring well exceeds the existing water quality value for that parameter (360-2.11(c)(5)(i)(c)), by three standard deviations; or • the groundwater quality for any parameter at any monitoring well exceeds the existing water quality value for that parameter (360-2.11(c)(5)(i)(c)) and exceeds the water quality standards for that parameter as specified in Part 701, 702, or 703 of this Title. • If the O/O determines that there is a significant increase from existing water quality levels for one or more of the parameters for the routine	• **Compliance/assessment monitoring:** Regulations are as or more stringent than 40 CFR Part 258.	• **Compliance/assessment monitoring:** The licensing authority or director may order the O/O to conduct a ground water assessment to determine the concentration of possible contaminants, and their extent and rate of migration within the ground water if the licensing authority or director determines that the facility may be affecting ground water quality. Such a determination may be supported by leachate quality reports and the following: (1) The ground water quality reports from a qualified ground water scientist. (2) Water quality data from documented leachate releases to seeps, springs, streams or other receptors. • Sampling and analysis will include the following: (1) Sampling of the affected well(s) and background well(s) and analysis of those samples for all leachate or leachate-derived constituents

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parameters at any monitoring well, the O/O • must, within 14 days of this finding, notify the department indicating which parameters have shown significant increases from existing water quality levels; and • must sample and analyze all monitoring points for the baseline parameters during the next quarterly sampling event. Subsequent sampling and analysis for baseline parameters must be conducted at least semiannually until the significant increase is determined not to be landfill-derived. • A system must be in place that includes a plan for contingency water quality monitoring, which must be conducted when a significant increase over existing water quality has been detected.		including those constituents listed in the appendix. (2) Within ninety days of sampling the affected well(s) and background well(s) as required by this paragraph, sampling of all other monitoring wells and analysis of those samples for those leachate or leachate-derived constituents found to be above background levels in the affected monitoring wells. (3) Sampling at least annually all monitoring wells included in the ground water assessment and analysis of those samples for all the parameters listed in the appendix. A monitoring well shall be considered part of the ground water assessment if it is needed to determine the concentration of any contaminants, and their extent and rate of migration within the ground water.
• **Closure activities and post-closure requirements** **For both C&D debris landfills:** In addition to the final cover system described in "operating and design criteria" above, O/Os must determine if remedial work in addition to final cover is necessary. A closure investigation must be conducted and must include the following: • A hydrogeologic investigation must be performed (360-7.3(a)(4) and 360-7.4(a)(4)). • A surface leachate investigation • A vector investigation. • An explosive gas survey.	• **Closure activities and post-closure requirements:** Regulations are as or more stringent than 40 CFR Part 258.	• **Closure activities and post-closure requirements:** Within seven days of closure, the O/O must provide written notification to the licensing authority of the date the facility ceased to accept debris, and block, by locked gates, fencing, or other sturdy obstacles, all entrances and access roads to the facility to prevent unauthorized access during the final closure period. • Within thirty days of closure, the O/O must post signs, easily visible from all access roads leading onto the facility, stating in letters a least three inches high that the construction

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• Maintenance is required of the following: soil cover integrity; slopes; cover vegetation; drainage structures; environmental and facility monitoring points (and sampled during the post-closure period for a minimum of 30 years); and any leachate removal systems (required to ensure the systems remain operational over the 30-year monitoring and maintenance period). • A post-closure monitoring and maintenance manual (360-7.4(a)(6)(xi)) must be submitted as part of the operation and maintenance manual (360-7.4(a)(6)). This document must provide personnel with instructions for assuring monitoring, including, leachate management, environmental sampling and analysis, reporting and proper maintenance of all facility components in order to maintain the facility in accordance with the provisions of the manual as approved by the department for a minimum period of 30 years after landfill closure. • Upon transfer of ownership of a C&D debris landfill, a provision must be included in the property deed indicating the period of time during which the property has been used as a landfill, a description of the wastes contained within and the fact that the records for the facility		and demolition debris facility is closed and no longer accepts construction and demolition debris. The signs shall be maintained in legible condition for at least two years after the facility ceases to accept debris. • Within sixty days of closure, the O/O must cover all uncapped disposal areas with at least six inches of recompacted soil and grade this soil to prevent ponding of water. This soil layer may be considered a part of the cap system described in the operating requirement section above. • Within one year of closure, the O/O must complete construction of a cap system over all areas of debris placement not previously certified in accordance with rule 3745-400-08 of the Administrative Code. After completion of construction of the cap system, the O/O must plug and abandon all ground water monitor wells. If any wells are constructed or used as a part of a ground water quality assessment program, and the licensing authority has ordered o /o to monitor any ground water monitor wells, the O/O must continue to conduct ground water monitoring in accordance with those orders. • The O/O must file with the appropriate County Recorder a plat of the facility and information describing the acreage, exact location, depth,

Selected State Regulations for Construction: Demolition Waste Landfills

New York	California *	Ohio
have been filed with the department. It must also reference a map filed with the county clerk, showing the limits of the landfilled areas within the property. • The O/O of a closing facility must also establish a long-term monitoring well network in the uppermost aquifer.		volume, and nature of the placed debris. • The O/O must record a notation on the deed to the facility that the land has been used as a construction and demolition debris facility and include the same information given to the County Recorder (see above).

* California CDI waste disposal facilities must obtain full solid waste facility permits and comply with all regulations set forth for municipal solid waste landfills. The regulations presented are therefore the same as those for MSW facilities in California and are as stringent or are more stringent than the regulations in 40 CFR Part 258.

Federal Regulations for Hazardous and Solid Waste Landfills

Subtitle C Hazardous Waste Landfills 40 CFR Part 264/265 Subpart N	**Subtitle D Municipal Solid Waste Landfills (MSWLFs) 40 CFR Part 258**	**Solid Waste Disposal Facilities and Practices* (40 CFR Part 257)**
♦ **Wastes received:** Listed or characteristic hazardous wastes.	♦ **Wastes received:** Household wastes, non-hazardous wastes such as commercial solid waste, nonhazardous sludge, conditionally exempt small quantity generator waste, and industrial solid waste.	♦ **Wastes Received:** Non-hazardous commercial and industrial solid wastes, construction and demolition wastes, and, in some cases, conditionally exempt small quantity generators (CESQG) hazardous wastes.
♦ **Waste Restrictions (264.312-264.317):** Restrictions and prohibitions on receipt of ignitable and reactive wastes, incompatible wastes, bulk and non-containerized wastes, and containers; and special requirements for lab packs and certain listed acutely hazardous wastes (F020-F023, F026 and F027).	♦ **Liquids Restrictions (258.28):** Prohibition on disposal of bulk and non-containerized liquid waste, unless it is household waste (other than septic) or leachate or gas condensate derived from the MSWLF unit. Prohibition on disposal of non-household waste containers holding liquids, unless the container is small and normally used to hold liquids for purposes other than storage.	♦ **Waste Restrictions:** Facilities not meeting the requirements of Part 257 Subpart B cannot accept hazardous wastes from CESQGs.
Location Standards (264.18): ♦ Seismic and floodplain considerations; prohibition on use of underground mines, caves, and salt dome/salt bed formations.	♦ **Location Restrictions (258.10-258.15):** Restrictions for siting MSWLFs in or near airports (due to bird hazards), floodplains, wetlands, fault areas, seismic impact zones, and unstable areas.	♦ **Location Restrictions (257.3-1):** Facilities or practices in floodplains shall not restrict the flow of the base flood; reduce the temporary water storage capacity of the floodplain; or result in washout of solid waste from the facility. ♦ **Solid waste units receiving CESQG waste.** 257.8 (floodplains) and 257.9 (wetlands restrictions).

* This includes Subtitle D industrial landfills and Construction and Demolition (C&D) landfills.

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Design and Operating Criteria **Design and Operating Requirements (264.301):** ♦ Existing landfills (pre-1992): Liner and leachate collection & removal system required. ♦ New landfills (constructed after 1992): Two or more liners with a leachate collection & removal system above and between such liners. ♦ All liners: Constructed of materials appropriate to prevent failure due to pressure gradients (static head), physical contact with the waste, climatic conditions, and the stress of daily operations. ♦ Double liner system: top liner (e.g., geomembrane) and a composite bottom liner.	**Design and Operating Criteria** **Design Criteria – New MSWLFs (258.40):** ♦ Performance standards: ➢ Designed to ensure that the concentration values of the chemicals listed in Table 1 of 40 CFR 258.40 will not be exceeded in the uppermost aquifer at the relevant point of compliance. ➢ With a composite liner and leachate collection system designed and constructed to maintain less than a 30-cm depth of leachate over the liner.	**Design and Operating Criteria** No Design Criteria in Part 257. **Operating Criteria** **Endangered Species (257.3-2):** Facilities or practices shall not cause or contribute to the taking of any endangered or threatened species of plant, fish or wildlife nor result in the destruction or adverse modification of the critical habitat of any such species. **Surface Water (257.3-3):** Facilities or practices shall not cause a discharge of pollutants or dredged or fill material into surface waters or any non-point source pollution that violates any requirement of the Clean Water Act. **Ground Water (257.3-4):** A facility or practice shall not contaminate an underground drinking water source beyond the solid waste boundary.
♦ Composite bottom liner: Upper layer must prevent migration of wastes into this component during the landfill's active life. Lower component: at least 3 feet (91 cm) of compacted soil with a hydraulic conductivity of 1x10-7 cm/sec. ♦ Leachate collection & removal systems (LCRS) performance standard: maintain leachate depth	♦ Composite liner requirements: Upper component must be a minimum 30-mil flexible membrane liner (FML) and lower component must consist of at least two-foot layer of compacted soil with maximum hydraulic conductivity of 1x10-7 cm/sec. ♦ FML components made of HDPE shall be at least 60-mil thick. The FML component must be	**Operating Requirements** **Disease Vector Control (257.3-6):** Facilities or practices shall not exist or occur unless on-site populations of disease vectors are minimized through periodic application of cover material or other appropriate techniques.

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over the liner not to exceed 30 cm (one foot). ♦ LCRS and Leak Detection System Minimum Requirements: ➢ Constructed with a bottom slope of one percent or more; ➢ Made of granular drainage materials with hydraulic conductivity of 1x10-2 cm/sec or more and a thickness of 12 inches (30.5 cm) or more (or constructed of synthetic or geonet materials with a minimum transmissivity of 3x10-5 m2/sec); ➢ Constructed of materials chemically resistant to materials being managed and leachate expected to be generated; ➢ Of sufficient strength to prevent collapse under pressure from overlying wastes; ➢ Designed and operated to function without clogging through life of landfill; and ➢ Constructed with sumps and liquid removal methods of sufficient size to collect and remove liquids and prevent liquids from backing up into drainage layer.	installed in direct and uniform contact with the compacted soil component. **Operating Criteria – All MSWLFs:** ♦ **Procedures for excluding hazardous wastes (258.20):** O/O must implement a program to detect and prevent disposal of regulated hazardous wastes and PCB wastes, to include: ➢ Random inspections of incoming loads; ➢ Records of any inspections; ➢ Training of facility personnel to recognize regulated hazardous wastes and PCB wastes; Notification of State Director if regulated haz or PCB wastes discovered.	**Air Criteria (257.3-7):** A facility or practice shall not engage in open burning of residential, commercial, institutional, or industrial solid waste. This prohibition does not apply to the infrequent burning of agricultural, silvicultural, (forest) or land-clearing wastes, or debris from emergency clean-up operations. **Safety Criteria (257.3-8):** **Explosive gases.** The concentration of explosive gases at a facility or practice shall not exceed: ▪ 25% of the lower explosive limit (LEL) for the gases in facility structures; and ▪ The LEL for the gases at the property boundary. **Fires.** A facility or practice must employ appropriate techniques to avoid the hazard of fires.
♦ **Action Leakage Rate (ALR) (264.302):** Maximum design flow rate that the leak detection system (LDS) can remove without the fluid head on the bottom liner exceeding one foot. To determine if the ALR has been exceeded, the O/O must convert the weekly or monthly flow rate from the monitoring data collected under 264.303 to an	**Operating Requirements:** ♦ **Cover material requirements (258.21):** At the end of each operating day (or more frequently if necessary), disposed material must be covered with six inches of earthen material to control disease vectors, fires, odor, blowing litter and scavenging. ♦ **Disease vector control (258.22):** O/Os must	**Access requirements.** A facility or practice shall not allow uncontrolled public access to the site. **Bird hazards to aircraft.** A facility disposing of putrescible waste that may attract birds and which occurs within 10,000 feet of any airport

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average daily flow rate for each sump. ♦ **Monitoring and Inspections (264.303):** During and immediately following construction and installation, liners and covers must be inspected for uniformity, damage and imperfections. ➢ During active life, a landfill must be inspected weekly and after storms to detect the following: Deterioration, malfunction or improper operation of run-on and run-off control systems; ➢ Proper functioning of wind dispersal control systems, where present; and ➢ The presence of leachate in and proper functioning of LCRS. ♦ For LDS, O/O must keep records of amount of liquid removed from each sump at least weekly during the active life and closure period.	prevent or control on-site populations of disease vectors using techniques appropriate for protection of human health and the environment. ♦ Explosive gases control (258.23): ➢ The concentration of methane gas generated by the landfill must not exceed 25 % of the lower explosive limit for methane in facility structures; and ➢ The concentration of methane gas must not exceed the lower explosive limit (LEL) for methane at the facility property boundary. ♦ O/O must implement a methane-monitoring program, monitoring on at least a quarterly basis. If exceedances are detected, immediately notify the State Director and take steps to ensure protection of human health and the environment (HHE). Within 7 days of detection, document in operating record the gas levels found and steps taken to protect human health.	runway used by turbojet aircraft (or within 5,000 feet of any runway used by piston-type aircraft) must take measures to eliminate bird hazards.
➢ Run-on control systems capable of preventing flow onto active portion of landfill during peak discharge from a 25-year storm. A run-off control system to collect and control at least the water volume resulting from a 24-hour, 25-year storm. ➢ Wind dispersal control system consisting of a cover or other means to control wind dispersal.	♦ Within 60 days, implement a remediation plan, place it in the operating record and notify the Director that plan has been implemented. ♦ **Air criteria (258.24):** MSWLF units must not violate any applicable requirements developed under a State Implementation Plan (SIP) approved under the Clean Air Act. Open burning of solid waste, other than wood waste or land-clearing debris, is prohibited at MSWLFs	

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	♦ **Access requirements (258.25):** O/Os must control public access and prevent unauthorized vehicular traffic and illegal dumping of wastes by using artificial or natural barriers. ♦ **Run-on/run-off control systems (258.26):** Run-on control systems capable of preventing flow onto active portion of landfill during peak discharge from a 25-year storm. A run-off control system to collect and control at least the water volume resulting from a 24-hour, 25-year storm. ♦ **Surface water requirements (258.27):** MSWLFs shall not cause a discharge of pollutants into surface waters or any non-point source discharge that violates any requirement of the Clean Water Act.	
Recordkeeping and Reporting: ♦ O/O must maintain operating record (264.73). ♦ O/O must submit biennial report (264.75). ♦ **Response Action Plan (264.304):** Must have approved response action plan before receipt of waste that specified actions to be taken if action leakage rate is exceeded. If the flow rate into the LDS exceeds the ALR for any sump, the O/O must: ➢ Notify the Regional Administrator (RA) of the exceedance, in writing, within 7 days of the determination; ➢ Submit preliminary assessment within 14 days detailing the amount of liquid, possible cause and location of leak; and short-term actions;	**Recordkeeping requirements (258.29):** O/Os must record and retain the following information: ➢ Any location restriction demonstration; ➢ Inspection records, training procedures and notification procedures required in 258.20; ➢ Gas monitoring results and any remediation plans required under 258.23; ➢ Any MSWLF design documentation for placement of leachate or gas condensate in a MSWLF unit, as required in 258.28; ➢ Any demonstration, certification, finding, monitoring, testing or analytical data required by the groundwater-monitoring program; ➢ Closure and post-closure care plans and any	**Recordkeeping requirements (257.30):** The O/O of a non-municipal, non-hazardous waste disposal unit must record and retain near the facility in an operating record, the following information as it becomes available: ▪ Any location restriction demonstration required under 257.7-257.12; and Any demonstration, certification, monitoring, testing or analytical data required under 257.21–257.28

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➢ Submit, within 30 days, results of analyses undertaken to determine extent of damage and whether waste receipt should cease, etc.; and ➢ Monthly thereafter, as long as the flow rate exceeds ALR, submit a report to the RA summarizing the results of any remedial actions taken or planned.	monitoring, testing or analytical data required in 258.60 and 258.61; ➢ Any cost estimates and financial assurance documentation; and ➢ Any documentation supporting a landfill exemption.	
Groundwater-Monitoring Program (Part 264, Subpart F) ♦ Groundwater monitoring system must consist of a sufficient number of wells, installed at appropriate locations and depths, to yield groundwater samples from the uppermost aquifer that represent the background quality of groundwater that has not been affected by leakage from a regulated unit. ♦ Install a groundwater monitoring system at the point(s) of compliance and maintain background wells at other locations. Data on each hazardous constituent specified in facility permit must be collected from both background and compliance wells and maintained in operating record. Also must determine the groundwater surface elevation each time groundwater is sampled. The number and type of samples collected to establish background must be appropriate for the form of statistical test employed.	**Groundwater-Monitoring and Corrective Action Program:** ♦ With the exception of certain small, remote landfills or landfills in certain arid regions, a groundwater monitoring system must be installed that consists of a sufficient number of wells, at appropriate locations and depths, to yield groundwater samples from the uppermost aquifer that: ➢ Represent the quality of background groundwater that has not been affected by leakage from a unit; ➢ Represent the quality of ground water passing the relevant point of compliance specified by the State Director. The downgradient monitoring system must be installed at the relevant point of compliance or at the waste management unit boundary to ensure detection of groundwater contamination in the uppermost aquifer.	**Groundwater-Monitoring and Corrective Action Program for Non-Municipal, Non-Hazardous Waste Disposal Units Receiving CESQG Hazardous Wastes (40 CFR Part 257, Subpart B):** Groundwater-monitoring and corrective action requirements are the same as for MSWLFs under Part 258 – see requirements summarized in column to the left.

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	♦ Sampling and analysis requirements. The groundwater-monitoring program must include consistent sampling and analysis procedures that are designed to ensure monitoring results that provide an accurate representation of groundwater quality at the background and downgradient wells. Procedures must cover: ➢ Sample collection; ➢ Sample preservation and shipment; ➢ Analytical procedures; ➢ Chain of custody control; and ➢ Quality assurance and quality control.	
♦ **Detection Monitoring Program (40 CFR 264.98)** to monitor for the parameters and hazardous constituents specified in the facility permit. ♦ A sequence of at least four samples must be collected from each well (background and compliance wells) at least quarterly. If O/O finds statistically significant evidence of contamination for any parameter or constituent specified in permit, O/O must: ➢ Notify implementing agency in writing within seven days, indicating which parameters or constituents have shown evidence of contamination; ➢ Immediately sample the groundwater in all monitoring wells to determine whether the constituents in Appendix IX to 40 CFR Part 264 are present and, if so, in what concentrations.	♦ **Detection Monitoring Program (258.54):** Detection monitoring is required at all monitoring wells. At a minimum, detection monitoring must include the constituents listed in Appendix I to Part 258. Monitoring frequency must be at least semi-annual and a minimum of four independent samples from each well must be collected and analyzed for the Appendix I constituents. ♦ If detection monitoring yields a statistically significant increase (SSI) over background for one or more constituents, the owner must, within 14 days, record in the operating record the constituents showing SSIs over background and, within 90 days, establish an assessment-monitoring program.	**Detection Monitoring Program (257.24):** See Part 258 requirements to left.

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These constituents will form the basis for compliance monitoring; ➢ Submit, within 90 days, an application for a permit modification to establish a compliance-monitoring program under 40 CFR 264.99; and ➢ Submit, within 180 days, an engineering feasibility plan for a corrective action program under 40 CFR 264.100, unless seeking an alternate concentration limit for every Appendix IX constituent found; or all Appendix IX constituents are listed in Table 1 of 40 CFR 264.94 and their concentrations do not exceed the respective values given in that Table. ♦ If any concentration limits have been exceeded at any monitoring wells at the point of compliance (i.e., if the groundwater protection standard has been exceeded), O/O must: ➢ Notify implementing agency in writing within seven days, indicating which concentration limits have been exceeded; ➢ Submit, within 180 days, an application for a permit modification to establish a corrective action program under 40 CFR 264.100. At a minimum, the application must include the following: o A detailed description of corrective actions that will achieve compliance with the groundwater protection standard specified in the permit; and		

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o A plan for a groundwater-monitoring program that will demonstrate the effectiveness of the corrective action program.		
♦ **Compliance Monitoring Program (264.99):** O/O must monitor the groundwater to determine compliance with the groundwater protection standard specified in the facility permit. A sequence of at least four samples must be collected from each well at the facility (background and compliance wells) at least quarterly during compliance monitoring. Based on these samples, O/O must determine whether there is statistically significant evidence of increased contamination for any parameter or constituent specified in the permit at each monitoring well at the point of compliance. ♦ In addition, O/O must analyze samples from the point of compliance in all wells for the constituents contained in Appendix IX to 40 CFR Part 264. This sampling must be conducted at least annually to determine whether additional hazardous constituents are present in the uppermost aquifer. If this sampling indicates new Appendix IX constituents not already identified in the permit (and the presence of these constituents is confirmed by resampling a month later), O/O must report to the implementing agency the concentrations of these additional constituents within seven days and add them to the list of monitoring constituents in	♦ **Assessment Monitoring Program (258.55):** At inception of the assessment-monitoring program and annually thereafter, the O/O must sample and analyze the groundwater for all constituents in Appendix II to Part 258. A minimum of one sample from each downgradient well must be collected and analyzed during each sampling event. ♦ For each Appendix II constituent detected in the groundwater, the O/O must establish a groundwater protection standard (GWPS). The GWPS shall be the MCL, if one exists, or the background concentration of the constituent established under 258.51. ♦ Within 90 days of finding that any Appendix II constituents have been detected at a SSI over the GWPS, the O/O must initiate an assessment of corrective measures. Based on the results of this assessment, the O/O must select a remedy that meets the following minimum standards: ➢ Is protective of human health and the environment; ➢ Attains the GWPS; and ➢ Controls the source(s) of releases of constituents so as to reduce or eliminate such releases.	♦ **Assessment Monitoring Program (257.25):** See Part 258 requirements to left.

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the permit.		
♦ **Closure and post-closure care (264.310):** Final cover must: ➢ Provide long-term minimization of migration of liquids through closed landfill; ➢ Function with minimal maintenance; ➢ Promote drainage and minimize erosion or abrasion of the cover; ➢ Accommodate settling and subsidence so as to maintain cover integrity; ➢ Have a permeability less than or equal to that of any bottom liner or natural subsoils present. ♦ Throughout closure period, O/O must comply with all post-closure requirements; maintain integrity of the final cover; continue to operate and monitor the LDS, LCRS, groundwater monitoring system, and run-on and run-off control systems, as needed.	♦ **Closure criteria (258.60):** The O/O must prepare a written closure plan and must install a final cover system designed to minimize infiltration and erosion. The final cover must: ➢ Have a permeability less than or equal to the permeability of any bottom liner system or natural subsoils present, or a permeability no greater than 1x10-5 cm/sec, whichever is less; ➢ Minimize infiltration through the closed MSWLF with an infiltration layer that contains a minimum of 18 inches of earthen material; and ➢ Minimize erosion of the final cover by the use of an erosion layer that contains a minimum of 6 inches of earthen material capable of sustaining native plant growth. ♦ **Post-closure care requirements (258.61):** The O/O must develop a written post-closure plan and conduct post-closure care for 30 years, to include maintaining the integrity of the final cover and, if applicable, maintaining and operating the leachate collection system (LCS); monitoring the groundwater; and maintaining and operating the gas monitoring system. ♦ O/Os must demonstrate financial assurance for closure, post-closure care, and for conducting corrective action at a MSWLF unit (258.71-258.74).	**Post-closure care period.** Under 257.24, the monitoring frequency for constituents under detection monitoring must be at least semiannual, throughout the active life of the unit plus 30 years.

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Waste Manifests 40 CFR Part 264 Subpart E All shipments of hazardous waste to a Subtitle C landfill must be accompanied by a manifest, which includes waste codes, volumes, etc. so that shipments received can be verified.	**Waste Manifests** No waste manifesting requirements.	**Waste Manifests** No waste manifesting requirements.

APPENDIX K
COST-BENEFIT ANALYSIS METHODOLOGY AND RESULTS

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Table of Contents

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1. Introduction

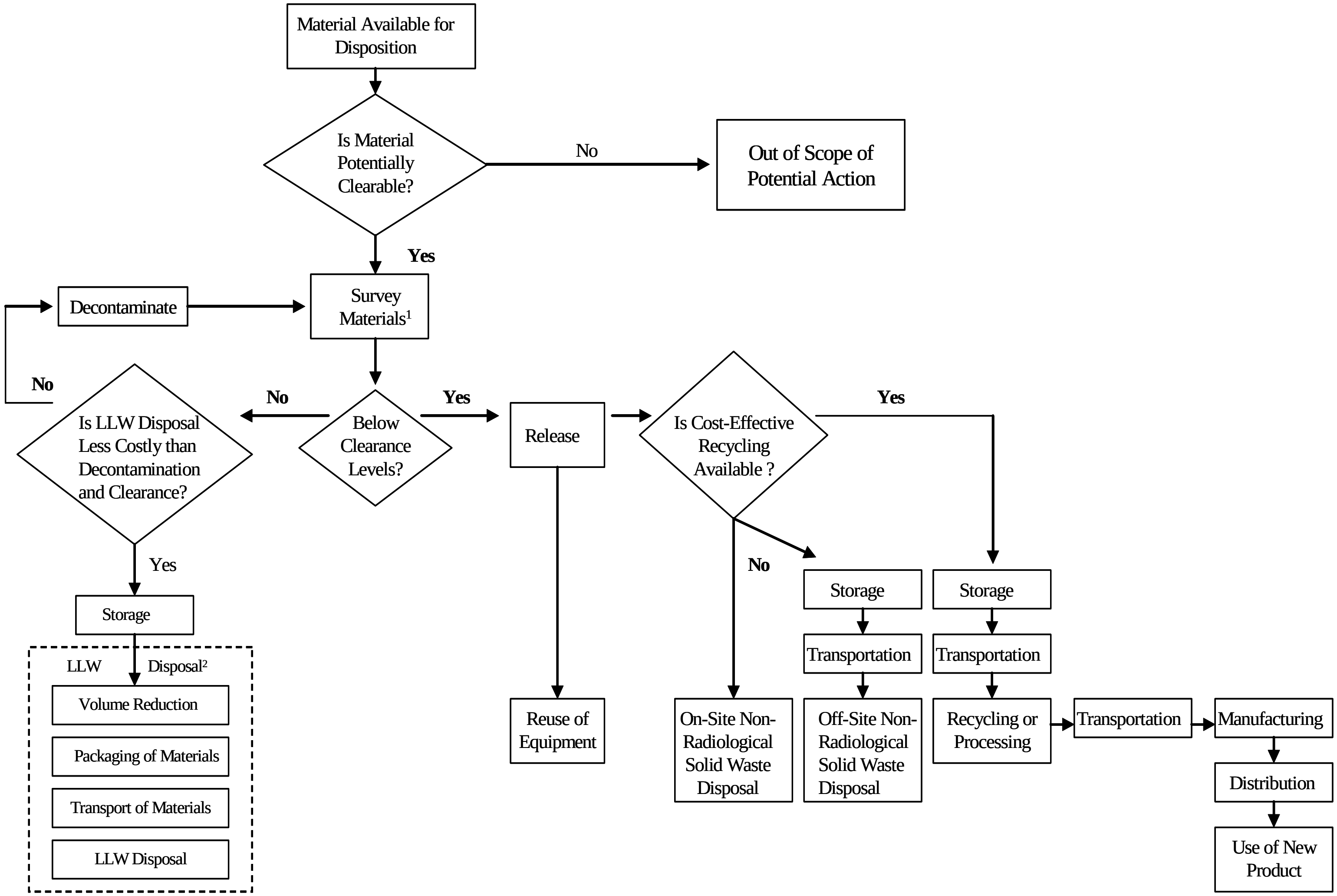
This Appendix presents the methodology used in preparing the cost-benefit analysis that is summarized in Chapter 4. According to NUREG/BR-0184 (NRC 1997b) a cost-benefit analysis should examine the costs and benefits of a proposed action. These costs and benefits are divided into 18 categories, described as attributes. Each attribute might contribute to costs or benefits or both. This analysis attempts to quantify both the costs and the benefits of the affected attributes. The costs and benefits within each attribute are driven by factors such as the different types of licensees, the different types of materials, and the life cycle of materials generated for release. The net benefit for each alternative is the difference between the sum of the benefits of all attributes and the sum of the costs of all attributes.

The analysis measures the incremental impacts of each alternative relative to a baseline, which is how things would be if the alternative were not imposed (i.e., the No Action Alternative). The baseline used in this analysis assumes full licensee compliance with existing NRC requirements, including current regulations. This is consistent with the *Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission*, which state that "...in evaluating a new requirement for existing plants, the staff should assume that all existing NRC and Agreement State requirements have been implemented."(NRC 2000c).

Exhibit 1 depicts the life cycle of materials generated for disposal or release for the Unrestricted Release Alternative. In the other alternatives, one or more of the pathways may not be allowed. The analysis is driven by how materials flow through the different paths of the life cycle. The main decision points in the life cycle flow path determination are (1) whether the material potentially has residual radioactivity; (2) whether the material is below the clearance level; (3) whether disposal as low-level waste is less costly than decontamination and release; and (4) whether cost-effective recycling is available for the material. Exhibit 1 also shows the four possible endpoints for radioactively contaminated materials that have been released: reuse of equipment, on-site disposal, off-site disposal, and recycling for use in new products.[1] For each of the alternatives and each of the materials, the analysis assumed that released materials will be recycled, reused, or sent to a municipal solid waste (MSW) landfill or incinerator, and that materials not meeting clearance levels will be sent to a low-level waste (LLW) facility for disposal. Table K-1 identifies the assumptions made for each alternative/material combination.

[1] On-site disposal is not considered in this analysis. Disposal in an on-site landfill is unlikely because (1) it would hurt the resale value of the property and (2) doses from the on-site landfill would have to be included in the dose analysis conducted in the licensee's decommissioning analysis. Reuse of equipment is only considered qualitatively because data on the amount of equipment that would be available for reuse were not available.

Exhibit 1: Generalized Material Life Cycle for Potentially Cleared Material



1 Survey may include knowledge of where material was located and/or measurement of radioactivity levels.

2 Material can be disposed of under other NRC regulations, such as 10 CFR Subpart K § 20.2002.

Table K-1 Disposition of Material under the Baseline and Alternatives

Alternative	Concrete	Ferrous metal	Trash
Baseline/No Action	Recycled	Recycled	MSW Landfill
Unrestricted Release	Recycled	Recycled	MSW Landfill
EPA-Regulated Landfill Disposal	MSW Landfill	MSW Landfill	MSW Landfill
LLW Disposal	LLW	LLW	LLW
Limited Dispositions	Recycled	MSW Landfill	MSW Landfill

MSW = municipal solid waste; LLW = low-level waste

* Because it is more expensive to transport material to, and dispose of material in, an MSW incinerator than in an MSW landfill, the analysis assumes that facilities will not choose to send their trash to an MSW incinerator, even if allowed to do so, but instead will dispose of their trash in a MSW landfill. Consequently, the costs and benefits of EPA-regulated trash incineration are the same as the RCRA Subtitle D Landfill Alternative.

Section 2 of this appendix describes the analytic approach used to evaluate each of the 18 “attributes” as defined in NUREG/BR-0184 (NRC 1997b). An in-house model was developed which draws upon input data including quantities and dose from SC&A 2003, survey costs from NRC 2004a, and various unit cost factors described in this appendix. SC&A 2003 presented data broken out by year. Consequently, the model calculates the costs in each year in which material is assumed to be released and then calculates the net present value for each alternative considered in 2003 dollars. For each attribute, Section 2 presents a description of the attribute and the equations used to quantify the associated costs and benefits. Section 2 also describes how costs are discounted to net present value. Section 3 provides the incremental results for each alternative (and dose option) considered, as well as a summary of these results.

2. Estimation of the Costs and Benefits by Attribute

This section describes how costs and benefits are estimated for each of the 18 attributes that must be considered in the cost-benefit analyses under NUREG/BR-0184. Of these 18 attributes, 11 are expected to be affected by the proposed action:[2]

- Environmental Considerations,
- Industry Operation,
- Public Health (Routine),
- Occupational Health (Routine),
- Public Health (Accident),
- Industry Implementation,
- NRC Implementation,
- NRC Operation,
- Other Government,
- Regulatory Efficiency, and
- Other Considerations.

These 11 attributes are discussed in Sections 2.1 through 2.11. Each section describes the attribute and presents the equations used to analyze the attribute. The section addressing environmental considerations has a more detailed discussion because the analysis of this attribute draws on different factors. Some of the attributes are partitioned into "sub-attributes" where more detailed analysis is required.

The equations present the cost or benefit in a given year for a material being cleared from light water reactors. As described in Chapter 4, although other types of facilities are affected by this rule, sufficient information was not available to calculate quantitative costs or benefits for these other types of facilities. The costs and benefits are calculated for each year in 2004 dollars in the analysis time horizon (2003-2049), converted to present value, and summed to calculate the net present value, as described in Section 2.12.

To determine the incremental benefit or cost relative to the baseline, the analysis subtracts the baseline benefits or costs from each alternative's benefits or cost. Negative results indicate net costs, while positive results indicate net benefits. The incremental costs associated with the No Action Alternative would be zero (because there is no change relative to the baseline). All unit costs are presented as negative numbers in the tables and assumptions following the equations, under the description where the numerical value of the cost is presented. The unit costs for the analysis are given in the format of a negative number so that the result of the equations, when calculated using numbers, yield the appropriate value indicating whether the alternative results in a net benefit or cost for that attribute.

[2] The following seven attributes are not expected to be affected by the proposed action: occupational health (accidental), offsite property, onsite property, other costs to general public (such as increased cleaning costs, property value losses, or inconveniences), improvements in knowledge, antitrust considerations, and safeguards and security considerations.

2.1 Attribute - Environmental Considerations

This section discusses the methodology for calculating the environmental benefits of the rule under each alternative. Most of the incremental environmental benefits are expected to result from air emissions avoided as a result of changes in transportation destinations and increases in recycling (i.e., reductions in manufacturing using virgin materials) due to clearance of additional materials. This section provides a detailed analysis of these benefits for structural ferrous metal, concrete, and trash. Due to data limitations and the small total volume of materials, the analysis presents discussions of the benefits associated with the reuse of aluminum and copper products in aggregate terms without the level of detail for the other materials.

The environmental benefits due to changes in transportation needs, which cause changes in air emissions, are calculated for the relevant solid materials by multiplying the changes in net miles (i.e., miles traveled under a specific alternative minus miles traveled under the baseline) by the appropriate emission factors for different pollutants and different transportation modes. These air emission changes are then monetized by multiplying by the price per ton for each pollutant. Aggregate environmental benefit estimates are then derived by summing over four pollutants (Sulfur Dioxide (SO_2), Nitrogen Oxides (NO_x), Particulate Matter (PM), and Carbon Dioxide (CO_2)).

Similarly, environmental benefits caused by changes in manufacturing needs for the relevant materials are calculated by multiplying the changes in the amount of recyclable material that are estimated to be released under this rule by the appropriate emission factors for relevant pollutants. Again, to monetize these benefits, total emission changes are multiplied by the price per ton for each pollutant. Finally, aggregate environmental benefits are derived by summing over the four pollutants.

Note that the overall methodology described above, while appropriate, has not been applied for all the different materials released under this rule. For example, environmental benefits due to recycling of released concrete are not expected to be significant and therefore, have been left out of the analysis. Sections 2.1.1 through 2.1.5 discuss the estimation of environmental benefits in detail for each material.

The quantities of materials released under this rule are not expected to be large enough to have a disruptive effect on the current market conditions, in terms of its impact on the recycling rates or the current demand/supply conditions. For example, the ferrous metal industry is likely to have the largest potential impact from recycling scrap ferrous metal as a result of this proposed rule. The net amount of scrap ferrous metal salvaged under the rulemaking alternatives (i.e., the amount salvaged relative to the No Action Alternative) would range between a maximum increase of 0.03 million tons and a maximum decrease of 0.13 million tons annually. According to the most recent data, annual U.S. production of ferrous metal is approximately 100 million tons. This means that the changes in ferrous metal scrap due to this rule would be approximately a tenth of a percent of the total U.S. ferrous metal market and therefore not expected to have any significant disruptions. Section 2.1.6 presents a brief discussion of the market share analysis for ferrous metal.

2.1.1 Ferrous Metal

Under the Unrestricted Release Alternative, the most significant environmental benefit is the recycling of ferrous metal released under this rule, which means less virgin ferrous metal is produced.[3] Virgin ferrous metal is produced in integrated ferrous metal mills using a three-step process that involves cokemaking, ironmaking, and Basic Oxygen Furnace (BOF) technology. Cokemaking and ironmaking processes have the greatest impact on the environment because large quantities of SO_2, NO_x, PM, and CO_2 are emitted. Electric Arc Furnace (EAF) facilities, often referred to as minimills, use up to 100 percent of scrap metal to produce ferrous metal. EAF technology does not require cokemaking and ironmaking processes. As a result, minimills emit less SO_2, NO_x, PM, and CO_2 per unit of output relative to integrated mills.

Under the EPA-Regulated Disposal Alternative, which prohibits recycling, environmental benefits result primarily from a reduction in the amount of fuel burned compared to the LLW Disposal Alternative. Less fuel is used because fewer vehicle miles are traveled (MSW landfills are located closer to NRC-licensed facilities than LLW facilities).

The following two sections explain the methodology for estimating environmental benefits in transportation and ferrous metal manufacturing sectors.

Benefits Due to Transportation Changes

The analysis calculates the change in air emissions by multiplying the net miles traveled by the corresponding emission factors for different pollutants. The following section explains how the emission factors are derived.

Based on the geographic location of NRC-licensed facilities relative to rail and highway infrastructure, the analysis assumes that ferrous metal scrap is transported by trucks. Depending on the alternative, one-way haul distances range from approximately 60 miles to over 1,500 miles. Given the range of haul distances, the analysis assumes that both short- and long-haul trucks transport ferrous metal scrap from NRC-licensed facilities. For the purpose of this analysis, long-haul trucks are characterized as: (1) class 8b heavy-duty diesel trucks; (2) trucks traveling long distances (greater than 200 miles from their home base); and (3) trucks traveling at higher speeds over longer distances. Short-haul trucks are characterized as: (1) class 8b heavy-duty diesel trucks; (2) trucks traveling less than 200 miles from their home base; and (3) trucks operating mostly in urban areas.

The air emissions standards for short- and long-haul trucks are expected to change over the period covered by this analysis. Therefore, the study models emission factors assuming that, on average, every five years a new standard for on-road vehicle emissions would be established. Thus, the standard established in 2003 would stay in effect until 2009 and a new standard would

[3] The ferrous metal industry has stated that it will not reprocess radiation-contaminated scrap ferrous metal. If true, this would substantially reduce the rule's environmental benefits. This analysis, however, assumes that recyclable ferrous metal will be recycled because it is not clear from available information how the steel industry views released steel. It is possible that it is currently being released and disposed, rather than released and recycled.

be established in 2010. This new standard would be applicable in 2010 and would stay in effect until 2014. The emission factors are not modeled past 2030 to avoid excessive speculation. Therefore, the standard established in 2030 is assumed to stay in effect until 2049. Fleet age and replacement also influence these factors, accounting for the increases seen in the CO_2 emission factors. The emission factors by pollutant for long-haul and short-haul trucks are presented in Tables K-2 and K-3, respectively.

Table K-2 Emission Factors (in grams/mile) for Long-Haul Trucks

Year	SO_2	NO_x	PM_{10}	CO_2
2003	0.3440	27.919	0.3096	1615.2
2010	0.0110	9.720	0.1471	1611.6
2015	0.0110	2.612	0.0910	1613.0
2020	0.0110	1.235	0.0779	1613.4
2025	0.0110	0.997	0.0770	1613.5
2030	0.0110	0.960	0.0767	1613.5

Table K-3 Emission Factors (in grams/mile) for Short-Haul Trucks

Year	SO_2	NO_x	PM_{10}	CO_2
2003	0.3557	25.779	0.6184	1665.2
2010	0.0111	13.765	0.2599	1617.6
2015	0.0110	6.394	0.1591	1612.1
2020	0.0110	2.737	0.0989	1612.6
2025	0.0110	1.143	0.0836	1613.2
2030	0.0110	0.702	0.0781	1613.4

Source: ICF Analyses using EPA MOBILE 6.2 emissions factor model and 1997 Vehicle Inventory and Use Survey (VIUS).

Benefits Due to Manufacturing Changes

Although this analysis assumes no significant disruptions to the ferrous metal market as a result of the rule (see market share analysis presented below), the slight change in the market price of ferrous metal is important to the analysis of virgin ferrous metal displacement. The ferrous metal market consists of ferrous metal products made from iron ore (i.e., using BOF technology) and those made from scrap (i.e., using EAF technology). Under the Unrestricted Release Alternative, the supply of ferrous metal products made from scrap would increase. The increase in the supply of ferrous metal made from scrap would ultimately lead to an overall increase in the supply of all ferrous metal. Based on the economic principles of supply and demand, this would cause the price of ferrous metal to decrease slightly.[4] The slight drop in the price of ferrous metal is expected to lead to a slight increase in quantity demanded for ferrous metal. In addition, the quantity supplied of virgin ferrous metal is expected to decrease slightly as a result of the decrease in the market price of ferrous metal.

[4] Assuming that the demand for ferrous metal is downward sloping and the supply of ferrous metal is upward sloping, the magnitude of the price change would depend on the elasticities of the supply and demand of ferrous metal. Although the price change estimation is beyond the scope of this analysis, the change in price is not expected to be significant as the increase in supply is relatively small.

The general approach used in this analysis is to estimate the quantity of ferrous metal scrap that would be recycled under each regulatory alternative relative to the baseline, determine the quantity of domestic virgin ferrous metal that would be displaced, derive emission factors for each pollutant emitted in the production of virgin ferrous metal, and then multiply emission factors by quantity of virgin ferrous metal displaced.

The industry data indicate that minimills use, on average, 1.07 kilograms of scrap to produce 1 kilogram of ferrous metal (IISI 2002). The study uses this ratio of scrap to ferrous metal to estimate the amount of ferrous metal that would be produced from licensees' scrap. As previously explained, the increase in the supply of ferrous metal made from NRC scrap would cause a slight decrease in the price of ferrous metal and, in turn, increase the quantity of ferrous metal demanded. In order to estimate how much of the ferrous metal would be replaced by the ferrous metal made from scrap generated by this rule, the study makes a simplifying assumption that the elasticities of supply and demand are equal. Under this assumption, an increase of one million ton in the supply of ferrous metal products made from ferrous metal scrap (released by licensees) generated by this rule would result in 0.5 million ton increase in quantity demanded of ferrous metal, and 0.5 million ton decrease in the quantity supplied of ferrous metal (both virgin ferrous metal and ferrous metal made from scrap). The assumed decreased supply of scrap metal would not be limited to material not generated by this rule. It is assumed that the decrease in supply could be from scrap generated by this rule or scrap not generated by this rule. This assumption is based on the idea that once the scrap metal enters the market, it becomes part of the total scrap market and no differentiation is made as to whether it was generated as a result of the rule or not.

The quantity of virgin ferrous metal consumed domestically is supplied by both domestic and foreign producers. The analysis, however, focuses only on air emissions avoided through the displacement of domestic virgin ferrous metal. In reality, CO_2 does have trans-boundary implications. Estimating the increase in ambient concentration of CO_2 in the US resulting from foreign production of virgin ferrous metal is, however, beyond the scope of this analysis.

To understand how much of domestic virgin ferrous metal can be replaced with the scrap generated by this rule under various alternatives, the study first estimates the share of virgin ferrous metal in the total domestic consumption of ferrous metal, and then calculates the share of US virgin ferrous metal consumed domestically.

The average annual US production of ferrous metal is 98 million tons (for the period 1997-2001), with 53 million tons of ferrous metal products produced using iron ore (i.e, virgin ferrous metal using BOF technology). In order to account properly for air emissions in manufacturing of virgin ferrous metal, the study assumes that all of the U.S. virgin ferrous metal is consumed domestically. Therefore, for the purpose of this analysis, the U.S. consumption of virgin ferrous metal is equal to the U.S. production of virgin ferrous metal plus the U.S. imports of virgin ferrous metal. Based on the estimated amount of foreign virgin ferrous metal imported annually, the estimated total amount of virgin ferrous metal available for domestic consumption is 77 million tons per year.[5]

[5] Using the USGS data for 1997-2001, the study estimates that approximately 75 percent of the

(continued...)

The next step in the analysis is to estimate the share of domestic virgin ferrous metal in the U.S. consumption of ferrous metal. The U.S. Geological Survey (USGS) data for 1997-2001 (USGS 2004e; USGS 2004f) indicate that the average annual U.S. consumption of ferrous metal is approximately 117 million tons. Based on the study estimates presented above, virgin ferrous metal products account for 66 percent of the total ferrous metal consumption in the U.S. (77 million tons / 117 million tons = 66 percent). Out of 77 million tons of virgin ferrous metal products consumed domestically, 53 million tons, or 69 percent, is produced domestically. Therefore, to derive the amount of domestic virgin ferrous metal displaced, the study first multiplies the total quantity of ferrous metal displaced by 0.66 to derive the amount of virgin ferrous metal displaced in the domestic consumption, and then by 0.69 to calculate the amount of domestic virgin ferrous metal displaced.

As stated previously, virgin ferrous metal production includes cokemaking and ironmaking processes. These two processes are not required when using EAF technology (i.e., when making ferrous metal products from ferrous metal scrap). The industry data indicate that the production of ferrous metal by BOF technology requires about 0.7 tons of pig iron and between 0.35 and 0.65 tons of coke (DOE 2000; IISI 2002). The study uses these factors to estimate the amount of pig iron and coke required to produce the amount of domestic virgin ferrous metal that would be displaced by the NRC ferrous metal scrap.[6]

The next step in the analysis is to estimate the total amount of emissions avoided through the displacement of domestic virgin ferrous metal. The analysis uses the emission factors for the iron and ferrous metal industry derived by DOE (DOE 2000). The emission factors are presented in Table K-4.

Table K-4 Emission Factors for Criteria Pollutants by Ferrous Metalmaking Process

Process	Units	SO_2	NO_x	PM	CO_2
Integrated Mills					
Cokemaking	lbs/ton of coke	4.1	0.98	1.374	389.17
Ironmaking	lbs/ton of ferrous metal	26.47	10.27	7.624	2,000.0

Source: DOE.

To estimate the total amount of emissions avoided, the study multiplies the emission factors by the amount of coke and pig iron saved through recycling of NRC ferrous metal scrap.

[5] (...continued)
world production of ferrous metal is produced from virgin ferrous metal (i.e., using BOF technology). The study then assumes that 75 percent of the ferrous metal products imported by the U.S. are made from virgin ferrous metal. The analysis estimates that out of 32 million tons of ferrous metal imported annually, approximately 24 million tons are virgin ferrous metal products (32 million tons * 75 percent = 24 million tons). Based on the estimated amount of imported virgin ferrous metal, the total amount of virgin ferrous metal available for domestic consumption is 77 million tons per year (53 million tons + 24 million tons = 77 million tons).

[6] Using the mid point of the 0.36-0.65 range yields an average ratio of coke to ferrous metal of 0.5.

Data on Pollutant Prices

The study estimates the monetary value of environmental benefits by multiplying the estimated net emissions by the estimated allowance price for each pollutant. Under competitive market conditions, allowance prices are expected to provide the estimated monetary value for reducing a unit of the relevant pollutant. For SO_2 and NO_x, allowance prices used are based on EPA's projections for 2006 to 2020 for the proposed multi-pollutant scenario, known as the Clear Skies Act found in ICF Consulting's Integrated Planning Model (an analytical model designed to evaluate various aspects of electric power production, including air pollution). Allowance prices for SO_2 and NO_x used in this analysis are as shown in Table K-5.

Table K-5 Allowance Prices for SO_2 and NO_x

Year	SO_2 ($/ton)	NO_x ($/ton)
2006	493	1844
2010	605	1,063
2015	785	1,081
2020	1,018	1,402

Note that the prices were not estimated past 2020 to avoid speculation. For the years past 2020, the estimated allowance price for 2020 is used.

For particulate matter and CO_2, this study uses the 1990 Pace University Study (Ottinger et al. 1990)[7] estimate of $3,516 per ton of particulate matter and $20 per ton of CO_2. The Pace study, prepared for the New York State Energy Research and Development Authority and DOE examines the environmental costs associated with a variety of energy sources and environmental effects (e.g., air pollution, global warming, land use).

2.1.2 Concrete

Benefits Due to Transportation Changes

Most of the incremental environmental benefits would be provided through reduction in fuel burned by decreasing haul distances. The study used the same methodology for estimating environmental benefits from the change in air emissions as presented above for ferrous metal.

Benefits Due to Manufacturing Changes

Recycled concrete is used in place of virgin aggregate primarily as road base material. The analysis assumes that concrete cleared from NRC-licensed facilities would be used in the same capacity. The available publications on concrete recycling, however, do not indicate that there are considerable environmental benefits in terms of emissions avoided from using recycled

[7] Reproduced from U.S. Congress, Office of Technology Assessment, Studies of the Environmental Costs of Electricity, OTA–ETI–134 (Washington, DC: U.S. Government Printing Office, September 1994, page 24).

concrete, instead of virgin aggregate, in road construction (DOT 2003). Therefore, the study does not estimate environmental benefits from recycling of concrete.

2.1.3 Trash

Benefits Due to Transportation Changes

Under both the Unrestricted Release and EPA-Regulated Disposal Alternatives, trash from NRC-licensed facilities would be disposed in MSW landfills or low-level waste facilities. Trash would not be recycled or used for any purpose that would yield environmental benefits. The type and location of permitted landfills, however, would vary depending on the alternative. Thus, some environmental benefits would be provided through reduction in fuel burned by decreasing the distances that material is hauled. The study uses the same methodology for estimating environmental benefits from the change in air emissions as presented above for ferrous metal. For the EPA-Regulated Disposal Alternative, no incineration of trash is expected because it is less expensive to send material to an MSW landfill for disposal.

2.1.4 Copper

This analysis presents a brief discussion of the environmental benefits from recycling copper. The analysis is constrained by the lack of detailed data on the quantity of copper expected to be recycled due to this rule. SC&A 2003 estimates there are about 6,584 tons of potentially clearable copper; this is about one-quarter percent of the total mass of ferrous metals (which is about 2.4 million tons). Also, lack of detailed annual estimates of potentially clearable copper for different alternatives precludes estimating incremental environmental benefits due to this rule (i.e., benefits over a No Action "baseline"). However, copper is a valuable material and any quantity generated by this rule can be expected to be recycled with tangible environmental benefits, since recycling copper is generally considered less energy-intensive than producing copper from ore.[8] Given the limitations of the data, this analysis does not quantify this environmental benefit but notes that the estimated 6,584 tons of potentially clearable copper will provide finite environmental benefits.

2.1.5 Aluminum

SC&A 2003 estimates there are about 212 tons of potentially clearable aluminum from decommissioning all licensed facilities; this is about a tenth of a percent of the total mass of ferrous metals.[9] Again, because of data limitations, this analysis does not attempt to quantify the incremental environmental benefits from this amount, but notes that the environmental benefit from this small amount of aluminum can be expected to be finite but less than that for copper.

[8] See for example, "The Life Cycle of Copper, its Co-Products and By-Products," International Institute for Environment and Development (IIED), 2002.

[9] *Ibid.*

2.1.6 Market Share Analysis

This section provides a market share analysis for ferrous metal, copper, and aluminum. The analysis provides a description of the effects that the proposed action could have on the market for these metals, if any.

Ferrous metal

In the period 1997-2001, U.S. production of ferrous metal was, on average, almost 100 million metric tons. Approximately 54 percent of ferrous metal products were produced from virgin materials such as iron ore and coal using BOF technology. The remainder, 46 percent, was produced from ferrous metal scrap in EAF facilities. These data show that the U.S. ferrous metal industry already has a high recycling rate. The rate is expected to increase under the Unrestricted Release Alternative. Although most of the U.S. demand is satisfied through domestic production, ferrous metal imports account for 25 to 30 percent of annual consumption of ferrous metal. The summary statistics for the U.S. iron and ferrous metal industry are presented in Table K-6 (USGS 2004e; USGS 2004f).

Table K-6 U.S. Iron and Ferrous Metal Industry Summary Statistics from USGS (in million metric tons of metal)

	1997	1998	1999	2000	2001[1]
Pig Iron Production	49.6	48.2	46.3	47.9	44.2
Ferrous Metal Production	98.5	98.6	97.4	102	92.9
Basic Oxygen Furnaces	55.4	54.1	52.3	54.1	49.4
Electric Arc Furnaces	43.1	44.5	45.1	47.9	43.5
Imports of Ferrous Metal Mill Products	28.3	37.7	32.4	34.4	26.2
Exports of Ferrous Metal Mill Products	5.5	5.0	4.9	5.9	5.6
Apparent Ferrous Metal Consumption[2]	114	118	116	119	118

[1] Estimated values.
[2] Apparent consumption = production + imports – exports + adjustment for industry stock changes + adjustment for imports of semi-finished ferrous metal products.

Source: USGS, 2004e, USGS 2004f

The net amount of scrap salvaged under the alternatives (i.e., the amount salvaged relative to the base case) would range between a maximum increase of 0.03 million tons to a maximum decrease of 0.13 million tons annually, or between 0.03 percent and 0.13 percent of the annual consumption, respectively. These quantities are relatively small compared to the total amount of ferrous metal products consumed annually. Therefore, the rule is not expected to cause any significant disruptions to the U.S. market for ferrous metal.

Copper

In the period 1997-2001, average annual U.S. production of copper was almost 3 million metric tons. Approximately 63 percent of copper products were produced from virgin materials such as ore, concentrate, or precipitate. The remaining 37 percent was produced from old scrap (secondary production), new scrap, or refinery scrap. Old scrap refers to obsolete or discarded end-use items that are recycled. New scrap represents the copper that is recovered from scrap generated during manufacturing (e.g., stampings, defective parts, etc.), and returned to smelters, refineries, or mills for reprocessing. Refinery scrap may have been processed through smelting and electrolytic refining or directly processed at a fire refinery. Although most of the U.S. demand is satisfied through domestic production, copper imports account for around 30 percent of annual consumption of copper. The summary statistics for the U.S. copper industry are presented in Table K-7 (USGS 2004c).

Table K-7 U.S. Copper Industry Summary Statistics from USGS (in million metric tons of metal)

	1997	1998	1999	2000	2001
Primary Production	2.07	2.14	1.89	1.59	1.63
Secondary Production	0.498	0.466	0.381	0.357	0.316
New Scrap	0.967	0.956	0.949	0.955	0.833
Refinery Scrap	0.396	0.349	0.23	0.208	0.172
Imports	0.632	0.683	0.837	1.06	0.991
Exports	0.0929	0.0862	0.0252	0.0936	0.0225
Apparent Copper Consumption[1]	2.94	3.03	3.13	3.13	2.5

[1] Apparent consumption = primary production + secondary production + imports – exports ± adjustment for industry stock changes.

Source: USGS, 2003a.

The net amount of scrap salvaged under the rulemaking alternatives (i.e., the amount salvaged relative to the base case) would total 6,584 tons. This quantity is relatively small compared to the total amount of copper consumed annually. Even if all of this copper was generated in the same year, it would only represent 0.22 percent of the average U.S. annual copper consumption. Therefore, the rule is not expected to cause any significant disruptions to the U.S. market for copper.

Aluminum

In the period 1996-2000, average annual U.S. production of aluminum was just over 7 million metric tons. Approximately 51 percent of aluminum products were produced from virgin materials. The remaining 49 percent was produced from secondary sources. Secondary production includes metal recovered from post-consumer aluminum scrap and fabrication aluminum scrap. Although the majority of the U.S. demand is satisfied through domestic production, aluminum imports account for about 48 percent of annual consumption of aluminum. The summary statistics for the U.S. aluminum industry are presented in Table K-8 (USGS 2004d).

The net amount of scrap salvaged under the rulemaking alternatives (i.e., the amount salvaged relative to the base case) would total 212 tons. This quantity is relatively small compared to the total amount of aluminum consumed annually. Even if all of this aluminum was generated in the same year, this amount would only represent 0.003 percent of the average U.S. annual aluminum consumption. Therefore, the rule is not expected to cause any significant disruptions to the U.S. market for aluminum.

Table K-8 U.S. Aluminum Industry Summary Statistics from USGS (in million metric tons of metal)

	1996	1997	1998	1999	2000
Primary Production	3.577	3.603	3.713	3.779	3.668
Secondary Production	3.31	3.55	3.44	3.69	3.45
Imports	2.81	3.08	3.55	4	3.91
Exports	1.5	1.57	1.59	1.64	1.76
Apparent Aluminum Consumption[1]	6.61	6.72	7.09	7.77	7.53

[1] Apparent consumption = primary production + secondary production + imports – exports ± adjustment for industry stock changes.

Source: USGS, 2002a

2.2 Attribute – Industry Operation

2.2.1 Attribute Definition and Identification of Driving Factors

Industry Operation measures yearly net incremental cost and benefits (e.g., relevant capital, operating, and maintenance costs) due to changes in industry operations, including incremental costs and savings for each of the following four sub-attributes:[10] (1) ongoing decision making/paperwork, (2) survey of materials, (3) solid waste disposal, recycling, or reuse, and (4) transportation.

1. *Sub-Attribute - Decision Making/Paperwork.* This sub-attribute captures the costs associated with preparing any required documents for the clearance of materials.

2. *Sub-Attribute - Survey of Materials.* Unit cost estimates for surveying materials reflect variations in the type of material to be surveyed, the physical shape of the material, contamination potential of the material, dose option that must be met, the initial activity level of the material, and whether materials are surveyed on or off site.

3. *Sub-Attribute - Solid Waste Disposal or Recycling.* This sub-attribute includes cost or revenue information for the following three elements: (1) Low-Level Waste Disposal, (2) Off-Site Solid Waste Disposal, and (3) Recycling. Unit costs include tipping fees and revenue from recycling materials.

[10] If decontamination were conducted, it also would be counted as a cost under industry operation. However, this analysis assumes that it is not cost-effective to decontaminate and re-survey materials in order to clear them.

4. *Sub-Attribute - Transportation*. Unit cost estimates for transportation reflect: (1) the average distances between licensees and the nearest LLW disposal facilities, EPA-regulated landfills, recycling facilities, or reuse facilities; (2) the average capacity of trucks used, and (3) the cost per ton-mile to ship cleared material versus controlled material.

The quantities of materials (ferrous metal, concrete, and trash) that are released in the baseline and for each alternative are taken from the collective dose assessment report, as described in Table K-9. For the alternatives with dose options (Unrestricted Release and EPA-Regulated Disposal), quantity information was provided for the 0.03 mrem/yr, 0.1 mrem/yr, 1 mrem/yr, and 10 mrem/yr options. For the IAEA Safety Guide No. RS-G-1.7 dose option, the quantities were assumed to be equal to the 1 mrem/yr dose option.

Table K-9 Quantity Sources in SC&A 2003

Description in Cost-Benefit Analysis	Description in SC&A 2003
Baseline/No Action	No Action (Case A)[11]
Unrestricted Release: Material-Specific Limits	Case A
Unrestricted Release: Material-Independent Limits	Case B
EPA-Regulated Disposal without Incineration	Case C
EPA-Regulated Disposal with Trash Incineration	Case C2
LLW Disposal	No Action (Case A)
Limited Disposition	Case B (Concrete); Case C (Ferrous metal and Trash)

[11] The collective dose report (SC&A 2003) presents different values for the dose associated with the No Action Alternative. This cost-benefit analysis assumes the most appropriate version of the quantities and dose associated with the No Action Alternative (and hence the baseline) is in fact the No Action Alternative in the collective dose report (SC&A 2003) associated with the Unrestricted Release Alternative.

Table K-10 presents the total quantities of material released under the baseline (No Action Alternative) and each alternative. As can be seen, different amounts of material are released under each alternative and dose option. That is, not only could a different amount of material be released between the 0.03 mrem/yr dose option and the 0.1 mrem/yr dose option, but within the 0.03 mrem dose options, different amounts are released depending on the alternative. In the 0.03 mrem/yr dose option in any alternative, less material clears and is available for release than in the baseline (or No Action Alternative). Positive values in the change in quantity released column indicate that more material meets release levels under the alternative than in the baseline. This "newly releasable" material is assumed to be sent to disposal in a LLW facility in the baseline. Often this change in the quantity that can be released drives the results of the cost modeling. Table K-11 presents the quantities of each type of material (ferrous metals, concrete, and trash) that could be released under each alternative and dose option. The totals in tables K-10 and K-11 are different from those presented in Chapter 3 because Chapter 3 uses an absolute analysis rather than an incremental analysis.

Table K-10 Material Quantities Released by Alternative

Alternative	Dose	Baseline Tons Released	Alternative Quantity Released	Change in Quantity Released
No Action	NA	17,954,742	17,954,742	0
Unrestricted Release Material Specific Limits	0.03	17,954,742	15,735,586	(2,219,156)
	0.1	17,954,742	18,768,310	813,568
	1	17,954,742	21,525,814	3,571,072
	10	17,954,742	21,909,149	3,954,407
Unrestricted Release Material Independent Limits	0.03	17,954,742	15,247,765	(2,706,977)
	0.1	17,954,742	18,080,580	125,838
	1	17,954,742	21,044,465	3,089,723
	10	17,954,742	21,709,582	3,754,840
	RS-G-1.7	17,954,742	21,044,465	3,089,723
EPA/State-Regulated Disposal (Landfill)	0.03	17,954,742	16,888,904	(1,065,838)
	0.1	17,954,742	19,570,465	1,615,723
	1	17,954,742	21,790,651	3,835,909
	10	17,954,742	21,928,420	3,973,678
	RS-G-1.7	17,954,742	21,790,651	3,835,909
LLW Disposal/ Prohibition	NA	17,954,742	17,954,742	-
Limited Disposition	RS-G-1.7	17,954,742	21,694,631	3,739,890

Table K-11 Quantities Released Under Baseline and Alternatives by Dose Option and Material

Alternative	Dose	Baseline Tons Released			Alternative Tons Released			Change in Quantity Released		
		Steel	Concrete	Trash	Steel	Concrete	Trash	Steel	Concrete	Trash
No Action	NA	1,803,602	16,130,738	20,402	1,803,602	16,130,738	20,402	0	0	0
Unrestricted Release Material Specific Limits	0.03	1,803,602	16,130,738	20,402	759,254	14,962,692	13,640	(1,044,347)	(1,168,047)	(6,762)
	0.1	1,803,602	16,130,738	20,402	1,256,607	17,490,696	21,007	(546,995)	1,359,958	605
	1	1,803,602	16,130,738	20,402	1,940,589	19,544,245	40,979	136,987	3,413,507	20,577
	10	1,803,602	16,130,738	20,402	2,171,232	19,671,833	66,084	367,630	3,541,094	45,682
Unrestricted Release Material Independent Limits	0.03	1,803,602	16,130,738	20,402	284,888	14,962,692	186	(1,518,714)	(1,168,047)	(20,216)
	0.1	1,803,602	16,130,738	20,402	589,452	17,490,696	432	(1,214,150)	1359958	(19,970)
	1	1,803,602	16,130,738	20,402	1,498,424	19,544,245	1,796	(305,178)	3,413,507	(18,606)
	10	1,803,602	16,130,738	20,402	2,031,852	19,671,833	5,897	228,250	3541094	(14,505)
	RS-G-1.7	1,803,602	16,130,738	20,402	1,498,424	19,544,245	1,796	(305,178)	3,413,507	(18,606)
EPA/State-Regulated Disposal (Landfill)	0.03	1,803,602	16,130,738	20,402	1,332,548	15,542,717	13,640	(471,054)	(588,021)	(6,762)
	0.1	1,803,602	16,130,738	20,402	1,742,296	17,807,161	21,007	(61,306)	1,676,423	605
	1	1,803,602	16,130,738	20,402	2,109,407	19,640,265	40,979	305,805	3,509,527	20,577
	10	1,803602	16,130,738	20,402	2,190,503	19,671,833	66,084	386,901	3,541,094	45,682
	RS-G-1.7	1,803602	16,130,738	20,402	2,109,407	19,640,265	40,979	305,805	3,509,527	20,577
LLW Disposal/ Prohibition	NA	1,803602	16,130,738	20,402	1,803,602	16,130,738	20,402	-	-	-
Limited Disposition	RS-G-1.7	1,803,602	16,130,738	20,402	2,109,407	19,544,245	40,979	305,805	3,413,507	20,577

2.2.2 Attribute Equations

The following four equations are used to calculate the net change in costs and benefits due to the Industry Operation attribute.

Equation 1 - Decision Making/Paperwork

The administrative costs associated with decision making and paperwork of the *Industry Operation* attribute are estimated as follows:

$$Decision\ Making/Paperwork = (HOURS_{Technical}\ x\ WAGE_{Technical})$$

Parameter	Description
$HOURS_{Technical}$	The number of additional hours required for administrative tasks by technical workers (see assumptions below)
$WAGE_{Technical}$	The loaded hourly wage per technical labor (see assumptions below)

Assumptions

- The number of administrative hours per licensee undergoing their first year of decommissioning required by technical staff ($HOURS_{Technical}$) is equal to 200 hours.[12]

- The hourly wage rates used throughout the equations in this appendix for each labor category are as follows:[13]

  (1) Technical labor ($WAGE_{Technical}$) = -$33.84 per hour per person (OPM, 2004)[14]
  (2) Managerial labor ($WAGE_{Managerial}$) = -$48.22 per hour per person (OPM, 2004)[15]
  (3) Attorney or lawyer labor ($WAGE_{Legal}$) = -$67.04 per hour per person (OPM, 2004)[16]
  (4) Clerical labor ($WAGE_{Clerical}$) = -$20.58 per hour per person (OPM, 2004)[17]

Equation 2 - Survey costs

The net survey costs associated with the *Industry Operation* attribute are estimated as follows:

[12] Based on Best Professional Judgement and guidance in NUREG-6477 (NRC 1998).

[13] As discussed in Section 2, the unit costs are presented as negative in order to provide results that correctly identify benefits as positive and costs as negative.

[14] GS-11, Step 1 with a standard overhead factor of 1.6.

[15] GS-13, Step 1 with a standard overhead factor of 1.6.

[16] GS-15, Step 1 with a standard overhead factor of 1.6.

[17] GS-6, Step 1 with a standard overhead factor of 1.6.

$$Survey = [(COST_{ferrous\ metal\ dose\ survey} \times QUANTITY_{ferrous\ metal\ dose}) + (COST_{concrete\ dose\ survey} \times QUANTITY_{concrete\ dose}) + (COST_{trash\ dose\ survey} \times QUANTITY_{trash\ dose})] - [(COST_{ferrous\ metal\ baseline\ survey} \times QUANTITY_{ferrous\ metal\ baseline}) + (COST_{baseline\ concrete\ survey} \times QUANTITY_{concrete\ baseline}) + (COST_{trash\ baseline\ survey} \times QUANTITY_{trash\ baseline})]$$

Parameter	**Description**
$COST_{baseline\ concrete\ survey}$	Baseline survey costs per ton of concrete (see table K-12 below)
$COST_{ferrous\ metal\ baseline\ survey}$	Baseline survey costs per ton of ferrous metal (see table K-12 below)
$COST_{trash\ baseline\ survey}$	Baseline survey costs per ton of trash (see table K-12 below)
$QUANTITY_{concrete\ baseline}$	Baseline total tons of concrete
$QUANTITY_{ferrous\ metal\ baseline}$	Baseline total tons of ferrous metal
$QUANTITY_{trash\ baseline}$	Baseline total tons of trash
$COST_{concrete\ dose\ survey}$	Survey costs per ton of concrete under dose option (see table K-12 below)
$COST_{ferrous\ metal\ dose\ survey}$	Survey costs per ton of ferrous metal under dose option (see table K-12 below)
$COST_{trash\ dose\ survey}$	Survey costs per ton of trash under dose option (see table K-12 below)
$QUANTITY_{concrete\ dose}$	Total tons of concrete to be released under dose option
$QUANTITY_{ferrous\ metal\ dose}$	Total tons of ferrous metal to be released under dose option
$QUANTITY_{trash\ dose}$	Total tons of trash to be released under dose option

Assumptions

- The available survey costs from the Clearance Survey Cost Report (ORISE 2004) are summarized in Table K-12.

- Because survey costs are dependent on MARSSIM classification, the survey costs were weighted to reflect the relative proportion of MARSSIM Class 2 and Class 3 material. The percentages for ferrous metal were taken from SC&A 2003. Based on data in tables on pages 3-10, 3-20, and the scaling factors from page 3-23, the relative proportion of Class 2 material was 27 percent and Class 3 material was 73 percent. Similar information was not available for concrete and trash in SC&A 2003. Attachment 1 describes the relative proportion of Class 1, 2, and 3 material for ferrous metal, concrete, and trash. Assuming that only Class 2 and Class 3 material would be surveyed to be released, this analysis calculates that 11 percent of concrete would be Class 2 and 89 percent would be Class 3. For trash, 50 percent is assumed to be Class 2 and 50 percent is assumed to be Class 3.

Table K-12: Survey Costs by Dose Option

Dose Option Level and MARSSIM Classification	Cost	Units	Source in Feb 2004 Clearance Survey Cost Report
Concrete Rubble			
baseline/no action	-26	$/ton	p. 7-9
0.03 mrem/yr - Class 2	Not Feasible		
0.1 mrem/yr- Class 2	-314	$/ton	p. 7-10
1 mrem/yr - Class 2	-84	$/ton	p. 7-10
10 mrem/yr - Class 2	-84	$/ton	p. 7-10
IAEA Standard - Class 2	-84	$/ton	Assumed to be equal to 1 mrem/yr
0.03 mrem/yr - Class 3	Not Feasible		
0.1 mrem/yr- Class 3	-85	$/ton	p. 7-10
1 mrem/yr - Class 3	-30	$/ton	p. 7-10
10 mrem/yr - Class 3	-30	$/ton	p. 7-10
IAEA Standard - Class 3	-30	$/ton	Assumed to be equal to 1 mrem/yr
Structural Ferrous Metal			
baseline/no action	-176	$/ton	p. 7-26
0.03 mrem/yr - Class 2	Not Feasible		
0.1 mrem/yr- Class 2	-89	$/ton	p. 7-28
1 mrem/yr - Class 2	-82	$/ton	p. 7-28
10 mrem/yr - Class 2	-82	$/ton	p. 7-28
IAEA Standard - Class 2	-82	$/ton	Assumed to be equal to 1 mrem/yr
0.03 mrem/yr - Class 3	Not Feasible		
0.1 mrem/yr- Class 3	-30	$/ton	p. 7-28
1 mrem/yr - Class 3	-27	$/ton	p. 7-28
10 mrem/yr - Class 3	-27	$/ton	p. 7-28
IAEA Standard - Class 3	-27	$/ton	Assumed to be equal to 1 mrem/yr
Trash			
baseline/no action	-50	$/ton	Assumed to be twice 0.1 mrem/yr (for class 3)
0.03 mrem/yr - Class 2	-246	$/ton	Assumed to be twice 0.1 mrem/yr
0.1 mrem/yr- Class 2	-123	$/ton	p. 7-53
1 mrem/yr - Class 2	-123	$/ton	p. 7-53
10 mrem/yr - Class 2	-123	$/ton	p. 7-53
IAEA Standard - Class 2	-123	$/ton	Assumed to be equal to 1 mrem/yr
0.03 mrem/yr - Class 3	-50	$/ton	Assumed to be twice 0.1 mrem/yr
0.1 mrem/yr- Class 3	-25	$/ton	p. 7-53
1 mrem/yr - Class 3	-25	$/ton	p. 7-53
10 mrem/yr - Class 3	-25	$/ton	p. 7-53
IAEA Standard - Class 3	-25	$/ton	Assumed to be equal to 1 mrem/yr

- It is not feasible to survey concrete and ferrous metal at the 0.03 mrem/yr dose option level, because the data quality objectives for the survey demand a very large number of samples (ORISE 2004). As a result, in the 0.03 mrem/yr dose options of the Unrestricted Release and EPA-Regulated Disposal Alternatives, ferrous metal and concrete are assumed to be sent for LLW disposal rather than surveyed and released.

Assumptions

- Survey costs for LLW disposal are not required by the proposed action. However, disposal facilities will not accept waste that has not been surveyed. Consequently, survey costs were included for all material being sent to LLW disposal. The survey costs for the 10 mrem/yr dose option were used as a proxy for the survey costs for LLW disposal.

Equation 3 - Disposal and recycling costs

The net disposal and recycling costs associated with the *Industry Operation* attribute are estimated as follows:

$$Disposal/Recycling = [(COST_{LLW\ Disposal} \times QUANTITY_{LLW\ Dose}) + (COST_{Landfill\ Disposal} \times QUANTITY_{Landfill\ Dose}) + (REVENUE_{ferrous\ metal\ recycled} \times QUANTITY_{ferrous\ metal\ recycled\ dose}) + (COST_{concrete\ recycled} \times QUANTITY_{concrete\ recycled\ dose}) + (COST_{LLW\ Disposal} \times QUANTITY_{baseline-dose})] - [(COST_{LLW\ Disposal} \times QUANTITY_{LLW\ baseline}) + (COST_{Landfill\ Disposal} \times QUANTITY_{Landfill\ baseline}) + (REVENUE_{ferrous\ metal\ recycled} \times QUANTITY_{ferrous\ metal\ recycled\ baseline}) + (COST_{concrete\ recycled} \times QUANTITY_{concrete\ recycled\ baseline})]$$

Parameter	**Description**
$QUANTITY_{LLW\ baseline}$	Baseline total tons of material disposed of offsite as LLW
$QUANTITY_{Landfill\ baseline}$	Baseline total tons of material disposed of offsite as MSW
$QUANTITY_{ferrous\ metal\ recycled\ baseline}$	Baseline total tons of ferrous metal recycled
$QUANTITY_{concrete\ recycled\ baseline}$	Baseline total tons of concrete recycled
$QUANTITY_{LLW\ Dose}$	Total tons of material disposed of offsite as LLW under dose option
$QUANTITY_{Landfill\ Dose}$	Total tons of material disposed of offsite as MSW under dose option
$QUANTITY_{ferrous\ metal\ recycled\ dose}$	Total tons of ferrous metal recycled under dose option
$QUANTITY_{concrete\ recycled\ dose}$	Total tons of concrete recycled under dose option
$QUANTITY_{baseline-dose}$	Net difference in tons cleared in baseline - tons cleared under dose option
$COST_{LLW\ Disposal}$	Offsite disposal costs per ton of material at a LLW facility (see assumptions below)
$COST_{Landfill\ Disposal}$	Offsite disposal costs per ton of material at a solid waste landfill (see assumptions below)
$REVENUE_{ferrous\ metal\ recycled}$	Revenue generated from the average market price of recycling scrap ferrous metal (see assumptions below)
$COST_{concrete\ recycled}$	Recycling cost per ton of concrete (see assumptions below)

Assumptions

- The cost for disposal at a LLW facility (Envirocare) is equal to -$14.72 per cubic foot (DOE 2002b). This cost reflects disposal of DOE waste, because prices for disposal of non-DOE wastes were not publicly available.

- The cost for disposal at a municipal or industrial solid waste landfill is equal to -$32.19 per ton (REPA 2001).

- The revenue associated with the average market price of scrap ferrous metal is equal to $85 per ton (Recycler's World 2003).[18]

- The cost of recycling concrete is equal to -$5 per ton.[19]

Equation 4 - Transportation costs

The net transportation cost associated with the *Industry Operation* attribute is estimated as follows:

$$Transportation = COST_{LLW\ transport\ truck} \times DISTANCE_{LLW\ facility} \times (QUANTITY_{LLW\ dose} + QUANTITY_{baseline\text{-}dose} - QUANTITY_{LLW\ baseline}) + COST_{Cleared\ transport\ truck} [(DISTANCE_{MSW\ Landfill} \times (QUANTITY_{Landfiill\ dose} - QUANTITY_{Landfiill\ baseline})) + (DISTANCE_{Recycling\ Facility\text{-}Ferrous\ metal} \times (QUANTITY_{ferrous\ metal\ recycled\ dose} - QUANTITY_{ferrous\ metal\ recycled\ baseline})) + (DISTANCE_{Recycling\ Facility\text{-}Concrete} \times (QUANTITY_{concrete\ recycled\ dose} - QUANTITY_{concrete\ recycled\ baseline}))]$$

Parameter	**Description**
$QUANTITY_{LLW\ baseline}$	Total baseline tons of material transported to a LLW facility
$QUANTITY_{Landfiill\ baseline}$	Total baseline tons of material transported to a municipal landfill
$QUANTITY_{ferrous\ metal\ recycled\ baseline}$	Total baseline tons of ferrous metal transported to a recycling facility
$QUANTITY_{concrete\ recycled\ baseline}$	Total baseline tons of concrete transported for recycling
$COST_{LLW\ transport\ truck}$	Cost per ton-mile for transport of LLW using a truck (see assumptions below)
$COST_{Cleared\ transport\ truck}$	Cost per ton-mile for transport of cleared material using a truck (see assumptions below)
$DISTANCE_{LLW\ facility}$	Distance to a LLW facility (see assumptions below)
$DISTANCE_{MSW\ Landfill}$	Distance to a MSW landfill (see assumptions below)
$DISTANCE_{Recycling\ Facility\text{-}Ferrous\ metal}$	Distance to a ferrous metal recycling facility (see assumptions below)
$DISTANCE_{Recycling\ Facility\text{-}Concrete}$	Distance to a concrete recycling facility (see assumptions below)

[18] Because the industry will pay licensees for the ferrous metal, this is considered a negative cost (actualized benefit).://www.recycle.net/price/metals.html

[19] Agretech. Phone Interview. November 25, 2003.

Parameter	**Description**
$QUANTITY_{baseline\text{-}dose}$	Net difference in tons cleared in baseline minus tons cleared under dose option
$QUANTITY_{LLW\ dose}$	Total tons of material transported under dose option to a LLW facility
$QUANTITY_{Landfiill\ dose}$	Total tons of material transported under dose option to a MSW landfill
$QUANTITY_{ferrous\ metal\ recycled\ dose}$	Total tons of ferrous metal transported under dose option to a recycling facility
$QUANTITY_{concrete\ recycled\ dose}$	Total tons of concrete transported under dose option to a recycling facility

Assumptions

The following transportation costs apply:

- LLW material using a truck: -$0.12/ton-mile (DOE 1999).
- Cleared material using a truck: -$0.06/ton-mile.[20]
- LLW ferrous metal using rail: -$0.016/ton-mile (DOE 2002b).
- LLW concrete using rail: -$0.044/ton-mile.[21]

The following average distances apply:

- LLW facility: 1,544 miles.[22]
- MSW Landfill: 58 miles.[23]
- Ferrous metal recycling facility: 269 miles (SC&A 2003).[24]
- Concrete recycling facility: 198 miles.[25]

Trucks are assumed to be able to transport 25 tons per truckload of ferrous metals, concrete, or mixed materials destined for a LLW disposal facility. Trucks are assumed to transport 10 tons per truckload of trash.

Attachment 2 provides a detailed discussion of this attribute.

[20] Best professional judgement.

[21] *Ibid.*

[22] Estimate based on average distance from existing LWRs to Clive, Utah, derived from GIS analysis.

[23] Best professional judgement.

[24] Table 9.62, page 9-97.

[25] *Ibid.*

2.3 Attribute - Public Health (Routine)

2.3.1 Attribute Definition and Identification of Driving Factors

Public Health (Routine) measures the yearly incremental cost or benefit due to changes in radiation exposures to the public associated with routine NRC licensee activities. The public is defined as any person not working in the nuclear industry. Exposures may occur from the following activities: material handling activities, storage, transportation, processing or recycling, disposal in solid waste landfills, manufacturing, and distribution and use of new products.

2.3.2 Attribute Equation

The following equation can be used to calculate the net change in costs and benefits due to the Public Health (Routine) attribute.

Equation 5 - Routine radiologic exposure

The routine radiologic exposure cost associated with the *Public Health (Routine)* attribute is estimated as follows:

$$Radiological\ Exposure = (DOSE_{baseline\ public} - DOSE_{dose\ alternative\ public}) \times COST_{exposure}$$

Parameter	Description
$DOSE_{baseline\ public}$	The baseline dose to the public due to routine exposures in person rem for clearance of materials
$DOSE_{dose\ alternative\ public}$	The dose to the public due to routine exposures in person rem for clearance of materials under the alternative
$COST_{exposure}$	Cost of exposure per person-rem (see assumptions below)

Assumptions

- The cost of exposure per person is assumed to be -$2,000 per person-rem (NRC 2003f).

- The dose to the public was taken from SC&A 2003. Table K-13 describes how the alternatives in this cost-benefit analysis relate to the naming conventions used in SC&A 2003. For the dose-specific alternatives (Unrestricted Release and EPA-Regulated Disposal), dose information was provided for the 0.03, 0.1, 1, and 10 mrem/yr options. For the IAEA Safety Guide No. RS-G-1.7 dose option, the quantities were assumed to be twice the dose associated with the 1 mrem/yr dose option based on NUREG-1640 (Appendix D).

- SC&A 2003 presents the collective dose to workers, such as truck drivers and recyclers, as well as members of the general public. Dose to members of the public and workers at non-licensed facilities normally would be captured in the attribute public health-routine, and dose to workers at licensed facilities normally would be captured in the attribute occupational health-routine. Because this analysis could not separate the collective doses into these two categories on a year-by-year basis for each alternative and dose-option considered, the public health-routine and occupational health routine attributes are combined in a single attribute described as public and occupational health-routine.

- The dose associated with equipment reuse was taken from Appendix D, Section 12.

Table K-13 Description of Alternatives and Naming Conventions

Description in Cost-Benefit Analysis	Description in SC&A 2003
Baseline	No Action (Case A)[26]
Unrestricted Release: Material-Specific Limits	Case A
Unrestricted Release: Material-Independent Limits	Case B
EPA-Regulated Disposal without Incineration	Case C
EPA-Regulated Disposal with Trash Incineration	Case C2
Limited Disposition	Case B (concrete), Case C (ferrous metal and trash)
LLW Disposal	Not provided in Report. Assumed to be 0 person-rem.

2.4 Attribute - Occupational Health (Routine)

2.4.1 Attribute Definition and Identification of Driving Factors

Occupational Health (Routine) measures the yearly incremental cost or benefit due to changes in radiation exposures to occupational workers at licensed facilities associated with routine activities. Exposures may occur from the following material handling activities: storage, surveying, decontamination, volume reduction, packaging for disposal or recycling, and disposal.

2.4.2 Attribute Equation

The following equation can be used to calculate the net change in costs and benefits due to the Occupational Health (Routine) attribute.

Equation 6 - Routine occupational radiologic exposures

The routine radiological exposure cost associated with the *Occupational Health (Routine)* attribute is estimated as follows:

$$Radiologic\ Exposure = (DOSE_{baseline\ worker} - DOSE_{dose\ alternative\ worker})\ x\ COST_{exposure}$$

Parameter	Description

[26] SC&A 2003 presents different values for the dose associated with the No Action Alternative. This cost-benefit analysis assumes the most appropriate version of the quantities and dose associated with the No Action Alternative (and hence the baseline) is in fact the No Action Alternative in SC&A 2003 associated with the Unrestricted Release Alternative.

$DOSE_{baseline\ worker}$	The baseline dose to occupational workers due to exposure in person-rem for clearance of materials.
$DOSE_{dose\ alternative\ worker}$	The dose to occupational workers due to exposure in person-rem for clearance of materials, under the alternative.
$COST_{exposure}$	Cost of exposure per person-rem (see assumptions below)

Assumptions

- The cost of exposure per person is assumed to be -$2,000 per person-rem (NRC 2003f).

- SC&A 2003 presents the collective dose to workers, such as truck drivers and recyclers, as well as members of the general public. Dose to members of the public and workers at non-licensed facilities normally would be captured in the attribute public health-routine, and dose to workers at licensed facilities normally would be captured in the attribute occupational health-routine. Because this analysis could not separate the collective doses into these two categories on a year-by-year basis for each alternative and dose-option considered, the public health-routine and occupational health routine attributes are combined in a single attribute described as public and occupational health-routine.

2.5 Attribute - Public Health (Accident)

2.5.1 Attribute Definition and Identification of Driving Factors

Public Health (Accident) measures the yearly net incremental cost or benefit due to changes in radiation exposures to occupational workers in non-licensed facilities and the general public associated with accidents. While exposures may occur from accidents related to storage, transportation, surveying, decontamination, volume reduction, packaging of materials, and random acts, such as fires, no such exposures are quantified in this analysis because the amount of radiation in any given quantity of material being considered for clearance would not result in a significant dose in the event of these types of accidents (Section 3.3).

Another dimension of the Public Health (Accident) attribute is yearly net incremental cost or benefit due to changes in non-radiologically induced deaths and disabilities related to transportation, decontamination, volume reduction, and packaging of materials.

2.5.2 Attribute Equation

The following equation can be used to calculate the net change in costs and benefits due to the Public Health (Accident) attribute. For this analysis, accidents are due to truck transport.

Equation 7 - Deaths and disabilities due to accidents

The cost of accidental deaths and disabilities associated with the *Public Health (Accident)* attribute is estimated as follows:

$$\textit{Accidental Deaths and Disabilities} = [(DISTANCE_{alternative\ total} - DISTANCE_{baseline\ total}) \times NUM_{accident\ deaths} \times COST_{lost\ life}] + [(DISTANCE_{alternative\ total} - DISTANCE_{baseline\ total}) \times NUM_{accident\ disabilities} \times COST_{lifetime\ disability}]$$

Parameter	**Description**
$DISTANCE_{baseline\ total}$	Total vehicle miles traveled in baseline
$DISTANCE_{alternative\ total}$	Total vehicle miles traveled in alternative
$NUM_{accident\ deaths}$	Number of deaths due to accidents per vehicle mile traveled
$COST_{lost\ life}$	Average cost of a lost life (see assumptions below)
$NUM_{accident\ disabilities}$	Number of disabilities due to accidents per vehicle mile traveled
$COST_{lifetime\ disability}$	Lifetime cost of disability

Assumptions

- The average cost of a life is assumed to be -$3,000,000 (NRC 2003f).

- This analysis does not calculate any lifetime disabilities.

- The number of accidents is based on vehicle miles traveled multiplied by the accident fatality rate. As discussed in Chapter 3 of this Draft GEIS, the fatal accident rate for a truck is 2.409 E-08 per vehicle mile traveled (NRC 1994b). This fatality rate includes both death to members of the public and to drivers.

2.6 Attribute - Industry Implementation

2.6.1 Attribute Definition and Identification of Driving Factors

Industry Implementation measures the initial incremental cost or benefit to licenses due to changes in industry implementation, including incremental costs and savings of the following: reading regulations and guidance documents; training employees on new procedures; capital outlay for new equipment (e.g., trucks, survey equipment); and researching markets and vendors for cleared material. No capital outlay is expected to be required under this rulemaking. Fees paid to NRC are not included in the analysis as they represent a transfer payment. Thus fees paid are a cost to industry and a benefit to NRC, with a net balance of zero.

2.6.2 Attribute Equation

The following equation can be used to calculate the net change in costs and benefits due to the Industry Implementation attribute.

Equation 8 - Implementation costs

The implementation costs associated with the *Industry Implementation* attribute are estimated as follows:

$$Implementation = (HOURS_{industry\ implementation\ managers} \times WAGE_{Managerial}) + (HOURS_{industry\ implementation\ legal} \times WAGE_{Legal}) + (HOURS_{industry\ implementation\ clerical} \times WAGE_{Clerical})$$

Parameter	**Description**
$HOURS_{industry\ implementation\ managers}$	The number of additional hours required for administrative implementation tasks by managers (see assumptions below)
$WAGE_{Managerial}$	The loaded hourly wage per managerial labor (see Equation 1 assumptions in Section 2.2.2)
$HOURS_{industry\ implementation\ legal}$	The number of additional hours required for administrative implementation tasks by attorneys (see assumptions below)
$WAGE_{Legal}$	The loaded hourly wage per attorney (see Equation 1 assumptions in Section 2.2.2)
$HOURS_{industry\ implementation\ clerical}$	The number of additional hours required for administrative implementation tasks by clerical workers (see assumptions below)
$WAGE_{Clerical}$	The loaded hourly wage per clerical labor (see Equation 1 assumptions in Section 2.2.2)

Assumptions

The following are the number of hours assumed, using best professional judgement:

- Number of Managerial hours: 60.
- Number of Legal hours: 10.
- Number of Clerical hours: 10.

2.7 Attribute - NRC Implementation

2.7.1 Attribute Definition and Identification of Driving Factors

NRC Implementation involves, among other considerations, NRC staff time to complete the following implementation tasks:

- Develop guidance, procedures, and aids for use by NRC and Agreement States
- Develop enforcement procedures
- Develop guidance, procedures, and aids for use by licensees

2.7.2 Attribute Equation

The following equation calculates the costs and benefits due to NRC Implementation of new control criteria.

Equation 9 - Develop guidance

The administrative costs associated with developing guidance under the *NRC Implementation* attribute are estimated as follows:

$$Develop\ Guidance = (HOURS_{NRC\ implementation\ managerial} \times WAGE_{Managerial}) + (HOURS_{NRC\ implementation\ technical} \times WAGE_{Technical}) + (HOURS_{NRC\ implementation\ clerical} \times WAGE_{Clerical})$$

Parameter	**Description**
$HOURS_{NRC\ implementation\ managerial}$	The number of additional hours required for NRC managerial staff (see assumptions below)
$HOURS_{NRC\ implementation\ technical}$	The number of additional hours required for NRC technical staff (see assumptions below)
$HOURS_{NRC\ implementation\ clerical}$	The number of additional hours required for NRC clerical staff (see assumptions below)
$WAGE_{Managerial}$	The loaded hourly wage per managerial labor (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Technical}$	The loaded hourly wage per technical labor (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Clerical}$	The loaded hourly wage per clerical labor (see Equation 1 assumptions in Section 2.2.2)

Assumptions

The following are the number of hours necessary to develop guidance for the clearance of material, for the first year only, using best professional judgement:

- Number of Managerial hours: 10.
- Number of Technical hours: 80.
- Number of Clerical hours: 10.

2.8 Attribute - NRC Operation

2.8.1 Attribute Definition and Identification of Driving Factors

NRC operation involves NRC staff time to conduct the following operational tasks on an annual basis:

- Conduct inspections;

- Conduct evaluations of licensee compliance; and
- Enforcement.

2.8.2 Attribute Equations

The following equations calculate the costs due to NRC Operations related to new control criteria.

Equation 10 - Paperwork

The administrative costs associated with the paperwork of the *NRC Operations* attribute are estimated as follows:

$$NRC\ Paperwork = (HOURS_{NRC\ Ops\ Managerial} \times WAGE_{Managerial}) + (HOURS_{NRC\ Ops\ Legal} \times WAGE_{Legal}) + (HOURS_{NRC\ Ops\ Technical} \times WAGE_{Technical}) + (HOURS_{NRC\ Ops\ Clerical} \times WAGE_{Clerical})$$

Parameter	Description
$HOURS_{NRC\ Ops\ Managerial}$	The number of additional hours required for NRC managerial staff, to review paperwork for the clearance of material
$HOURS_{NRC\ Ops\ Legal}$	The number of additional hours required for NRC legal staff, to review paperwork for the clearance of material
$HOURS_{NRC\ Ops\ Technical}$	The number of additional hours required for NRC technical staff, to review paperwork for the clearance of material
$HOURS_{NRC\ Ops\ Clerical}$	The number of additional hours required for NRC clerical staff, to review paperwork for the clearance of material
$WAGE_{Managerial}$	The loaded hourly wage per managerial labor (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Legal}$	The loaded hourly wage per attorney (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Technical}$	The loaded hourly wage per technical labor (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Clerical}$	The loaded hourly wage per clerical labor (see Equation 1 assumptions in Section 2.2.2)

Assumptions

The analysis assumes that no hours will be required for NRC because no additional paperwork will be submitted by licensees, and therefore Equation 10 is equal to zero.

Equation 11 - Enforcement activities

The administrative costs associated with enforcement activities of the *NRC Operations* attribute are estimated as follows:

$$NRC\ Enforcement = (HOURS_{Enforcement\ Managerial} \times WAGE_{Managerial}) + (HOURS_{Enforcement\ Legal} \times WAGE_{Legal}) + (HOURS_{Enforcement\ Technical} \times WAGE_{Technical}) + (HOURS_{Enforcement\ Clerical} \times WAGE_{Clerical}) + COST_{Inspection\ Travel}$$

Parameter	Description
$HOURS_{Enforcement\ Managerial}$	The number of additional hours required for NRC managerial staff to conduct inspections for the clearance of material
$HOURS_{Enforcement\ Legal}$	The number of additional hours required for NRC legal staff to conduct inspections for the clearance of material
$HOURS_{Enforcement\ Technical}$	The number of additional hours required for NRC technical staff to conduct inspections for the clearance of material
$HOURS_{Enforcement\ Clerical}$	The number of additional hours required for NRC clerical staff to conduct inspections for the clearance of material
$WAGE_{Managerial}$	The loaded hourly wage per managerial labor (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Legal}$	The loaded hourly wage per attorney (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Techical}$	The loaded hourly wage per technical labor (see Equation 1 assumptions in Section 2.2.2)
$WAGE_{Clerical}$	The loaded hourly wage per clerical labor (see Equation 1 assumptions in Section 2.2.2)
$COST_{Inspection\ Travel}$	The travel-related costs associated with inspection of cleared material

Assumptions

The analysis assumes that no hours will be required because no additional enforcement activities will be necessary for NRC; therefore, Equation 11 is equal to zero.

2.9 Attribute - Other Government

2.9.1 Attribute Definition and Identification of Driving Factors

This analysis estimates Other Government costs, excluding facilities that are assumed to be covered under the attributes Industry Implementation and Industry Operation, such as DOE and Department of Defense (DoD) facilities. Since regulation of LWRs is not delegated to Agreement States, they will not incur costs related to these facilities. The administrative tasks for other government agencies that have been identified are rulemakings in the Agreement States.

2.9.2 Attribute Equation

The following equation calculates the Other Government costs due to the implementation of new control criteria.

Equation 12 - Burden to Agreement States

The administrative costs associated with State agencies under the *Other Government* attribute are estimated as follows:

$$Environmental\ Agencies = \sum(HOURS_{State\ Employees}\ x\ WAGE_x)$$

Parameter	Description
$HOURS_{State\ Employees}$	The number of additional hours required for State employees for rulemakings
$WAGE_x$	The loaded hourly wage per worker type x.

Assumptions

- 33 Agreement States will need to adapt their regulations to this rulemaking.
- 25 of these States are assumed to require 520 hours of managerial labor (NRC 2003e).
- 8 of these States are assumed to require 208 hours of managerial labor (NRC 2003e).

2.10 Attribute - Regulatory Efficiency

This attribute is considered qualitatively in Section 3, regarding the significant benefits associated with the streamlining of clearance procedures in the post regulatory environment compared with baseline clearance procedures.

2.11 Attribute - Other Considerations

This attribute is considered qualitatively in Section 3, regarding public confidence in NRC.

2.12 Calculating Net Present Value

Present value is a future cash flow, or stream of cash flows, recalculated as an equivalent current amount of money. Net Present Value (NPV) is the present value of all cash flows, *positive and negative*, connected to a project. To calculate NPV, the amount and timing of the cash flows must be determined. Additionally, a discount rate must be used to find the present value. Solving for the present value of a future cash flow is also known as discounting. The following formula shows how NPV is calculated by summing the discounted cash flows that occur in each year:

$$Net\ \ Present\ Value\ = \sum_{t=1}^{n}\left[\frac{CF_t}{(1+r)^t}\right]$$

Parameter	Description
CF	cash flow in year t
t	year in which the cash flow takes place
n	life span (years) of the project
r	discount rate in year t

Assumptions

- For this analysis, the discount rate used is 7 percent, in accordance with NUREG/BR-0184, *Regulatory Analysis Technical Evaluation Handbook* (NRC 1997b).

- As a sensitivity analysis, the results also are calculated using a 3 percent discount rate.

3. Results

This section presents the results of the cost-benefit analysis. Table K-14 presents a summary of the net incremental benefits for each attribute by alternative and dose-option and the total net benefit. Tables K-15 through K-30 present the undiscounted annual incremental costs associated with each attribute for each alternative-dose option under consideration, with the exception of the No Action alternative. Note that costs appear in some years and not in others; this is a result of the distribution of plants shutting down in different years. For the periods where there are no net costs or benefits for Industry Implementation, these are years during which no active D&D is occurring at any decommissioning plant. The cost summary tables follow the information contained in SC&A 2003, Chapter 3. The following general conclusions can be drawn from these results:

- By definition, there are no benefits or costs associated with the No Action Alternative.

- The Unrestricted Release Alternative is expected to result in net incremental benefits under the 1 mem/yr, 10 mrem/yr, and IAEA Safety Guide No. RS-G-1.7 dose options. As shown in Table K-14, most of the benefits result from changes in industry operations (i.e., costs and benefits associated with survey, transportation, and recycling or disposal of material). Public health benefits arise as there are fewer vehicular accidents. Environmental benefits arise as there are fewer air emissions due to a decrease in vehicle miles traveled and as a result of favorable manufacturing tradeoffs as recycled ferrous metal replaces virgin ferrous metal. Sometimes these benefits are slightly offset by a cost resulting from a slight increase in dose to the public.

- Conversely, under the Unrestricted Release Alternative, at the 0.1 mrem/yr or 0.03 mrem/yr dose option levels, the analysis projects net costs, because more material fails to clear and, therefore, must be transported across the country for disposal as low-level waste.

- The EPA/State-Regulated Disposal Alternative, while less beneficial than the Unrestricted Release Alternative also is expected to result in substantial net incremental benefits at the 1 mrem/yr, 10 mrem/yr, and IAEA Safety Guide No. RS-G-1.7 dose options. In this alternative, benefits result from changes in industry operation. A small additional benefit results from changes in public health (routine) because the dose to the public is less than in the baseline. However, some benefit is offset by environmental costs related to a decrease in recycling.

- The LLW Disposal Alternative is projected to result in a net cost of approximately $1.4 billion. Most of this cost results from changes in industry operation, including transportation and disposal of materials as LLW. Other substantial costs result from change in public health - accidental, as a result of more deaths from the increased transportation distances. A lower collective dose to the public is the only benefit of this alternative. All of the other quantifiable attributes contribute to a net cost.

- The Limited Disposition Alternative is expected to result in a net incremental benefit of about $260 million. Most of the benefits result from changes in industry operations (i.e., benefits associated with survey, transportation, and recycling or disposal of material). Public health benefits arise from both lower radiological doses and fewer vehicular accidents. There is a slight environmental cost associated with the loss of otherwise recyclable ferrous metals being disposed in landfills. Because this material is not recycled, recycled ferrous metal cannot replace virgin ferrous metal production.

- For the 0.03 mrem/yr dose options (regardless of the Alternative) it is economically infeasible to survey concrete and ferrous metal. Consequently, these materials are sent to LLW disposal, resulting in costs similar to the LLW disposal alternative. Because trash can still be surveyed at this dose level, some trash is sent to EPA landfills, resulting in a slightly lower cost than the LLW disposal alternative.

- Note that OMB considers a rule “economically significant” under Executive Order 12866 if annual effects are greater than $100 million; by this criterion, the 47-year 7 percent discounted net cost for the LLW Disposal Alternative, and the 0.03 dose options of the Unrestricted Release and EPA-Regulated Disposal Alternatives would qualify as “economically significant.”

Qualitative Results

- Regulatory Efficiency - By developing standardized procedures to clear material, there will be increased regulatory efficiency for both NRC and for facilities that are undergoing decommissioning (except under the No Action Alternative). Currently, material may be released under Regulatory Guide 1.86 on a case-by-case basis. By having clearly defined procedures for clearing materials, facilities will be more certain of the options open to them at decommissioning. At the same time, NRC will have procedures in place that address how material can be released.

- Other Considerations - Public confidence in NRC likely will be affected by this action, regardless of which one of the alternatives NRC adopts. Early public comment indicated that the public is concerned about the safety issues related to radioactive materials in consumer products. NRC will need to consider public confidence as it proceeds in the decision making process.

Table K-14 Net Incremental Benefit (Cost) Associated with Attributes by Alternative and Dose Level (2003$)

Alternative	Dose Option	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations	Total
No Action	NA	$0	$0	$0	$0	$0	$0	$0	$0	$0
Unrestricted Release Material Specific Limits	0.03	$1,174,216	($13,514,350)	($219,720)	($1,376,897,891)	($3,395)	$0	($451,377)	($12,878,667)	($1,402,791,183)
	0.1	$960,746	$0	($219,720)	($226,113,873)	($3,395)	$0	($451,377)	($618,308)	($226,445,926)
	1	($787,022)	$0	($219,720)	$293,675,372	($3,395)	$0	($451,377)	$2,125,995	$294,339,854
	10	($8,167,397)	$0	($219,720)	$329,263,365	($3,395)	$0	($451,377)	$2,801,081	$323,222,558
Unrestricted Release Material Independent Limits	0.03	$1,233,593	($13,514,350)	($219,720)	($1,378,418,237)	($3,395)	$0	($451,377)	($12,902,162)	($1,404,275,647)
	0.1	$1,205,052	$0	($219,720)	($291,974,108)	($3,395)	$0	($451,377)	($2,278,274)	($293,721,822)
	1	$713,415	$0	($219,720)	$246,021,542	($3,395)	$0	($451,377)	$987,754	$247,048,219
	10	($1,851,424)	$0	($219,720)	$306,935,439	($3,395)	$0	($451,377)	$2,352,109	$306,761,633
	RS-G-1.7	$186,142	$0	($219,720)	$246,021,542	($3,395)	$0	($451,377)	$987,754	$246,520,945
EPA/State-Regulated Disposal (Landfill)	0.03	$1,240,634	($13,514,350)	($219,720)	($1,376,897,891)	($3,395)	$0	($451,377)	($12,878,667)	($1,402,724,765)
	0.1	$1,240,530	$0	($219,720)	($281,093,000)	($3,395)	$0	($451,377)	($2,259,193)	($282,786,154)
	1	$1,239,881	$0	($219,720)	$181,462,308	($3,395)	$0	($451,377)	($1,033,674)	$180,994,024
	10	$1,237,267	$0	($219,720)	$193,637,557	($3,395)	$0	($451,377)	($922,985)	$193,277,348
	RS-G-1.7	$1,239,074	$0	($219,720)	$181,462,308	($3,395)	$0	($451,377)	($1,033,674)	$180,993,217
LLW Disposal/ Prohibition	NA	$1,240,689	($13,514,350)	$0	($1,378,439,254)	($3,395)	$0	($451,377)	($12,902,486)	($1,404,070,173)
Limited Dispositions	RS-G-1.7	$1,227,219	$0	($219,720)	$258,149,485	($3,395)	$0	($451,377)	($1,500,316)	$257,201,896

Table K-15 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Specific Limits - 0.03 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$14,362	$0	($18,848)	($73,792,689)	($3,395)	$0	($451,377)	($1,348,379)
2004	$20,530	$0	($11,309)	($40,532,801)	$0	$0	$0	($745,860)
2005	$19,384	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2006	$18,192	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2007	$17,212	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2008	$16,348	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2009	$15,600	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2010	$14,928	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2011	$14,352	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2012	$13,854	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2013	$13,392	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2014	$13,236	$0	($3,770)	($3,662,425)	$0	$0	$0	($57,614)
2015	$24,478	$0	($18,848)	($110,212,760)	$0	$0	$0	($868,326)
2016	$43,140	($3,000,000)	($26,387)	($166,548,785)	$0	$0	$0	($1,342,084)
2017	$54,720	$0	($18,848)	($113,032,649)	$0	$0	$0	($952,889)
2018	$75,220	($3,000,000)	($33,926)	($221,381,781)	$0	$0	$0	($1,765,758)
2019	$116,760	($3,000,000)	($60,314)	($370,432,493)	$0	$0	$0	($3,044,680)
2020	$165,600	($6,000,000)	($67,853)	($476,413,898)	$0	$0	$0	($3,882,032)
2021	$185,960	($3,000,000)	($41,466)	($316,584,440)	$0	$0	$0	($2,556,884)
2022	$195,360	($3,000,000)	($30,157)	($203,730,363)	$0	$0	$0	($1,775,903)
2023	$208,580	($3,000,000)	($37,696)	($230,909,345)	$0	$0	$0	($2,016,965)
2024	$204,720	$0	($22,618)	($111,286,568)	$0	$0	$0	($1,047,434)
2025	$189,280	$0	($15,078)	($53,367,953)	$0	$0	$0	($506,990)
2026	$181,220	$0	($18,848)	($81,613,878)	$0	$0	$0	($769,510)
2027	$191,200	($3,000,000)	($30,157)	($168,001,997)	$0	$0	$0	($1,572,635)
2028	$208,280	($3,000,000)	($37,696)	($253,776,649)	$0	$0	$0	($2,204,502)
2029	$221,580	($3,000,000)	($37,696)	($301,038,895)	$0	$0	$0	($2,457,628)
2030	$253,960	($6,000,000)	($52,774)	($423,645,204)	$0	$0	$0	($3,506,365)
2031	$290,020	($6,000,000)	($56,544)	($454,470,162)	$0	$0	$0	($3,841,311)
2032	$320,440	($6,000,000)	($56,544)	($465,170,953)	$0	$0	$0	($3,869,190)
2033	$343,160	($6,000,000)	($52,774)	($409,017,991)	$0	$0	$0	($3,494,670)
2034	$327,820	($3,000,000)	($22,618)	($146,593,443)	$0	$0	$0	($1,375,334)
2035	$303,260	$0	($11,309)	($95,796,042)	$0	$0	$0	($811,410)
2036	$278,580	$0	($11,309)	($94,261,732)	$0	$0	$0	($797,075)
2037	$248,200	$0	($3,770)	($24,769,000)	$0	$0	$0	($234,464)
2038	$219,860	$0	($3,770)	($5,746,314)	$0	$0	$0	($45,140)
2039	$204,620	$0	($15,078)	($70,650,437)	$0	$0	$0	($651,218)
2040	$208,460	($3,000,000)	($26,387)	($160,753,698)	$0	$0	$0	($1,434,603)
2041	$202,760	$0	($18,848)	($119,968,404)	$0	$0	$0	($1,053,780)
2042	$185,840	$0	($7,539)	($44,134,092)	$0	$0	$0	($413,940)
2043	$166,880	$0	($3,770)	($19,968,177)	$0	$0	$0	($187,148)
2044	$149,680	$0	($3,770)	($35,919,945)	$0	$0	$0	($265,184)
2045	$134,540	$0	($3,770)	($35,919,945)	$0	$0	$0	($265,184)
2046	$117,860	$0	$0	$0	$0	$0	$0	$0
2047	$107,620	$0	($3,770)	($22,049,890)	$0	$0	$0	($207,017)
2048	$103,040	$0	($7,539)	($44,154,494)	$0	$0	$0	($414,420)
2049	$97,780	$0	($7,539)	($51,774,275)	$0	$0	$0	($426,393)

Table K-16 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Specific Limits - 0.1 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$11,560	$0	($18,848)	($11,184,825)	($3,395)	$0	($451,377)	($19,826)
2004	$16,520	$0	($11,309)	($6,068,223)	$0	$0	$0	($11,345)
2005	$15,660	$0	$0	$341,960	$0	$0	$0	($3,104)
2006	$14,720	$0	$0	$341,960	$0	$0	$0	($3,104)
2007	$13,960	$0	$0	$341,960	$0	$0	$0	($3,104)
2008	$13,300	$0	$0	$341,960	$0	$0	$0	($3,104)
2009	$12,720	$0	$0	$341,960	$0	$0	$0	($3,104)
2010	$12,180	$0	$0	$341,960	$0	$0	$0	($2,467)
2011	$11,740	$0	$0	$341,960	$0	$0	$0	($2,467)
2012	$11,360	$0	$0	$341,960	$0	$0	$0	($2,467)
2013	$11,000	$0	$0	$341,960	$0	$0	$0	($2,467)
2014	$10,880	$0	($3,770)	($112,632)	$0	$0	$0	($2,468)
2015	$20,220	$0	($18,848)	($19,148,387)	$0	$0	$0	($24,671)
2016	$35,700	$0	($26,387)	($28,569,167)	$0	$0	$0	($48,994)
2017	$45,240	$0	($18,848)	($18,794,514)	$0	$0	$0	($44,321)
2018	$62,200	$0	($33,926)	($38,362,185)	$0	$0	$0	($62,318)
2019	$96,200	$0	($60,314)	($62,893,590)	$0	$0	$0	($135,006)
2020	$136,200	$0	($67,853)	($82,557,664)	$0	$0	$0	($197,561)
2021	$153,200	$0	($41,466)	($55,393,885)	$0	$0	$0	($125,416)
2022	$160,600	$0	($30,157)	($32,965,874)	$0	$0	$0	($110,930)
2023	$171,200	$0	($37,696)	($37,258,254)	$0	$0	$0	($126,882)
2024	$168,000	$0	($22,618)	($16,869,877)	$0	$0	$0	($81,219)
2025	$155,200	$0	($15,078)	($7,943,692)	$0	$0	$0	($38,385)
2026	$148,200	$0	($18,848)	($12,629,780)	$0	$0	$0	($61,374)
2027	$156,200	$0	($30,157)	($26,127,824)	$0	$0	$0	($126,524)
2028	$170,000	$0	($37,696)	($41,668,898)	$0	$0	$0	($142,292)
2029	$180,800	$0	($37,696)	($51,534,325)	$0	$0	$0	($121,991)
2030	$207,600	$0	($52,774)	($72,180,246)	$0	$0	$0	($188,050)
2031	$237,000	$0	($56,544)	($76,405,003)	$0	$0	$0	($227,927)
2032	$262,000	$0	($56,544)	($78,791,904)	$0	$0	$0	($214,203)
2033	$280,400	$0	($52,774)	($68,172,897)	$0	$0	$0	($216,099)
2034	$267,600	$0	($22,618)	($23,032,927)	$0	$0	$0	($115,351)
2035	$247,800	$0	($11,309)	($16,117,932)	$0	$0	$0	($49,027)
2036	$227,400	$0	($11,309)	($15,806,209)	$0	$0	$0	($47,115)
2037	$202,400	$0	($3,770)	($3,839,024)	$0	$0	$0	($19,525)
2038	$179,600	$0	($3,770)	($1,006,356)	$0	$0	$0	($1,323)
2039	$166,800	$0	($15,078)	($11,101,342)	$0	$0	$0	($50,654)
2040	$170,000	$0	($26,387)	($25,732,687)	$0	$0	$0	($101,016)
2041	$165,200	$0	($18,848)	($19,426,231)	$0	$0	$0	($70,901)
2042	$151,400	$0	($7,539)	($6,812,504)	$0	$0	$0	($34,285)
2043	$136,000	$0	($3,770)	($3,035,259)	$0	$0	$0	($14,935)
2044	$122,000	$0	($3,770)	($6,546,047)	$0	$0	$0	($6,713)
2045	$109,800	$0	($3,770)	($6,546,047)	$0	$0	$0	($6,713)
2046	$96,000	$0	$0	$0	$0	$0	$0	$0
2047	$87,600	$0	($3,770)	($3,438,472)	$0	$0	$0	($17,603)
2048	$83,800	$0	($7,539)	($6,904,404)	$0	$0	$0	($35,381)
2049	$79,600	$0	($7,539)	($8,857,740)	$0	$0	$0	($23,068)

Table K-17 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Specific Limits - 1 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	($10,560)	$0	($18,848)	$16,743,605	($3,395)	$0	($451,377)	$237,554
2004	($15,000)	$0	($11,309)	$9,249,725	$0	$0	$0	$129,903
2005	($14,200)	$0	$0	$732,608	$0	$0	$0	$5,136
2006	($13,640)	$0	$0	$732,608	$0	$0	$0	$5,136
2007	($13,060)	$0	$0	$732,608	$0	$0	$0	$5,136
2008	($12,760)	$0	$0	$732,608	$0	$0	$0	$5,136
2009	($12,340)	$0	$0	$732,608	$0	$0	$0	$5,136
2010	($12,040)	$0	$0	$732,608	$0	$0	$0	$2,859
2011	($11,640)	$0	$0	$732,608	$0	$0	$0	$2,859
2012	($11,360)	$0	$0	$732,608	$0	$0	$0	$2,859
2013	($11,240)	$0	$0	$732,608	$0	$0	$0	$2,859
2014	($11,200)	$0	($3,770)	$1,214,413	$0	$0	$0	$6,848
2015	($17,800)	$0	($18,848)	$22,359,758	$0	$0	$0	$149,095
2016	($28,800)	$0	($26,387)	$34,175,733	$0	$0	$0	$227,935
2017	($36,800)	$0	($18,848)	$23,776,945	$0	$0	$0	$156,869
2018	($50,000)	$0	($33,926)	$45,149,318	$0	$0	$0	$301,877
2019	($76,800)	$0	($60,314)	$76,800,837	$0	$0	$0	$512,193
2020	($105,400)	$0	($67,853)	$97,322,953	$0	$0	$0	$644,834
2021	($116,000)	$0	($41,466)	$64,387,344	$0	$0	$0	$426,412
2022	($124,000)	$0	($30,157)	$44,310,196	$0	$0	$0	$289,831
2023	($134,000)	$0	($37,696)	$50,279,371	$0	$0	$0	$328,589
2024	($132,000)	$0	($22,618)	$25,376,779	$0	$0	$0	$163,806
2025	($124,200)	$0	($15,078)	$12,220,040	$0	$0	$0	$78,488
2026	($120,600)	$0	($18,848)	$18,356,316	$0	$0	$0	$119,223
2027	($130,000)	$0	($30,157)	$37,756,101	$0	$0	$0	$246,062
2028	($138,000)	$0	($37,696)	$54,101,628	$0	$0	$0	$354,459
2029	($148,000)	$0	($37,696)	$61,800,707	$0	$0	$0	$408,465
2030	($166,000)	$0	($52,774)	$87,201,747	$0	$0	$0	$577,084
2031	($190,000)	$0	($56,544)	$94,607,147	$0	$0	$0	$622,616
2032	($208,000)	$0	($56,544)	$96,936,105	$0	$0	$0	$638,232
2033	($224,000)	$0	($52,774)	$86,923,790	$0	$0	$0	$571,652
2034	($218,000)	$0	($22,618)	$32,928,364	$0	$0	$0	$214,516
2035	($200,000)	$0	($11,309)	$19,796,783	$0	$0	$0	$130,304
2036	($186,000)	$0	($11,309)	$19,555,954	$0	$0	$0	$128,407
2037	($166,000)	$0	($3,770)	$5,595,958	$0	$0	$0	$36,004
2038	($144,000)	$0	($3,770)	$1,148,336	$0	$0	$0	$7,604
2039	($138,000)	$0	($15,078)	$15,594,693	$0	$0	$0	$101,832
2040	($138,000)	$0	($26,387)	$34,848,628	$0	$0	$0	$228,383
2041	($134,000)	$0	($18,848)	$25,840,903	$0	$0	$0	$169,283
2042	($125,800)	$0	($7,539)	$10,001,286	$0	$0	$0	$65,004
2043	($111,800)	$0	($3,770)	$4,533,931	$0	$0	$0	$29,785
2044	($100,000)	$0	($3,770)	$6,893,933	$0	$0	$0	$46,325
2045	($90,000)	$0	($3,770)	$6,893,933	$0	$0	$0	$46,325
2046	($79,600)	$0	$0	$0	$0	$0	$0	$0
2047	($72,400)	$0	($3,770)	$4,991,783	$0	$0	$0	$31,973
2048	($70,000)	$0	($7,539)	$9,923,992	$0	$0	$0	$63,460
2049	($66,200)	$0	($7,539)	$10,478,626	$0	$0	$0	$68,865

Table K-18 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Specific Limits - 10 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	($105,560)	$0	($18,848)	$18,975,651	($3,395)	$0	($451,377)	$295,470
2004	($155,200)	$0	($11,309)	$10,624,203	$0	$0	$0	$164,154
2005	($156,200)	$0	$0	$1,127,062	$0	$0	$0	$13,061
2006	($157,440)	$0	$0	$1,127,062	$0	$0	$0	$13,061
2007	($158,460)	$0	$0	$1,127,062	$0	$0	$0	$13,061
2008	($159,360)	$0	$0	$1,127,062	$0	$0	$0	$13,061
2009	($160,140)	$0	$0	$1,127,062	$0	$0	$0	$13,061
2010	($160,840)	$0	$0	$1,127,062	$0	$0	$0	$7,646
2011	($161,440)	$0	$0	$1,127,062	$0	$0	$0	$7,646
2012	($161,960)	$0	$0	$1,127,062	$0	$0	$0	$7,646
2013	($162,440)	$0	$0	$1,127,062	$0	$0	$0	$7,646
2014	($164,000)	$0	($3,770)	$1,659,095	$0	$0	$0	$12,429
2015	($238,000)	$0	($18,848)	$24,946,800	$0	$0	$0	$188,170
2016	($352,400)	$0	($26,387)	$38,036,241	$0	$0	$0	$290,582
2017	($420,200)	$0	($18,848)	$26,618,558	$0	$0	$0	$205,058
2018	($550,600)	$0	($33,926)	$50,134,101	$0	$0	$0	$382,867
2019	($810,800)	$0	($60,314)	$85,221,386	$0	$0	$0	$658,094
2020	($1,105,400)	$0	($67,853)	$107,887,663	$0	$0	$0	$836,424
2021	($1,228,000)	$0	($41,466)	$71,376,167	$0	$0	$0	$550,662
2022	($1,290,000)	$0	($30,157)	$49,315,056	$0	$0	$0	$386,193
2023	($1,374,000)	$0	($37,696)	$55,979,397	$0	$0	$0	$439,957
2024	($1,342,000)	$0	($22,618)	$28,445,874	$0	$0	$0	$227,831
2025	($1,246,200)	$0	($15,078)	$13,791,563	$0	$0	$0	$109,745
2026	($1,208,600)	$0	($18,848)	$20,622,590	$0	$0	$0	$165,456
2027	($1,276,000)	$0	($30,157)	$42,196,128	$0	$0	$0	$339,505
2028	($1,374,000)	$0	($37,696)	$60,225,271	$0	$0	$0	$474,312
2029	($1,458,000)	$0	($37,696)	$68,575,749	$0	$0	$0	$531,340
2030	($1,644,000)	$0	($52,774)	$96,815,447	$0	$0	$0	$756,609
2031	($1,854,000)	$0	($56,544)	$105,165,132	$0	$0	$0	$825,706
2032	($2,042,000)	$0	($56,544)	$107,453,319	$0	$0	$0	$837,002
2033	($2,178,000)	$0	($52,774)	$96,443,459	$0	$0	$0	$757,652
2034	($2,114,000)	$0	($22,618)	$36,721,286	$0	$0	$0	$296,432
2035	($1,940,000)	$0	($11,309)	$22,012,568	$0	$0	$0	$172,593
2036	($1,786,000)	$0	($11,309)	$21,746,406	$0	$0	$0	$170,186
2037	($1,596,000)	$0	($3,770)	$6,275,605	$0	$0	$0	$50,322
2038	($1,404,000)	$0	($3,770)	$1,289,270	$0	$0	$0	$9,665
2039	($1,322,000)	$0	($15,078)	$17,414,991	$0	$0	$0	$140,288
2040	($1,340,000)	$0	($26,387)	$38,764,819	$0	$0	$0	$308,980
2041	($1,302,000)	$0	($18,848)	$28,682,859	$0	$0	$0	$226,773
2042	($1,195,800)	$0	($7,539)	$11,123,450	$0	$0	$0	$89,203
2043	($1,071,800)	$0	($3,770)	$5,037,197	$0	$0	$0	$40,533
2044	($960,000)	$0	($3,770)	$7,611,559	$0	$0	$0	$57,429
2045	($862,000)	$0	($3,770)	$7,611,559	$0	$0	$0	$57,429
2046	($755,600)	$0	$0	$0	$0	$0	$0	$0
2047	($688,400)	$0	($3,770)	$5,556,406	$0	$0	$0	$44,270
2048	($655,200)	$0	($7,539)	$11,065,139	$0	$0	$0	$88,317
2049	($618,800)	$0	($7,539)	$11,659,353	$0	$0	$0	$90,704

Table K-19 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Independent - 0.03 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,145	$0	($18,848)	($73,918,704)	($3,395)	$0	($451,377)	($1,351,148)
2004	$21,659	$0	($11,309)	($40,656,978)	$0	$0	$0	($748,588)
2005	$20,457	$0	$0	($1,256,768)	$0	$0	$0	($48,760)
2006	$19,216	$0	$0	($1,256,768)	$0	$0	$0	($48,760)
2007	$18,194	$0	$0	($1,256,768)	$0	$0	$0	($48,760)
2008	$17,293	$0	$0	($1,256,768)	$0	$0	$0	($48,760)
2009	$16,511	$0	$0	($1,256,768)	$0	$0	$0	($48,760)
2010	$15,810	$0	$0	($1,256,768)	$0	$0	$0	($37,086)
2011	$15,209	$0	$0	($1,256,768)	$0	$0	$0	($37,086)
2012	$14,689	$0	$0	($1,256,768)	$0	$0	$0	($37,086)
2013	$14,208	$0	$0	($1,256,768)	$0	$0	$0	($37,086)
2014	$14,046	$0	($3,770)	($3,784,630)	$0	$0	$0	($58,955)
2015	$25,790	$0	($18,848)	($110,334,964)	$0	$0	$0	($869,427)
2016	$45,298	($3,000,000)	($26,387)	($166,670,917)	$0	$0	$0	($1,343,184)
2017	$57,442	$0	($18,848)	($113,151,384)	$0	$0	$0	($953,959)
2018	$78,932	($3,000,000)	($33,926)	($221,498,041)	$0	$0	$0	($1,766,805)
2019	$122,504	($3,000,000)	($60,314)	($370,546,753)	$0	$0	$0	($3,045,709)
2020	$173,658	($6,000,000)	($67,853)	($476,522,308)	$0	$0	$0	($3,882,983)
2021	$194,958	($3,000,000)	($41,466)	($316,683,843)	$0	$0	$0	($2,557,756)
2022	$204,904	($3,000,000)	($30,157)	($203,820,426)	$0	$0	$0	($1,776,693)
2023	$218,834	($3,000,000)	($37,696)	($230,997,130)	$0	$0	$0	($2,017,735)
2024	$214,848	$0	($22,618)	($111,367,514)	$0	$0	$0	($1,048,144)
2025	$198,718	$0	($15,078)	($53,445,682)	$0	$0	$0	($507,669)
2026	$190,354	$0	($18,848)	($81,689,214)	$0	$0	$0	($770,169)
2027	$200,896	($3,000,000)	($30,157)	($168,076,981)	$0	$0	$0	($1,573,291)
2028	$218,814	($3,000,000)	($37,696)	($253,847,702)	$0	$0	$0	($2,205,122)
2029	$232,756	($3,000,000)	($37,696)	($301,105,132)	$0	$0	$0	($2,458,206)
2030	$266,602	($6,000,000)	($52,774)	($423,706,158)	$0	$0	$0	($3,506,898)
2031	$304,404	($6,000,000)	($56,544)	($454,525,519)	$0	$0	$0	($3,841,795)
2032	$336,242	($6,000,000)	($56,544)	($465,214,150)	$0	$0	$0	($3,869,568)
2033	$360,124	($6,000,000)	($52,774)	($409,053,376)	$0	$0	$0	($3,494,979)
2034	$344,194	($3,000,000)	($22,618)	($146,617,220)	$0	$0	$0	($1,375,542)
2035	$318,342	$0	($11,309)	($95,813,031)	$0	$0	$0	($811,558)
2036	$292,474	$0	($11,309)	($94,277,207)	$0	$0	$0	($797,210)
2037	$260,634	$0	($3,770)	($24,781,927)	$0	$0	$0	($234,577)
2038	$230,794	$0	($3,770)	($5,758,047)	$0	$0	$0	($45,242)
2039	$214,872	$0	($15,078)	($70,662,169)	$0	$0	$0	($651,321)
2040	$218,862	($3,000,000)	($26,387)	($160,765,263)	$0	$0	$0	($1,434,704)
2041	$212,890	$0	($18,848)	($119,976,328)	$0	$0	$0	($1,053,850)
2042	$195,172	$0	($7,539)	($44,137,577)	$0	$0	$0	($413,970)
2043	$175,272	$0	($3,770)	($19,970,346)	$0	$0	$0	($187,167)
2044	$157,168	$0	($3,770)	($35,920,962)	$0	$0	$0	($265,193)
2045	$141,252	$0	($3,770)	($35,920,962)	$0	$0	$0	($265,193)
2046	$123,740	$0	$0	$0	$0	$0	$0	$0
2047	$112,996	$0	($3,770)	($22,051,117)	$0	$0	$0	($207,028)
2048	$108,222	$0	($7,539)	($44,156,969)	$0	$0	$0	($414,442)
2049	$102,658	$0	($7,539)	($51,776,375)	$0	$0	$0	($426,412)

Table K-20 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Independent - 0.1 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$14,754	$0	($18,848)	($15,859,375)	($3,395)	$0	($451,377)	($159,941)
2004	$21,092	$0	($11,309)	($8,699,774)	$0	$0	$0	($88,736)
2005	$19,916	$0	$0	($109,642)	$0	$0	$0	($13,569)
2006	$18,694	$0	$0	($109,642)	$0	$0	$0	($13,569)
2007	$17,690	$0	$0	($109,642)	$0	$0	$0	($13,569)
2008	$16,804	$0	$0	($109,642)	$0	$0	$0	($13,569)
2009	$16,038	$0	$0	($109,642)	$0	$0	$0	($13,569)
2010	$15,348	$0	$0	($109,642)	$0	$0	$0	($9,505)
2011	$14,758	$0	$0	($109,642)	$0	$0	$0	($9,505)
2012	$14,248	$0	$0	($109,642)	$0	$0	$0	($9,505)
2013	$13,774	$0	$0	($109,642)	$0	$0	$0	($9,505)
2014	$13,616	$0	($3,770)	($631,696)	$0	$0	$0	($11,129)
2015	$25,124	$0	($18,848)	($23,006,590)	$0	$0	$0	($113,097)
2016	$44,226	$0	($26,387)	($35,019,321)	$0	$0	$0	($199,643)
2017	$56,104	$0	($18,848)	($23,964,935)	$0	$0	$0	($164,367)
2018	$77,140	$0	($33,926)	($46,636,165)	$0	$0	$0	($256,952)
2019	$119,700	$0	($60,314)	($78,452,965)	$0	$0	$0	($504,598)
2020	$169,740	$0	($67,853)	($101,477,497)	$0	$0	$0	($678,976)
2021	$190,600	$0	($41,466)	($67,533,324)	$0	$0	$0	($433,171)
2022	$200,300	$0	($30,157)	($43,072,339)	$0	$0	$0	($366,869)
2023	$213,880	$0	($37,696)	($48,789,185)	$0	$0	$0	($419,463)
2024	$209,940	$0	($22,618)	($23,703,776)	$0	$0	$0	($253,521)
2025	$194,120	$0	($15,078)	($11,274,456)	$0	$0	$0	($120,761)
2026	$185,900	$0	($18,848)	($17,705,374)	$0	$0	$0	($188,539)
2027	$196,160	$0	($30,157)	($36,418,806)	$0	$0	$0	($387,304)
2028	$213,660	$0	($37,696)	($54,228,478)	$0	$0	$0	($461,336)
2029	$227,300	$0	($37,696)	($63,730,261)	$0	$0	$0	($431,902)
2030	$260,440	$0	($52,774)	($90,168,567)	$0	$0	$0	($646,417)
2031	$297,360	$0	($56,544)	($97,011,487)	$0	$0	$0	($753,557)
2032	$328,520	$0	($56,544)	($98,759,123)	$0	$0	$0	($723,923)
2033	$351,860	$0	($52,774)	($87,405,235)	$0	$0	$0	($707,295)
2034	$336,220	$0	($22,618)	($32,064,015)	$0	$0	$0	($345,735)
2035	$311,020	$0	($11,309)	($20,466,917)	$0	$0	$0	($159,760)
2036	$285,720	$0	($11,309)	($20,084,861)	$0	$0	$0	($156,104)
2037	$254,580	$0	($3,770)	($5,401,096)	$0	$0	$0	($59,040)
2038	$225,460	$0	($3,770)	($1,199,716)	$0	$0	$0	($5,831)
2039	$209,860	$0	($15,078)	($15,263,308)	$0	$0	$0	($156,797)
2040	$213,780	$0	($26,387)	($34,387,521)	$0	$0	$0	($322,227)
2041	$207,920	$0	($18,848)	($25,570,643)	$0	$0	$0	($227,958)
2042	$190,600	$0	($7,539)	($9,514,335)	$0	$0	$0	($103,346)
2043	$171,160	$0	($3,770)	($4,260,362)	$0	$0	$0	($46,228)
2044	$153,500	$0	($3,770)	($7,499,693)	$0	$0	$0	($31,096)
2045	$137,960	$0	($3,770)	($7,499,693)	$0	$0	$0	($31,096)
2046	$120,840	$0	$0	$0	$0	$0	$0	$0
2047	$110,340	$0	($3,770)	($4,793,703)	$0	$0	$0	($52,264)
2048	$105,660	$0	($7,539)	($9,610,936)	$0	$0	$0	($104,602)
2049	$100,260	$0	($7,539)	($11,006,085)	$0	$0	$0	($78,007)

Table K-21 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Independent - 1 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$8,340	$0	($18,848)	$13,418,392	($3,395)	$0	($451,377)	$142,936
2004	$12,020	$0	($11,309)	$7,255,578	$0	$0	$0	$75,691
2005	$11,480	$0	$0	$168,496	$0	$0	$0	($5,669)
2006	$10,820	$0	$0	$168,496	$0	$0	$0	($5,669)
2007	$10,300	$0	$0	$168,496	$0	$0	$0	($5,669)
2008	$9,860	$0	$0	$168,496	$0	$0	$0	($5,669)
2009	$9,460	$0	$0	$168,496	$0	$0	$0	($5,669)
2010	$9,100	$0	$0	$168,496	$0	$0	$0	($3,387)
2011	$8,800	$0	$0	$168,496	$0	$0	$0	($3,387)
2012	$8,540	$0	$0	$168,496	$0	$0	$0	($3,387)
2013	$8,300	$0	$0	$168,496	$0	$0	$0	($3,387)
2014	$8,240	$0	($3,770)	$600,554	$0	$0	$0	($581)
2015	$15,460	$0	($18,848)	$19,380,272	$0	$0	$0	$86,144
2016	$27,260	$0	($26,387)	$29,461,816	$0	$0	$0	$123,749
2017	$34,200	$0	($18,848)	$20,039,265	$0	$0	$0	$75,669
2018	$47,000	$0	($33,926)	$39,178,995	$0	$0	$0	$167,442
2019	$72,200	$0	($60,314)	$65,971,458	$0	$0	$0	$262,120
2020	$102,800	$0	($67,853)	$84,066,938	$0	$0	$0	$315,696
2021	$115,800	$0	($41,466)	$55,758,237	$0	$0	$0	$214,214
2022	$120,800	$0	($30,157)	$37,375,753	$0	$0	$0	$120,028
2023	$128,200	$0	($37,696)	$42,389,042	$0	$0	$0	$134,332
2024	$125,400	$0	($22,618)	$20,717,459	$0	$0	$0	$51,169
2025	$115,200	$0	($15,078)	$9,852,682	$0	$0	$0	$23,970
2026	$109,600	$0	($18,848)	$14,885,463	$0	$0	$0	$36,542
2027	$114,800	$0	($30,157)	$30,890,787	$0	$0	$0	$77,247
2028	$125,200	$0	($37,696)	$45,583,568	$0	$0	$0	$143,438
2029	$133,600	$0	($37,696)	$53,336,462	$0	$0	$0	$198,469
2030	$153,800	$0	($52,774)	$74,869,268	$0	$0	$0	$268,667
2031	$175,400	$0	($56,544)	$80,592,498	$0	$0	$0	$271,138
2032	$194,200	$0	($56,544)	$83,268,822	$0	$0	$0	$294,697
2033	$207,800	$0	($52,774)	$73,956,030	$0	$0	$0	$245,300
2034	$196,800	$0	($22,618)	$26,997,098	$0	$0	$0	$65,784
2035	$182,600	$0	($11,309)	$16,820,600	$0	$0	$0	$56,034
2036	$167,400	$0	($11,309)	$16,642,459	$0	$0	$0	$55,620
2037	$148,800	$0	($3,770)	$4,554,848	$0	$0	$0	$10,519
2038	$132,400	$0	($3,770)	$983,419	$0	$0	$0	$4,256
2039	$122,400	$0	($15,078)	$12,851,053	$0	$0	$0	$33,086
2040	$124,800	$0	($26,387)	$29,130,525	$0	$0	$0	$84,190
2041	$121,400	$0	($18,848)	$21,756,129	$0	$0	$0	$66,255
2042	$110,600	$0	($7,539)	$8,231,138	$0	$0	$0	$20,360
2043	$99,200	$0	($3,770)	$3,732,438	$0	$0	$0	$9,614
2044	$89,200	$0	($3,770)	$6,187,055	$0	$0	$0	$28,472
2045	$80,400	$0	($3,770)	$6,187,055	$0	$0	$0	$28,472
2046	$70,400	$0	$0	$0	$0	$0	$0	$0
2047	$64,200	$0	($3,770)	$4,107,966	$0	$0	$0	$9,645
2048	$61,200	$0	($7,539)	$8,153,607	$0	$0	$0	$18,737
2049	$58,200	$0	($7,539)	$9,008,663	$0	$0	$0	$31,735

Table K-22 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Independent - 10 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	($24,560)	$0	($18,848)	$17,313,589	($3,395)	$0	($451,377)	$254,977
2004	($35,000)	$0	($11,309)	$9,381,712	$0	$0	$0	$136,282
2005	($33,800)	$0	$0	$343,833	$0	$0	$0	($999)
2006	($32,840)	$0	$0	$343,833	$0	$0	$0	($999)
2007	($31,860)	$0	$0	$343,833	$0	$0	$0	($999)
2008	($31,160)	$0	$0	$343,833	$0	$0	$0	($999)
2009	($30,340)	$0	$0	$343,833	$0	$0	$0	($999)
2010	($29,840)	$0	$0	$343,833	$0	$0	$0	$42
2011	($29,240)	$0	$0	$343,833	$0	$0	$0	$42
2012	($28,760)	$0	$0	$343,833	$0	$0	$0	$42
2013	($28,440)	$0	$0	$343,833	$0	$0	$0	$42
2014	($28,400)	$0	($3,770)	$860,222	$0	$0	$0	$4,459
2015	($44,800)	$0	($18,848)	$23,411,217	$0	$0	$0	$163,770
2016	($71,200)	$0	($26,387)	$35,976,200	$0	$0	$0	$253,707
2017	($87,400)	$0	($18,848)	$24,891,088	$0	$0	$0	$175,747
2018	($117,200)	$0	($33,926)	$47,724,349	$0	$0	$0	$337,092
2019	($180,800)	$0	($60,314)	$81,344,324	$0	$0	$0	$577,239
2020	($249,400)	$0	($67,853)	$103,249,196	$0	$0	$0	$730,426
2021	($278,000)	$0	($41,466)	$68,184,587	$0	$0	$0	$480,447
2022	($294,000)	$0	($30,157)	$46,701,157	$0	$0	$0	$329,620
2023	($314,000)	$0	($37,696)	$53,072,560	$0	$0	$0	$375,694
2024	($310,000)	$0	($22,618)	$26,602,875	$0	$0	$0	$189,853
2025	($288,200)	$0	($15,078)	$12,681,057	$0	$0	$0	$90,074
2026	($280,600)	$0	($18,848)	$19,181,885	$0	$0	$0	$137,149
2027	($300,000)	$0	($30,157)	$39,744,030	$0	$0	$0	$285,504
2028	($326,000)	$0	($37,696)	$57,265,437	$0	$0	$0	$407,005
2029	($346,000)	$0	($37,696)	$65,602,724	$0	$0	$0	$463,177
2030	($388,000)	$0	($52,774)	$92,688,108	$0	$0	$0	$658,608
2031	($442,000)	$0	($56,544)	$100,544,873	$0	$0	$0	$714,586
2032	($486,000)	$0	($56,544)	$102,944,105	$0	$0	$0	$727,365
2033	($522,000)	$0	($52,774)	$92,221,838	$0	$0	$0	$654,454
2034	($506,000)	$0	($22,618)	$34,777,896	$0	$0	$0	$249,735
2035	($462,000)	$0	($11,309)	$20,992,713	$0	$0	$0	$148,582
2036	($428,000)	$0	($11,309)	$20,751,891	$0	$0	$0	$146,653
2037	($384,000)	$0	($3,770)	$5,881,302	$0	$0	$0	$41,730
2038	($336,000)	$0	($3,770)	$1,180,040	$0	$0	$0	$8,174
2039	($318,000)	$0	($15,078)	$16,499,508	$0	$0	$0	$118,350
2040	($322,000)	$0	($26,387)	$36,925,771	$0	$0	$0	$263,602
2041	($314,000)	$0	($18,848)	$27,384,292	$0	$0	$0	$194,707
2042	($289,800)	$0	($7,539)	$10,569,439	$0	$0	$0	$75,535
2043	($259,800)	$0	($3,770)	$4,779,947	$0	$0	$0	$34,248
2044	($232,000)	$0	($3,770)	$7,385,450	$0	$0	$0	$51,809
2045	($208,000)	$0	($3,770)	$7,385,450	$0	$0	$0	$51,809
2046	($181,600)	$0	$0	$0	$0	$0	$0	$0
2047	($166,400)	$0	($3,770)	$5,274,950	$0	$0	$0	$37,265
2048	($159,200)	$0	($7,539)	$10,498,179	$0	$0	$0	$74,207
2049	($148,800)	$0	($7,539)	$11,189,626	$0	$0	$0	$79,022

Table K-23 Net Incremental Benefit (Cost) Associated with Attributes for Unrestricted Release - Material Independent - RS-G-1.7 ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$1,440	$0	($18,848)	$13,418,392	($3,395)	$0	($451,377)	$142,936
2004	$2,240	$0	($11,309)	$7,255,578	$0	$0	$0	$75,691
2005	$2,360	$0	$0	$168,496	$0	$0	$0	($5,669)
2006	$2,280	$0	$0	$168,496	$0	$0	$0	($5,669)
2007	$2,260	$0	$0	$168,496	$0	$0	$0	($5,669)
2008	$2,280	$0	$0	$168,496	$0	$0	$0	($5,669)
2009	$2,260	$0	$0	$168,496	$0	$0	$0	($5,669)
2010	$2,240	$0	$0	$168,496	$0	$0	$0	($3,387)
2011	$2,240	$0	$0	$168,496	$0	$0	$0	($3,387)
2012	$2,240	$0	$0	$168,496	$0	$0	$0	($3,387)
2013	$2,240	$0	$0	$168,496	$0	$0	$0	($3,387)
2014	$2,280	$0	($3,770)	$600,554	$0	$0	$0	($581)
2015	$4,920	$0	($18,848)	$19,380,272	$0	$0	$0	$86,144
2016	$8,920	$0	($26,387)	$29,461,816	$0	$0	$0	$123,749
2017	$10,600	$0	($18,848)	$20,039,265	$0	$0	$0	$75,669
2018	$14,600	$0	($33,926)	$39,178,995	$0	$0	$0	$167,442
2019	$21,200	$0	($60,314)	$65,971,458	$0	$0	$0	$262,120
2020	$31,000	$0	($67,853)	$84,066,938	$0	$0	$0	$315,696
2021	$35,600	$0	($41,466)	$55,758,237	$0	$0	$0	$214,214
2022	$35,600	$0	($30,157)	$37,375,753	$0	$0	$0	$120,028
2023	$36,400	$0	($37,696)	$42,389,042	$0	$0	$0	$134,332
2024	$34,800	$0	($22,618)	$20,717,459	$0	$0	$0	$51,169
2025	$30,600	$0	($15,078)	$9,852,682	$0	$0	$0	$23,970
2026	$27,800	$0	($18,848)	$14,885,463	$0	$0	$0	$36,542
2027	$27,600	$0	($30,157)	$30,890,787	$0	$0	$0	$77,247
2028	$30,400	$0	($37,696)	$45,583,568	$0	$0	$0	$143,438
2029	$33,200	$0	($37,696)	$53,336,462	$0	$0	$0	$198,469
2030	$39,600	$0	($52,774)	$74,869,268	$0	$0	$0	$268,667
2031	$44,800	$0	($56,544)	$80,592,498	$0	$0	$0	$271,138
2032	$50,400	$0	($56,544)	$83,268,822	$0	$0	$0	$294,697
2033	$53,600	$0	($52,774)	$73,956,030	$0	$0	$0	$245,300
2034	$47,600	$0	($22,618)	$26,997,098	$0	$0	$0	$65,784
2035	$45,200	$0	($11,309)	$16,820,600	$0	$0	$0	$56,034
2036	$40,800	$0	($11,309)	$16,642,459	$0	$0	$0	$55,620
2037	$35,600	$0	($3,770)	$4,554,848	$0	$0	$0	$10,519
2038	$32,800	$0	($3,770)	$983,419	$0	$0	$0	$4,256
2039	$28,800	$0	($15,078)	$12,851,053	$0	$0	$0	$33,086
2040	$29,600	$0	($26,387)	$29,130,525	$0	$0	$0	$84,190
2041	$28,800	$0	($18,848)	$21,756,129	$0	$0	$0	$66,255
2042	$25,000	$0	($7,539)	$8,231,138	$0	$0	$0	$20,360
2043	$22,200	$0	($3,770)	$3,732,438	$0	$0	$0	$9,614
2044	$20,400	$0	($3,770)	$6,187,055	$0	$0	$0	$28,472
2045	$18,800	$0	($3,770)	$6,187,055	$0	$0	$0	$28,472
2046	$16,400	$0	$0	$0	$0	$0	$0	$0
2047	$14,800	$0	($3,770)	$4,107,966	$0	$0	$0	$9,645
2048	$13,600	$0	($7,539)	$8,153,607	$0	$0	$0	$18,737
2049	$13,200	$0	($7,539)	$9,008,663	$0	$0	$0	$31,735

Table K-24 Net Incremental Benefit (Cost) Associated with Attributes for EPA/State-Regulated Disposal (Landfill) - 0.03 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,236	$0	($18,848)	($73,792,689)	($3,395)	$0	($451,377)	($1,348,379)
2004	$21,798	$0	($11,309)	($40,532,801)	$0	$0	$0	($745,860)
2005	$20,600	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2006	$19,360	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2007	$18,340	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2008	$17,440	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2009	$16,660	$0	$0	($1,134,637)	$0	$0	$0	($46,077)
2010	$15,960	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2011	$15,360	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2012	$14,840	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2013	$14,360	$0	$0	($1,134,637)	$0	$0	$0	($35,746)
2014	$14,200	$0	($3,770)	($3,662,425)	$0	$0	$0	($57,614)
2015	$25,997	$0	($18,848)	($110,212,760)	$0	$0	$0	($868,326)
2016	$45,595	($3,000,000)	($26,387)	($166,548,785)	$0	$0	$0	($1,342,084)
2017	$57,796	$0	($18,848)	($113,032,649)	$0	$0	$0	($952,889)
2018	$79,393	($3,000,000)	($33,926)	($221,381,781)	$0	$0	$0	($1,765,758)
2019	$123,187	($3,000,000)	($60,314)	($370,432,493)	$0	$0	$0	($3,044,680)
2020	$174,584	($6,000,000)	($67,853)	($476,413,898)	$0	$0	$0	($3,882,032)
2021	$195,990	($3,000,000)	($41,466)	($316,584,440)	$0	$0	$0	($2,556,884)
2022	$205,991	($3,000,000)	($30,157)	($203,730,363)	$0	$0	$0	($1,775,903)
2023	$219,990	($3,000,000)	($37,696)	($230,909,345)	$0	$0	$0	($2,016,965)
2024	$215,994	$0	($22,618)	($111,286,568)	$0	$0	$0	($1,047,434)
2025	$199,797	$0	($15,078)	($53,367,953)	$0	$0	$0	($506,990)
2026	$191,396	$0	($18,848)	($81,613,878)	$0	$0	$0	($769,510)
2027	$201,992	($3,000,000)	($30,157)	($168,001,997)	$0	$0	$0	($1,572,635)
2028	$219,990	($3,000,000)	($37,696)	($253,776,649)	$0	$0	$0	($2,204,502)
2029	$233,990	($3,000,000)	($37,696)	($301,038,895)	$0	$0	$0	($2,457,628)
2030	$267,985	($6,000,000)	($52,774)	($423,645,204)	$0	$0	$0	($3,506,365)
2031	$305,983	($6,000,000)	($56,544)	($454,470,162)	$0	$0	$0	($3,841,311)
2032	$337,983	($6,000,000)	($56,544)	($465,170,953)	$0	$0	$0	($3,869,190)
2033	$361,984	($6,000,000)	($52,774)	($409,017,991)	$0	$0	$0	($3,494,670)
2034	$345,992	($3,000,000)	($22,618)	($146,593,443)	$0	$0	$0	($1,375,334)
2035	$319,996	$0	($11,309)	($95,796,042)	$0	$0	$0	($811,410)
2036	$293,996	$0	($11,309)	($94,261,732)	$0	$0	$0	($797,075)
2037	$261,999	$0	($3,770)	($24,769,000)	$0	$0	$0	($234,464)
2038	$232,000	$0	($3,770)	($5,746,314)	$0	$0	$0	($45,140)
2039	$215,997	$0	($15,078)	($70,650,437)	$0	$0	$0	($651,218)
2040	$219,993	($3,000,000)	($26,387)	($160,753,698)	$0	$0	$0	($1,434,603)
2041	$213,995	$0	($18,848)	($119,968,404)	$0	$0	$0	($1,053,780)
2042	$196,198	$0	($7,539)	($44,134,092)	$0	$0	$0	($413,940)
2043	$176,199	$0	($3,770)	($19,968,177)	$0	$0	$0	($187,148)
2044	$157,999	$0	($3,770)	($35,919,945)	$0	$0	$0	($265,184)
2045	$141,999	$0	($3,770)	($35,919,945)	$0	$0	$0	($265,184)
2046	$124,400	$0	$0	$0	$0	$0	$0	$0
2047	$113,599	$0	($3,770)	($22,049,890)	$0	$0	$0	($207,017)
2048	$108,798	$0	($7,539)	($44,154,494)	$0	$0	$0	($414,420)
2049	$103,198	$0	($7,539)	($51,774,275)	$0	$0	$0	($426,393)

Table K-25 Net Incremental Benefit (Cost) Associated with Attributes for EPA/State-Regulated Disposal (Landfill) - 0.1 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,229	$0	($18,848)	($14,151,766)	($3,395)	$0	($451,377)	($83,417)
2004	$21,794	$0	($11,309)	($7,800,722)	$0	$0	$0	($53,266)
2005	$20,599	$0	$0	$71,845	$0	$0	$0	($26,236)
2006	$19,359	$0	$0	$71,845	$0	$0	$0	($26,236)
2007	$18,339	$0	$0	$71,845	$0	$0	$0	($26,236)
2008	$17,439	$0	$0	$71,845	$0	$0	$0	($26,236)
2009	$16,659	$0	$0	$71,845	$0	$0	$0	($26,236)
2010	$15,959	$0	$0	$71,845	$0	$0	$0	($25,837)
2011	$15,359	$0	$0	$71,845	$0	$0	$0	($25,837)
2012	$14,839	$0	$0	$71,845	$0	$0	$0	($25,837)
2013	$14,359	$0	$0	$71,845	$0	$0	$0	($25,837)
2014	$14,199	$0	($3,770)	($482,717)	$0	$0	$0	($26,339)
2015	$25,990	$0	($18,848)	($23,629,392)	$0	$0	$0	($103,257)
2016	$45,584	$0	($26,387)	($35,182,862)	$0	$0	$0	($183,249)
2017	$57,788	$0	($18,848)	($23,309,568)	$0	$0	$0	($164,729)
2018	$79,380	$0	($33,926)	($47,062,983)	$0	$0	$0	($226,471)
2019	$123,162	$0	($60,314)	($77,247,910)	$0	$0	$0	($461,968)
2020	$174,554	$0	($67,853)	($100,888,590)	$0	$0	$0	($655,713)
2021	$195,971	$0	($41,466)	($67,627,427)	$0	$0	$0	($416,605)
2022	$205,976	$0	($30,157)	($40,823,039)	$0	$0	$0	($384,018)
2023	$219,972	$0	($37,696)	($46,142,690)	$0	$0	$0	($438,533)
2024	$215,984	$0	($22,618)	($21,165,364)	$0	$0	$0	($282,650)
2025	$199,792	$0	($15,078)	($10,090,514)	$0	$0	$0	($141,690)
2026	$191,388	$0	($18,848)	($15,775,067)	$0	$0	$0	($213,365)
2027	$201,976	$0	($30,157)	($32,462,176)	$0	$0	$0	($426,534)
2028	$219,970	$0	($37,696)	($51,366,526)	$0	$0	$0	($481,596)
2029	$233,970	$0	($37,696)	($63,153,664)	$0	$0	$0	($422,482)
2030	$267,957	$0	($52,774)	($88,410,978)	$0	$0	$0	($640,737)
2031	$305,951	$0	($56,544)	($93,741,172)	$0	$0	$0	($762,763)
2032	$337,952	$0	($56,544)	($96,557,829)	$0	$0	$0	($719,021)
2033	$361,955	$0	($52,774)	($83,659,322)	$0	$0	$0	($720,361)
2034	$345,979	$0	($22,618)	($28,443,165)	$0	$0	$0	($376,032)
2035	$319,989	$0	($11,309)	($19,791,386)	$0	$0	$0	($162,866)
2036	$293,989	$0	($11,309)	($19,417,851)	$0	$0	$0	($158,358)
2037	$261,996	$0	($3,770)	($4,768,605)	$0	$0	$0	($65,480)
2038	$231,999	$0	($3,770)	($1,250,548)	$0	$0	$0	($6,604)
2039	$215,990	$0	($15,078)	($13,748,598)	$0	$0	$0	($169,196)
2040	$219,979	$0	($26,387)	($31,792,317)	$0	$0	$0	($338,949)
2041	$213,985	$0	($18,848)	($23,963,999)	$0	$0	$0	($236,966)
2042	$196,194	$0	($7,539)	($8,453,233)	$0	$0	$0	($112,050)
2043	$176,197	$0	($3,770)	($3,784,511)	$0	$0	$0	($50,218)
2044	$157,997	$0	($3,770)	($7,951,527)	$0	$0	$0	($23,948)
2045	$141,997	$0	($3,770)	($7,951,527)	$0	$0	$0	($23,948)
2046	$124,400	$0	$0	$0	$0	$0	$0	$0
2047	$113,596	$0	($3,770)	($4,249,220)	$0	$0	$0	($56,418)
2048	$108,793	$0	($7,539)	($8,530,045)	$0	$0	$0	($113,019)
2049	$103,195	$0	($7,539)	($10,845,065)	$0	$0	$0	($76,314)

Table K-26 Net Incremental Benefit (Cost) Associated with Attributes for EPA/State-Regulated Disposal (Landfill) - 1 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,188	$0	($18,848)	$10,196,041	($3,395)	$0	($451,377)	$60,330
2004	$21,768	$0	($11,309)	$5,605,693	$0	$0	$0	$27,713
2005	$20,590	$0	$0	$401,448	$0	$0	$0	($20,943)
2006	$19,349	$0	$0	$401,448	$0	$0	$0	($20,943)
2007	$18,329	$0	$0	$401,448	$0	$0	$0	($20,943)
2008	$17,429	$0	$0	$401,448	$0	$0	$0	($20,943)
2009	$16,648	$0	$0	$401,448	$0	$0	$0	($20,943)
2010	$15,948	$0	$0	$401,448	$0	$0	$0	($23,194)
2011	$15,348	$0	$0	$401,448	$0	$0	$0	($23,194)
2012	$14,827	$0	$0	$401,448	$0	$0	$0	($23,194)
2013	$14,347	$0	$0	$401,448	$0	$0	$0	($23,194)
2014	$14,186	$0	($3,770)	$704,185	$0	$0	$0	($21,343)
2015	$25,948	$0	($18,848)	$14,031,442	$0	$0	$0	($13,996)
2016	$45,519	$0	($26,387)	$21,329,573	$0	$0	$0	($50,056)
2017	$57,734	$0	($18,848)	$14,685,257	$0	$0	$0	($74,658)
2018	$79,298	$0	($33,926)	$28,249,757	$0	$0	$0	($48,958)
2019	$123,023	$0	($60,314)	$47,735,563	$0	$0	$0	($168,625)
2020	$174,384	$0	($67,853)	$60,430,917	$0	$0	$0	($285,375)
2021	$195,858	$0	($41,466)	$40,043,951	$0	$0	$0	($167,667)
2022	$205,883	$0	($30,157)	$27,557,562	$0	$0	$0	($226,453)
2023	$219,869	$0	($37,696)	$31,280,028	$0	$0	$0	($260,469)
2024	$215,921	$0	($22,618)	$15,593,721	$0	$0	$0	($197,501)
2025	$199,756	$0	($15,078)	$7,477,842	$0	$0	$0	($101,084)
2026	$191,339	$0	($18,848)	$11,161,184	$0	$0	$0	($150,512)
2027	$201,886	$0	($30,157)	$23,030,455	$0	$0	$0	($297,893)
2028	$219,862	$0	($37,696)	$33,322,099	$0	$0	$0	($288,630)
2029	$233,862	$0	($37,696)	$38,458,390	$0	$0	$0	($192,053)
2030	$267,800	$0	($52,774)	$54,026,834	$0	$0	$0	($317,955)
2031	$305,772	$0	($56,544)	$58,382,683	$0	$0	$0	($418,052)
2032	$337,778	$0	($56,544)	$60,276,909	$0	$0	$0	($361,832)
2033	$361,790	$0	($52,774)	$53,919,204	$0	$0	$0	($404,564)
2034	$345,899	$0	($22,618)	$20,073,968	$0	$0	$0	($262,852)
2035	$319,946	$0	($11,309)	$12,144,670	$0	$0	$0	($90,924)
2036	$293,950	$0	($11,309)	$12,044,746	$0	$0	$0	($87,495)
2037	$261,980	$0	($3,770)	$3,418,544	$0	$0	$0	($46,335)
2038	$231,993	$0	($3,770)	$713,046	$0	$0	$0	($2,047)
2039	$215,950	$0	($15,078)	$9,522,377	$0	$0	$0	($116,076)
2040	$219,904	$0	($26,387)	$21,385,944	$0	$0	$0	($218,816)
2041	$213,932	$0	($18,848)	$15,911,160	$0	$0	$0	($146,779)
2042	$196,168	$0	($7,539)	$6,125,910	$0	$0	$0	($78,454)
2043	$176,184	$0	($3,770)	$2,777,188	$0	$0	$0	($35,324)
2044	$157,985	$0	($3,770)	$4,351,403	$0	$0	$0	$3,632
2045	$141,985	$0	($3,770)	$4,351,403	$0	$0	$0	$3,632
2046	$124,397	$0	$0	$0	$0	$0	$0	$0
2047	$113,585	$0	($3,770)	$3,059,277	$0	$0	$0	($39,412)
2048	$108,769	$0	($7,539)	$6,066,406	$0	$0	$0	($79,193)
2049	$103,172	$0	($7,539)	$6,464,498	$0	$0	$0	($37,645)

Table K-27 Net Incremental Benefit (Cost) Associated with Attributes for EPA/State-Regulated Disposal (Landfill) - 10 mrem/yr ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,032	$0	($18,848)	$10,947,420	($3,395)	$0	($451,377)	$72,939
2004	$21,643	$0	($11,309)	$6,186,051	$0	$0	$0	$37,452
2005	$20,497	$0	$0	$763,279	$0	$0	$0	($14,872)
2006	$19,252	$0	$0	$763,279	$0	$0	$0	($14,872)
2007	$18,227	$0	$0	$763,279	$0	$0	$0	($14,872)
2008	$17,323	$0	$0	$763,279	$0	$0	$0	($14,872)
2009	$16,539	$0	$0	$763,279	$0	$0	$0	($14,872)
2010	$15,835	$0	$0	$763,279	$0	$0	$0	($20,162)
2011	$15,233	$0	$0	$763,279	$0	$0	$0	($20,162)
2012	$14,710	$0	$0	$763,279	$0	$0	$0	($20,162)
2013	$14,228	$0	$0	$763,279	$0	$0	$0	($20,162)
2014	$14,063	$0	($3,770)	$1,082,335	$0	$0	$0	($18,174)
2015	$25,750	$0	($18,848)	$15,056,026	$0	$0	$0	($6,949)
2016	$45,274	$0	($26,387)	$22,662,750	$0	$0	$0	($40,886)
2017	$57,522	$0	($18,848)	$15,670,225	$0	$0	$0	($67,883)
2018	$79,014	$0	($33,926)	$29,901,486	$0	$0	$0	($37,597)
2019	$122,602	$0	($60,314)	$50,164,318	$0	$0	$0	($151,919)
2020	$173,900	$0	($67,853)	$63,497,935	$0	$0	$0	($264,826)
2021	$195,506	$0	($41,466)	$42,171,597	$0	$0	$0	($153,412)
2022	$205,584	$0	($30,157)	$28,946,326	$0	$0	$0	($217,148)
2023	$219,546	$0	($37,696)	$32,822,650	$0	$0	$0	($250,133)
2024	$215,704	$0	($22,618)	$16,411,646	$0	$0	$0	($192,021)
2025	$199,603	$0	($15,078)	$7,982,041	$0	$0	$0	($97,719)
2026	$191,150	$0	($18,848)	$11,792,948	$0	$0	$0	($146,296)
2027	$201,608	$0	($30,157)	$24,093,204	$0	$0	$0	($290,801)
2028	$219,542	$0	($37,696)	$34,919,551	$0	$0	$0	($277,969)
2029	$233,534	$0	($37,696)	$40,410,416	$0	$0	$0	($179,025)
2030	$267,366	$0	($52,774)	$56,618,999	$0	$0	$0	($300,652)
2031	$305,304	$0	($56,544)	$61,112,951	$0	$0	$0	($399,827)
2032	$337,316	$0	($56,544)	$63,061,762	$0	$0	$0	($343,242)
2033	$361,352	$0	($52,774)	$56,283,908	$0	$0	$0	($388,779)
2034	$345,678	$0	($22,618)	$20,877,457	$0	$0	$0	($257,489)
2035	$319,811	$0	($11,309)	$12,728,683	$0	$0	$0	($87,025)
2036	$293,817	$0	($11,309)	$12,620,983	$0	$0	$0	($83,648)
2037	$261,906	$0	($3,770)	$3,582,327	$0	$0	$0	($45,242)
2038	$231,947	$0	($3,770)	$780,242	$0	$0	$0	($1,598)
2039	$215,833	$0	($15,078)	$9,920,166	$0	$0	$0	($113,421)
2040	$219,702	$0	($26,387)	$22,266,518	$0	$0	$0	($212,938)
2041	$213,782	$0	($18,848)	$16,571,919	$0	$0	$0	($142,368)
2042	$196,094	$0	($7,539)	$6,352,559	$0	$0	$0	($76,941)
2043	$176,139	$0	($3,770)	$2,878,845	$0	$0	$0	($34,645)
2044	$157,940	$0	($3,770)	$4,583,305	$0	$0	$0	$5,180
2045	$141,942	$0	($3,770)	$4,583,305	$0	$0	$0	$5,180
2046	$124,379	$0	$0	$0	$0	$0	$0	$0
2047	$113,545	$0	($3,770)	$3,174,033	$0	$0	$0	($38,646)
2048	$108,708	$0	($7,539)	$6,299,100	$0	$0	$0	($77,640)
2049	$103,117	$0	($7,539)	$6,781,883	$0	$0	$0	($35,526)

Table K-28 Net Incremental Benefit (Cost) Associated with Attributes for EPA/State-Regulated Disposal (Landfill) - RS-G-1.7

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,136	$0	($18,848)	$10,196,041	($3,395)	$0	($451,377)	$60,330
2004	$21,737	$0	($11,309)	$5,605,693	$0	$0	$0	$27,713
2005	$20,579	$0	$0	$401,448	$0	$0	$0	($20,943)
2006	$19,339	$0	$0	$401,448	$0	$0	$0	($20,943)
2007	$18,318	$0	$0	$401,448	$0	$0	$0	($20,943)
2008	$17,417	$0	$0	$401,448	$0	$0	$0	($20,943)
2009	$16,636	$0	$0	$401,448	$0	$0	$0	($20,943)
2010	$15,936	$0	$0	$401,448	$0	$0	$0	($23,194)
2011	$15,335	$0	$0	$401,448	$0	$0	$0	($23,194)
2012	$14,815	$0	$0	$401,448	$0	$0	$0	($23,194)
2013	$14,334	$0	$0	$401,448	$0	$0	$0	($23,194)
2014	$14,173	$0	($3,770)	$704,185	$0	$0	$0	($21,343)
2015	$25,896	$0	($18,848)	$14,031,442	$0	$0	$0	($13,996)
2016	$45,439	$0	($26,387)	$21,329,573	$0	$0	$0	($50,056)
2017	$57,668	$0	($18,848)	$14,685,257	$0	$0	$0	($74,658)
2018	$79,197	$0	($33,926)	$28,249,757	$0	$0	$0	($48,958)
2019	$122,845	$0	($60,314)	$47,735,563	$0	$0	$0	($168,625)
2020	$174,168	$0	($67,853)	$60,430,917	$0	$0	$0	($285,375)
2021	$195,716	$0	($41,466)	$40,043,951	$0	$0	$0	($167,667)
2022	$205,765	$0	($30,157)	$27,557,562	$0	$0	$0	($226,453)
2023	$219,737	$0	($37,696)	$31,280,028	$0	$0	$0	($260,469)
2024	$215,842	$0	($22,618)	$15,593,721	$0	$0	$0	($197,501)
2025	$199,712	$0	($15,078)	$7,477,842	$0	$0	$0	($101,084)
2026	$191,278	$0	($18,848)	$11,161,184	$0	$0	$0	($150,512)
2027	$201,772	$0	($30,157)	$23,030,455	$0	$0	$0	($297,893)
2028	$219,724	$0	($37,696)	$33,322,099	$0	$0	$0	($288,630)
2029	$233,724	$0	($37,696)	$38,458,390	$0	$0	$0	($192,053)
2030	$267,600	$0	($52,774)	$54,026,834	$0	$0	$0	($317,955)
2031	$305,544	$0	($56,544)	$58,382,683	$0	$0	$0	($418,052)
2032	$337,556	$0	($56,544)	$60,276,909	$0	$0	$0	($361,832)
2033	$361,580	$0	($52,774)	$53,919,204	$0	$0	$0	($404,564)
2034	$345,798	$0	($22,618)	$20,073,968	$0	$0	$0	($262,852)
2035	$319,892	$0	($11,309)	$12,144,670	$0	$0	$0	($90,924)
2036	$293,899	$0	($11,309)	$12,044,746	$0	$0	$0	($87,495)
2037	$261,960	$0	($3,770)	$3,418,544	$0	$0	$0	($46,335)
2038	$231,986	$0	($3,770)	$713,046	$0	$0	$0	($2,047)
2039	$215,901	$0	($15,078)	$9,522,377	$0	$0	$0	($116,076)
2040	$219,809	$0	($26,387)	$21,385,944	$0	$0	$0	($218,816)
2041	$213,864	$0	($18,848)	$15,911,160	$0	$0	$0	($146,779)
2042	$196,136	$0	($7,539)	$6,125,910	$0	$0	$0	($78,454)
2043	$176,168	$0	($3,770)	$2,777,188	$0	$0	$0	($35,324)
2044	$157,970	$0	($3,770)	$4,351,403	$0	$0	$0	$3,632
2045	$141,971	$0	($3,770)	$4,351,403	$0	$0	$0	$3,632
2046	$124,395	$0	$0	$0	$0	$0	$0	$0
2047	$113,569	$0	($3,770)	$3,059,277	$0	$0	$0	($39,412)
2048	$108,738	$0	($7,539)	$6,066,406	$0	$0	$0	($79,193)
2049	$103,144	$0	($7,539)	$6,464,498	$0	$0	$0	($37,645)

Table K-29 Net Incremental Benefit (Cost) Associated with Attributes for LLW Disposal/Prohibition ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,240	$0	$0	($73,920,446)	($3,395)	$0	($451,377)	($1,351,186)
2004	$21,800	$0	$0	($40,658,693)	$0	$0	$0	($748,626)
2005	$20,600	$0	$0	($1,258,455)	$0	$0	$0	($48,797)
2006	$19,360	$0	$0	($1,258,455)	$0	$0	$0	($48,797)
2007	$18,340	$0	$0	($1,258,455)	$0	$0	$0	($48,797)
2008	$17,440	$0	$0	($1,258,455)	$0	$0	$0	($48,797)
2009	$16,660	$0	$0	($1,258,455)	$0	$0	$0	($48,797)
2010	$15,960	$0	$0	($1,258,455)	$0	$0	$0	($37,104)
2011	$15,360	$0	$0	($1,258,455)	$0	$0	$0	($37,104)
2012	$14,840	$0	$0	($1,258,455)	$0	$0	$0	($37,104)
2013	$14,360	$0	$0	($1,258,455)	$0	$0	$0	($37,104)
2014	$14,200	$0	$0	($3,786,318)	$0	$0	$0	($58,973)
2015	$26,000	$0	$0	($110,336,652)	$0	$0	$0	($869,442)
2016	$45,600	($3,000,000)	$0	($166,672,604)	$0	$0	$0	($1,343,199)
2017	$57,800	$0	$0	($113,153,026)	$0	$0	$0	($953,974)
2018	$79,400	($3,000,000)	$0	($221,499,649)	$0	$0	$0	($1,766,820)
2019	$123,200	($3,000,000)	$0	($370,548,333)	$0	$0	$0	($3,045,724)
2020	$174,600	($6,000,000)	$0	($476,523,809)	$0	$0	$0	($3,882,996)
2021	$196,000	($3,000,000)	$0	($316,685,220)	$0	$0	$0	($2,557,769)
2022	$206,000	($3,000,000)	$0	($203,821,677)	$0	$0	$0	($1,776,704)
2023	$220,000	($3,000,000)	$0	($230,998,348)	$0	$0	$0	($2,017,746)
2024	$216,000	$0	$0	($111,368,638)	$0	$0	$0	($1,048,154)
2025	$199,800	$0	$0	($53,446,760)	$0	$0	$0	($507,678)
2026	$191,400	$0	$0	($81,690,258)	$0	$0	$0	($770,178)
2027	$202,000	($3,000,000)	$0	($168,078,021)	$0	$0	$0	($1,573,300)
2028	$220,000	($3,000,000)	$0	($253,848,686)	$0	$0	$0	($2,205,131)
2029	$234,000	($3,000,000)	$0	($301,106,048)	$0	$0	$0	($2,458,214)
2030	$268,000	($6,000,000)	$0	($423,707,002)	$0	$0	$0	($3,506,905)
2031	$306,000	($6,000,000)	$0	($454,526,287)	$0	$0	$0	($3,841,802)
2032	$338,000	($6,000,000)	$0	($465,214,749)	$0	$0	$0	($3,869,573)
2033	$362,000	($6,000,000)	$0	($409,053,868)	$0	$0	$0	($3,494,984)
2034	$346,000	($3,000,000)	$0	($146,617,553)	$0	$0	$0	($1,375,545)
2035	$320,000	$0	$0	($95,813,268)	$0	$0	$0	($811,560)
2036	$294,000	$0	$0	($94,277,422)	$0	$0	$0	($797,212)
2037	$262,000	$0	$0	($24,782,108)	$0	$0	$0	($234,579)
2038	$232,000	$0	$0	($5,758,210)	$0	$0	$0	($45,244)
2039	$216,000	$0	$0	($70,662,333)	$0	$0	$0	($651,322)
2040	$220,000	($3,000,000)	$0	($160,765,424)	$0	$0	$0	($1,434,706)
2041	$214,000	$0	$0	($119,976,438)	$0	$0	$0	($1,053,851)
2042	$196,200	$0	$0	($44,137,625)	$0	$0	$0	($413,971)
2043	$176,200	$0	$0	($19,970,375)	$0	$0	$0	($187,167)
2044	$158,000	$0	$0	($35,920,975)	$0	$0	$0	($265,193)
2045	$142,000	$0	$0	($35,920,975)	$0	$0	$0	($265,193)
2046	$124,400	$0	$0	$0	$0	$0	$0	$0
2047	$113,600	$0	$0	($22,051,134)	$0	$0	$0	($207,028)
2048	$108,800	$0	$0	($44,157,004)	$0	$0	$0	($414,442)
2049	$103,200	$0	$0	($51,776,404)	$0	$0	$0	($426,412)

Table K-30 Net Incremental Benefit (Cost) Associated with Attributes for Limited Dispositions Alternative ($)

Year	Public and Occupational Health Routine	Public and Occupational Health Accident	Industry Implementation	Industry Operation	NRC Implementation	NRC Operation	Other Government	Environmental Considerations
2003	$15,018	$0	($18,848)	$14,197,311	($3,395)	$0	($451,377)	$9,867
2004	$21,561	$0	($11,309)	$7,782,076	$0	$0	$0	$197
2005	$20,420	$0	$0	$401,448	$0	$0	$0	($20,943)
2006	$19,197	$0	$0	$401,448	$0	$0	$0	($20,943)
2007	$18,192	$0	$0	$401,448	$0	$0	$0	($20,943)
2008	$17,305	$0	$0	$401,448	$0	$0	$0	($20,943)
2009	$16,536	$0	$0	$401,448	$0	$0	$0	($20,943)
2010	$15,845	$0	$0	$401,448	$0	$0	$0	($23,194)
2011	$15,254	$0	$0	$401,448	$0	$0	$0	($23,194)
2012	$14,742	$0	$0	$401,448	$0	$0	$0	($23,194)
2013	$14,268	$0	$0	$401,448	$0	$0	$0	($23,194)
2014	$14,109	$0	($3,770)	$849,614	$0	$0	$0	($22,412)
2015	$25,692	$0	($18,848)	$20,294,026	$0	$0	$0	($51,928)
2016	$45,061	$0	($26,387)	$30,757,208	$0	$0	$0	($106,862)
2017	$57,250	$0	($18,848)	$21,009,910	$0	$0	$0	($112,490)
2018	$78,422	$0	($33,926)	$40,815,886	$0	$0	$0	($124,802)
2019	$121,496	$0	($60,314)	$68,608,128	$0	$0	$0	($294,188)
2020	$172,373	$0	($67,853)	$87,381,423	$0	$0	$0	($434,816)
2021	$193,702	$0	($41,466)	$57,994,670	$0	$0	$0	($267,221)
2022	$203,688	$0	($30,157)	$38,925,140	$0	$0	$0	($289,311)
2023	$217,635	$0	($37,696)	$44,177,926	$0	$0	$0	($331,556)
2024	$213,780	$0	($22,618)	$21,717,759	$0	$0	$0	($230,606)
2025	$197,731	$0	($15,078)	$10,393,612	$0	$0	$0	($115,989)
2026	$189,368	$0	($18,848)	$15,610,281	$0	$0	$0	($173,396)
2027	$199,810	$0	($30,157)	$32,237,495	$0	$0	$0	($345,142)
2028	$217,742	$0	($37,696)	$47,458,259	$0	$0	$0	($362,202)
2029	$231,732	$0	($37,696)	$55,452,885	$0	$0	$0	($281,346)
2030	$265,320	$0	($52,774)	$77,845,672	$0	$0	$0	($440,936)
2031	$302,587	$0	($56,544)	$83,836,251	$0	$0	$0	($548,861)
2032	$334,024	$0	($56,544)	$86,511,515	$0	$0	$0	($496,572)
2033	$357,912	$0	($52,774)	$76,840,506	$0	$0	$0	($522,109)
2034	$342,330	$0	($22,618)	$28,115,088	$0	$0	$0	($303,341)
2035	$316,753	$0	($11,309)	$17,495,562	$0	$0	$0	($118,441)
2036	$291,053	$0	($11,309)	$17,314,591	$0	$0	$0	($114,640)
2037	$259,388	$0	($3,770)	$4,767,711	$0	$0	$0	($53,191)
2038	$229,664	$0	($3,770)	$1,039,773	$0	$0	$0	($3,727)
2039	$213,803	$0	($15,078)	$13,394,872	$0	$0	$0	($135,806)
2040	$217,751	$0	($26,387)	$30,288,586	$0	$0	$0	($264,217)
2041	$211,768	$0	($18,848)	$22,595,140	$0	$0	$0	($180,834)
2042	$194,122	$0	($7,539)	$8,546,877	$0	$0	$0	($90,711)
2043	$174,291	$0	($3,770)	$3,869,445	$0	$0	$0	($40,888)
2044	$156,223	$0	($3,770)	$6,409,222	$0	$0	$0	($7,249)
2045	$140,340	$0	($3,770)	$6,409,222	$0	$0	$0	($7,249)
2046	$122,899	$0	$0	$0	$0	$0	$0	$0
2047	$112,196	$0	($3,770)	$4,273,399	$0	$0	$0	($45,512)
2048	$107,476	$0	($7,539)	$8,492,696	$0	$0	$0	($91,404)
2049	$101,981	$0	($7,539)	$9,366,489	$0	$0	$0	($52,720)

Attachment 1 to Appendix K

Distribution of "MARSSIM" Survey Unit Classes Associated with Controlling the Disposition of Solid Materials

In assessing the conduct of release surveys, there is a need to determine how materials might be distributed among the three survey classes of "MARSSIM." The survey classification system includes Class 1, 2, and 3. Under Class 1, contamination levels are expected to be above the release criteria over some portion of the material. For Class 2, materials are expected to have contamination levels near but not exceed the release criteria anywhere on the material. Under Class 3, the material are expected to have contamination levels well below release criteria anywhere on the material. Also, the determination of the appropriate classification is fundamentally premised on the specific value of the release criterion for a given radionuclide. That is, it appears reasonable to expect that 70 percent of some material coming from an area within a reactor building to be Class 3 if the release criterion were 10 mrem/yr; however, it is unlikely that a Class 3 designation would be 70 percent if the release criterion were 0.1 mrem/yr instead. This connection of a release criterion to classification distributions is an important consideration which can only be addressed with facility and material specific information. NUREG-1761 on survey methodology for solid materials and the ORISE report on survey costs provide further discussions on these topics (NRC 2004, ORISE 2004).

The types of contaminants and contamination levels are expected to reflect the operational history of such materials in impacted areas, i.e., radiologically controlled areas. For example, steel reinforcement bars used in structures are expected to be mostly free of contamination given that they were encapsulated in concrete during the operating life of a plant, excluding neutron activated materials (i.e., rebars and concrete in bioshields). On the other hand, some process systems may be both externally and internally contaminated. Internal contamination may be associated with process fluids that contained radioactivity, while external contamination may be due to spills and leaks from nearby components. Another consideration addresses how materials were processed and removed out of controlled areas. For example, if precautions were taken in the handling and removal process, external surface contamination levels might be kept to levels that may not warrant a Class 1 designation. Accordingly, such considerations would be addressed as part of an initial assessment, including the use of current operational survey results and by conduct scoping and characterization surveys to supplement that information.

Given the objective of the GEIS, the assignment of survey unit classification focuses on the major types of materials. This discussion does not consider materials that would be shipped as low-level radioactive waste. It is assumed that the provisions of a release rule would only apply to materials considered to be relatively free of both internal and external surface or volumetric contamination, with levels that straddle release criteria. In other words, the provisions of the release rule is not expected to change the practice in identifying and segregating materials with contamination levels that warrant disposal as low-level radioactive waste. Moreover, it is assumed that if decontamination were considered as a precursor to releasing materials, the initial contamination levels would be such that release criteria could be readily achieved given the selection of a proper decontamination method. This recognizes that if contamination levels were too high or the decontamination factor were too low, it would be a futile exercise to spend any time and resources on decontamination. Finally, these considerations are assumed to apply as well to the reuse of equipment and tools in their original form or intended applications.

The discussions that follow address metals, concrete, trash, and equipment reuse with results summarized in Table 1.

1. Metals

Metals include ferrous and non-ferrous metals, such as aluminum and copper. In the context of the release rule, metals can be grouped into three categories by origins, (i) metals that were completely encapsulated, (ii) metals that were contained in enclosures or isolated with some degree of protection, and (iii) metals that were exposed to ambient conditions or were part of some systems or components. The best example of metals that were completely encapsulated is structural rebars used in concrete structures. Such metals are expected to be essentially all Class 3. Metals that were contained in enclosures or isolated with some degree of protection may be found in utility chases, pipe penetrations, overhead spaces, or contained in electrical panels or conduits. This category also includes some structural steel and pipe hangers. Most of this material is expected to be Class 2. Metals that were exposed to ambient conditions are assumed to be characterized by contamination levels that would be at or above release criteria. Such metals would originate from radiologically controlled areas, be part of systems and components, pipe hangers, and include some structural steel. Most of this type of metal would be Class 1.

A review of material inventories compiled in the SC&A report (SC&A 2003) indicates that rebars from a BWR plant comprise about 60 to 85 percent of the metals inventory that is potentially releasable, also assumed to be representative of PWRs as well. The balance consists of structural steel, pipe hangers, and other miscellaneous ferrous metals. A Class 3 designation is assigned to the inventory of rebars, assuming that 70 percent of metals are rebars. For the balance, it is assumed that 20 percent is Class 2 and 10 percent is Class 1, given the discussion above on the grouping of metals by origins. Finally, metals that would be subject to decontamination are assumed to have an equal distribution among Class 1, 2, and 3, lacking specific information.

2. Concrete

Essentially all of the concrete present in facilities is associated with structures and building foundations. However, some concrete is used as equipment pedestals and perimeter curbing around floor and equipment drains. Accordingly, contamination profiles of concrete are expected to be primarily surficial in nature for most areas, and volumetric in areas where the contamination is associated with liquid spills and leaks from components. In addition, some volumetric contamination is expected around embedded piping servicing floor and equipment drains, and at wall-to-floor joints and floor-to-floor joints. Generally, the decontamination of concrete is undertaken when the contamination is present within the near surface (few inches) and its distribution is well known. For areas where contamination levels are present at depths or is due to neutron activation, the practice is to remove the entire layer and dispose of it as low-level waste. The methods rely on aggressive techniques, e.g., scabbler or jack hammers, with the removal of a layer that overshoots the original depth of the contamination. This approach is used to remove the contamination on the first pass, as it is costly to repeat such procedures in serial steps involving more decontamination and surveys. Given such aggressive methods, it is expected that most of the contamination would be removed, thereby, leaving exposed concrete surfaces that would most likely be below cleanup criteria.

A review of the material inventories presented in the SC&A report (SC&A 2003) indicates that nearly all concrete from BWR and BWR plants are expected to be below or near release criteria. The balance is expected to come from areas that were decontaminated and, as a result, would reflect a classification initially assigned to the area before decontamination. Lacking specific information, a Class 3 designation is assigned to 80 percent of the total inventory of releasable concrete. For the balance, it is assumed that 10 percent is Class 2 and 10 percent is Class 1.

3. Trash

Trash is expected to be generated routinely out of radiologically controlled areas. Various types of materials fall in the designation of trash. Trash generally consists of paper, wood, plastic, glass, cloth, filters, rubber, cardboard, small metallic objects, among others. Other types of materials may be included in trash when quantities are too small and do not warrant segregation for disposal via other means. Such additional materials may include concrete rubble, bricks, asphalt, metal scraps, and discarded tools and equipment. Given that trash is being generated frequently, licensees are routinely surveying and segregating trash, with some items being disposed of as LLW depending on radioactivity levels. For expediency and cost considerations, this segregation process tends to err on the side of safety by labeling some items as being contaminated while more detailed surveys might reveal otherwise. As a result, this process tends to generate trash that might have a greater number of items with Class 2 and 3 distributions than Class 1.

Trash can be grouped into three categories by origins, (i) items that have introduced in a radiologically controlled area with little potential of being contaminated, (ii) items that have been introduced in a radiologically controlled area and have become contaminated at levels at or above release criteria, and (iii) items that have been in a radiologically controlled area and have become contaminated at significant levels. In illustrating the first example, a pallet used to deliver some equipment would fall in this category. The pallet might be protected with some covering. Once the equipment is removed, the pallet would be taken out of the controlled area as part of that same operation. In the second category, the pallet might become contaminated and contamination levels would dictate whether it can be released or should be disposed of as radioactive waste, assuming that decontamination is not feasible. For the third category, an example might include the use of a disposable covering (e.g., plastic sheeting) to protect some equipment during some maintenance evolution. Once the work is completed, the covering would be removed and surveyed to determine whether it can be released or needs to be disposed of as radioactive waste, assuming that decontamination is not feasible. Given the relative protection afforded by plastic wrappings or any other forms of encapsulation methods, it cannot be assumed that this level of protection would be totally effective against contamination, as a result a lesser survey classification than Class 1 could not be justified. Given the variability of the radiological properties of trash that might be potentially released, trash is assumed to have an equal distribution among Class 1, 2, and 3 considering the potential heterogeneous distributions of contaminants.

4. Equipment, Tools, and Vehicles

As with materials described above, it is known that different types of equipment and tools are used in radiologically controlled areas and later taken out. The types of equipment that could be potentially released from nuclear facilities for reuse in an environment free of radiological controls ranges from small items, such as hand tools, to very large ones, such as mechanized equipment and industrial vehicles. The following are examples of potentially reusable equipment, tools, and miscellaneous items:

- small hand tools (wrenches, screw drivers, etc.) and power tools (drills, saws, etc.)
- electrical equipment, such as control panels, motors, pumps, and generators
- office furniture (desks, chairs, filing cabinets, etc.) and office equipment (copiers, computers, printers, fax machines, etc.)
- construction equipment, such as scaffolding, noise or dust-control barriers, wheelbarrows, etc.
- mechanized equipment, such as backhoes, bulldozers, cranes, drill rigs, etc.
- vehicles, such as dump trucks, flat-bed trucks, pickup trucks, vans, etc.
- materials and supplies for use in their original forms, but taken out as excess, such as piping, tubing, electrical wiring, floor covering, ductwork, sheet metal, pipe hangers, light fixtures, wall board, and sheet glass.

It should be noted that these examples are assumed to characterize the profile of equipment, tools, and miscellaneous items that may be released by various types of licensees.

It is recognized that the release of equipment is an extremely dynamic process involving different types of facilities and activities, such as routine operations, research and development, major and minor power plant outages, refurbishment, decommissioning, etc. In addition, this process is taking place simultaneously at thousands of facilities across the nation and conducted every hour of the day and every day of the week. As a result, it is not readily possible to define what types of objects and how many are routinely used in radiologically controlled areas, and what fraction is surveyed and released for reuse *versus* those that are discarded as LLW.

In practice, equipment and tools are surveyed before being taken out of radiologically controlled areas. The survey consists of conducting a scan with a portable radiation survey meter and taking wipes to assess the presence of removable surface activity. The presence of radioactivity on wipes is evaluated using separate instrumentation. Some survey methods involve the introduction of the item into an instrument (e.g., gamma tool monitor) that measures radioactivity *in toto* from all external and internal surfaces. Depending on the results of surveys, the items are either cleaned to meet release criteria, not taken out of the controlled area and set aside for later use in any controlled area, or simply discarded as LLW.

Given that equipment, tools, and vehicles have a productive life cycle, it is assumed that the impetus will be keep on using equipment to their maximum useful lives. The productive cycle lof equipment is driven by operational conditions and economic considerations, taking into account replacement costs *vs.* cost of repairs, amortization rates, and cost of money. These factors are expected to be different among facilities. Accordingly, it is expected that licensees will take all appropriate measures to protect equipment, tools, vehicles, etc.

Together, these practices are expected to mitigate the presence of residual radioactivity on potentially releasable equipment and should result in residual levels that are below release criteria for most items. As a result, it is expected that most of the equipment will be Class 2 and 3, with a smaller fraction being Cass 1. Given the paucity of information and potential for heterogeneous distributions of contaminants, it is assumed that 50 percent of the potentially release equipment is Class 3, 30 percent is Class 2, and 20 percent is Class 1.

Table 1 Assignment of Survey Classification to Potentially Releasable Materials and Equipment

Material	**Percent of Material**		
	Class 1	**Class 2**	**Class 3**
Metals - no decon	10	20	70
Metals - with decon	33	33	33
Concrete	10	10	80
Trash	33	33	33
Equipment, tools, vehicles, etc.	20	30	50

Note: The assumed distributions of survey classifications for concrete and steel do not consider the presence of neutron activation products. The presence of radionuclides associated with neutron activation is too complex of an issue to be addressed generically and should be dealt with on a case-by-case basis.

References

ORISE 2004 Oak Ridge Institute for Science and Education, "Clearance Survey Costs - Technical Bases for Developing Survey Costs," Oak Ridge, TN, prepared for the NRC under contract, draft report, February 2004.

SC&A 2003 S. Cohen & Associates, Inc., Collective Doses Associated with Clearance of Material from NRC/Agreement State-Licensed Facilities, 2nd draft, Dec. 2003, McLean, VA.

NRC 2004 U.S. Nuclear Regulatory Commission, Radiological Surveys for Controlling Release of Solid Materials, NUREG-1761, Washington, DC, June 2004.

Attachment 2 to Appendix K

Description of Industry Operation Attribute

This attachment provides a detailed description of how the benefits and costs were calculated for one of the attributes - Industry Operation - which is by far the most significant of the cost-benefit attributes shown in Tables 4-3 and K-14. The Industry Operation attribute includes four sub-attributes, but two in particular -- transportation and disposal -- are the significant drivers in the analysis. The information provided here is intended to help the reader understand how the cost-benefit analysis is performed and also to provide the values of the assumed parameters necessary to duplicate the Industry Operation portion of the analysis in the year 2020 for three Alternatives compared to No Action. (The sample year 2020 was chosen because it is a year with a higher volume of potentially clearable solid material.) This will be helpful in understanding the extent to which transportation and disposal activities influence the overall analysis.

1. Description of the Model's Calculations

The cost-benefit model is based on a set of linked calculations (via spreadsheets). The spreadsheets contain information on potentially clearable solid materials (steel, concrete and trash in units of tons) for each of the Alternatives and for each dose option. The spreadsheets also contain parameters used to model costs, for example truck transportation in units of $/ton-mile and concrete rubble surveys in units of $/ton.

The cost-benefit model considered inventories of potentially clearable solid materials that may accumulate during the dismantlement of commercial nuclear power reactors. The dismantlement of these facilities is the major source of potentially clearable materials. The inventories are developed as a function of time based on the scheduled shutdown dates of the existing nuclear power plants. Dismantlement of a facility is assumed to be completed in 7 years, with 5 years for post-shutdown activities and 2 years for dismantlement.

Table K-31 shows a summary of the total inventory of clearable solid materials over the study period. The solid materials shown below are either “released” or they are disposed in a LLW facility. Two examples of release destinations are (1) an EPA/State-Regulated landfill used for trash, concrete and/or ferrous metals, or (2) a recycling facility used to process released concrete only for use as roadbed material. For the comparison of Alternatives in this attachment, the Unrestricted Release and EPA/State-Regulated Disposal Alternatives all have a dose option of 1 mrem/yr based on NUREG-1640. The Limited Dispositions Alternative is based on IAEA Safety Guide No. RS-G-1.7, which is derived from a dose of 1 mrem/yr.

The Unrestricted Release inventory is for material-independent values. Note that in Table K-31 the amount of tons of concrete released under the Unrestricted Release Alternative is larger than the inventory of concrete released under the No Action Alternative. However, for steel the situation is reversed. This is because the material-independent values are based on the most limiting scenario, which is concrete, and thus inventory values for steel are normalized to a lower value. The concept of material-independent values is explained on page 3-20 and in Appendix D of this GEIS.

The cost-benefit results are generated by multiplying material amounts by unit costs, on an annual basis for each of the Alternatives and dose options. Using the convention described earlier in this Appendix, negative numbers represent either costs or decreases in benefits, while positive numbers represent either benefits or decreases in costs. The costs and benefits associated with the No Action Alternative are subtracted from the costs and benefits associated with each Alternative, to estimate the incremental cost of the rule. After the annual incremental total costs are calculated in current year dollars, these dollars are discounted to present value 2003$ on an annual basis. Summing over all years provides the total discounted cost or benefit for an attribute (e.g., Industry Operation, Environmental Considerations) for each Alternative (e.g., Unrestricted Release, Limited Disposition) and dose option (e.g., 1 mrem/yr). A final sum over all of the attributes provides the Total Net Incremental Benefit or Cost (2003$) for the Alternative and dose option compared to the No Action Alternative. Table 4-3 presents these results.

Table K-31: Total Inventory of Clearable Solid Materials - All Alternatives Except No Action are for a 1 mrem/yr Dose Option (Thousand Tons)

	No Action	Unrestricted Release	EPA/State-Regulated Disposal	Limited Dispositions
Material Recycled				
Steel	1,800	1,500	NA	NA
Concrete	16,000	20,000	NA	20,000
Trash	NA	NA	NA	NA
Material Disposed at EPA/State-Regulated Landfills				
Steel	0	0	2,100	2,100
Concrete	0	0	20,000	0
Trash	20	1.8	41	41

Source: SC&A 2003 Tables 4.6, 4.7, 10.3 and 10.7. For steel, the decontaminated quantity was not included in the release volumes because of the high cost of steel decontamination.

The overall analysis covers the years 2003 through 2049, but this discussion presents results only for a single sample year, 2020. It is important to keep in mind that the amount of solid material normally varies from year to year, and some years have very little material generated from decommissioning. The sample year 2020 represents a high volume year. The annual tonnage of potentially clearable solid material is based on three items in the analysis methodology:

- dismantlement activity in that year,
- the method by which the materials are managed for the Alternative (recycled or disposed), and
- the dose at which materials are allowed to be released.

With the amount of potentially clearable solid material changing each year, the dollar impacts – either cost or benefit – also change each year. These changes are seen in the stream of current year dollars (both benefits and costs compared to No Action) in Table K-23 for Unrestricted

Release, Table K-28 for EPA/State-Regulated Disposal, and Table K-30 for Limited Dispositions. All three tables show major annual benefits under the Industry Operation attribute, and to a lesser extent under the Public and Occupational Health Routine attribute. These tables also show major annual costs under the Environmental Considerations and Industry Implementation attributes.

Table K-32 shows the quantity of potentially clearable solid materials in the sample year 2020, and how the specific quantities are managed for each material. These quantities are shown for the No Action, Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives. The amounts of material (in metric tons) in the year 2020 serve as a starting point to describe how the analysis is performed for the Industry Operation attribute.

Table K-32: Inventory of Clearable Solid Materials
for the Industry Operation Attribute in the Year 2020 -
All Alternatives Except No Action are for a 1 mrem/yr Dose Option
(Thousand Tons)

		No Action	**Unrestricted Release**	**EPA/State-Regulated Disposal**	**Limited Dispositions**
Material Recycled					
Steel		120	99	NA	NA
Concrete		1,293	1,564	NA	1,564
Trash		0	0	NA	NA
Material Disposed at EPA/State-Regulated Landfills					
Steel		0	0	141	141
Concrete		0	0	1,572	0
Trash		1	< 1	1	1
Material Disposed at LLW Facility					
Steel	Unrestricted	0	22		
	EPA/State	21		0	
	Limited Disp	21			0
Concrete	Unrestricted	271	0		
	EPA/State	279		0	
	Limited Disp	271			0
Trash	Unrestricted	0	1		
	EPA/State	1		0	
	Limited Disp	1			0

Because different amounts of each material clear in each Alternative, the No Action Alternative is divided into three baselines, one corresponding to each of the other Alternatives (Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions). The unaccounted for material (for example, the 271,000 ton difference in the amount of concrete released in the No Action and Unrestricted Release Alternatives) is added back to the No Action – Unrestricted Release baseline, so like quantities are compared. Because any material that does not clear would need to be sent to a LLW disposal facility, this change in quantity is assumed to be disposed of at a LLW disposal facility.

As noted above, the Industry Operation attribute has four "sub-attributes," or cost components. These sub-attributes are (in their order of cost significance):

- transportation;
- disposal and recycling;
- survey; and
- paperwork.

The next sections explain how the costs and benefits are calculated for the year 2020. Assumed parameters are discussed to provide transparency on how costs and benefits are calculated. These sections illustrate the large beneficial impacts due to transportation and disposal activities associated with each of the three 1 mrem/yr Alternatives.

When the impacts from the four sub-attributes are summed for each Alternative at the end of this section, the resulting total net benefits for the Industry Operation attribute (compared to No Action) will match the following values with some allowance for rounding:

- $84,066,938 for Unrestricted Release shown in Table K-23
- $60,430,917 for EPA/State-Regulated Disposal shown in Table K-28
- $87,381,423 for Limited Dispositions shown in Table K-30.

2. Transportation Sub-Attribute

The annual net benefits or costs attributed to transportation are calculated for each year of the analysis, 2003-2049, by subtracting the estimated transportation costs of the No Action approach (or "baseline") from the estimated transportation costs of the Alternative under consideration. Lower costs for the Alternative produce positive values, or net "benefits." Higher costs for the Alternative produce negative values, or net "costs." These annual values are calculated first in current year dollars and then discounted to 2003$ for present value comparison.

Transportation costs are estimated by multiplying the quantity (tons) of each material released in a year by (1) the number of miles traveled to the appropriate destination, and (2) the $ per ton-mile rate for transporting the material by truck.

Table K-33 shows the assumed unit costs used to calculate transportation costs.

Table K-34 shows net transportation costs and benefits in sample year 2020 for the Alternatives in 2020$.

The released solid material is either transported to a recycling facility (steel and concrete only) or to an EPA/State-Regulated landfill. Solid material also is transported to a LLW facility. Multiplying the tons released (Table K-32) by the unit cost assumptions provides the transportation costs for each Alternative compared to No Action.

Table K-33
Assumed Parameters for Transportation Cost Calculations

Transportation Cost Component	Cost or Mileage
Cost per ton-mile for non-LLW (truck)	-$0.06
Cost per ton-mile for LLW (truck)	-$0.12
Number of miles to an MSW Landfill	58 miles
Number of miles to a steel recycling facility	269 miles
Number of miles to a concrete recycling facility	198 miles
Number of miles to a LLW facility	1,544 miles

Transportation of concrete to a LLW facility under the No Action baseline is the most significant influence in the transportation costs. The Alternatives that use the 1 mrem/yr dose option release more concrete compared to the No Action baseline, and their costs for these releases are much less than the baseline assumption of sending the material to a LLW facility. The Unrestricted Release Alternative has the added cost of transporting steel a greater distance to a recycling facility compared to transporting steel to a mixed solid waste (MSW) landfill for the EPA/State-Regulated Disposal and Limited Dispositions Alternatives.

In summary, there are three differences associated with the Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives compared to the No Action Alternative in the year 2020:

- more tons of concrete are released for the 1 mrem/yr dose option,
- each ton of concrete released and transported to a landfill is about 3.5 times closer (58 miles compared to 198 miles) than the concrete sent to a recycling facility, and
- the Unrestricted Release Alternative has an additional $4 million cost in year 2020 for transporting steel to LLW compared to the EPA/State-Regulated Disposal and Limited Dispositions Alternatives.

3. Disposal and Recycling Sub-Attribute

The annual net benefits or costs attributed to disposal and recycling activities are calculated for each year of the analysis, 2003-2049. The estimated costs of the No Action approach (or “baseline”) are subtracted from the estimated costs of the other Alternative under consideration. These annual values are calculated first in current year dollars and then discounted to 2003$ for present value comparison.

Disposal and recycling costs are estimated by multiplying the quantity (tons) of each material released in a year by the $ per ton unit cost for disposal and recycling activities.

Table K-35 shows the assumed unit costs used to calculate disposal and recycling costs. Note that there is a cost to recycle concrete but a benefit to recycle steel.

Table K-34
Calculation of Transportation Benefits and Costs (Year 2020)
(Millions 2020$)

		No Action Baseline	Unrestricted Release	EPA/State-Regulated Disposal	Limited Dispositions
Material Recycled Assumptions: 269 miles to steel recycling facility 198 miles to concrete recycling facility $0.06 cost per ton-mile for truck transport					
Steel		-1.9	-1.6	0	0
Concrete		-15.4	-18.6	0	-18.6
Trash		0	0	0	0
Material Disposed at EPA/State-Regulated Landfills Assumptions: 58 miles to a MSW landfill $0.06 cost per ton-mile for truck transport					
Steel		0	0	-0.5	-0.5
Concrete		0	0	-5.5	0
Trash		< 0.1	< 0.1	< 0.1	< 0.1
Material Disposed at LLW Facility Assumptions: 1,544 miles to LLW facility $0.12 cost per ton-mile for truck transport					
Steel	Unrestricted	0	-4.0		
	EPA/State	-3.8		0	
	Limited Disp	-3.8			0
Concrete	Unrestricted	-50.3	0		
	EPA/State	-51.7		0	
	Limited Disp	-50.3			0
Trash	Unrestricted	0	-0.1		
	EPA/State	-0.1		0	
	Limited Disp	-0.1			0
Alternative Total $					
	Unrestricted	-67.6	-24.3		
	EPA/State	-72.9		-6.0	
	Limited Disp	-71.5			-19.1
Net Benefit (Cost) compared to No Action			+43.3	+66.9	+52.4

Table K-35
Assumed Parameters for Disposal and Recycling Cost Calculations

Disposal, Recycling and Reuse Cost Component	Cost ($/ton)
Steel, concrete and trash disposal in a landfill	-32.19
Concrete recycling	-5.00
Steel recycling revenue	+85.00
Steel, concrete and trash disposal in a LLW facility	-164.00

Table K-36 shows net disposal and recycling costs and benefits in sample year 2020 for the Alternatives in 2020$.

The released solid material is either disposed at a recycling facility (steel and concrete only) or at an EPA/State-Regulated landfill. Solid material also is disposed at a LLW facility. Multiplying the tons released (Table K-32) by the disposal unit cost assumptions provides the disposal costs and recycling revenue for each Alternative compared to No Action.

As shown in Table K-36, both Unrestricted Release and Limited Disposition Alternatives have significant benefits compared to No Action, while the EPA/State-Regulated Disposal Alternative is more costly than No Action. The No Action baseline is about the same for all three Alternatives (i.e., $40-$45 million). The EPA/State-Regulated Disposal Alternative has a $50 million expense in disposing of concrete in a landfill at $32.19 per ton. The Unrestricted Release Alternative obtains a benefit of about $8 million in 2020 from the sale of steel to a recycling facility, but not as much steel is recycled as that for the No Action Alternative ($10 million). The significant benefit for the Unrestricted Release and Limited Dispositions Alternatives compared to No Action is in the disposal of concrete at a recycling facility at $5.00 per ton compared to disposal at a LLW facility at $164.00 per ton.

In summary, there are three differences associated with the Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives compared to the No Action Alternative in the year 2020:

- the amount of concrete disposed in a landfill compared to the amount released for recycling,
- the cost of disposing of concrete in a landfill is more than 6 times the cost ($32.19/ton compared to $5/ton) of releasing concrete to a recycling facility, and
- the amount of concrete sent to a LLW facility.

4. Survey Costs Sub-Attribute

The annual net benefits or costs attributed to survey activities are calculated for each year of the analysis, 2003-2049. The estimated costs of the No Action approach (or "baseline") are subtracted from the estimated costs of the Alternative under consideration. These annual values are calculated first in current year dollars and then discounted to 2003$ for present value comparison.

Survey costs are estimated by multiplying the quantity (tons) of each material released in a year by the $ per ton survey cost.

Table K-36
Calculation of Disposal and Recycle Benefits and Costs (Year 2020)
(Millions 2020$)

		No Action Baseline	**Unrestricted Release**	**EPA/State-Regulated Disposal**	**Limited Dispositions**
Material Recycled Assumptions: $85.00 revenue per ton for steel $ 5.00 cost per ton for concrete					
Steel		+10.2	+8.4	0	0
Concrete		-6.5	-7.8	0	-7.8
Trash		0	0	0	0
Material Disposed at EPA/State-Regulated Landfills Assumptions: $32.19 cost per ton for steel, concrete, and trash					
Steel		0	0	-4.5	-4.5
Concrete		0	0	-50.6	0
Trash		< -0.1	< -0.1	< -0.1	< -0.1
Material Disposed at LLW Facility Assumption: $164.00 cost per ton for steel, concrete and trash					
Steel	Unrestricted	0	-3.5		
	EPA/State	-3.4		0	
	Limited Disp	-3.4			0
Concrete	Unrestricted	-44.4	0		
	EPA/State	-45.7		0	
	Limited Disp	-44.4			0
Trash	Unrestricted	0	-0.1		
	EPA/State	-0.1		0	
	Limited Disp	-0.1			0
Alternative Total $					
	Unrestricted	-40.7	-3.0		
	EPA/State	-45.5		-55.1	
	Limited Disp	-44.2			-12.3
Net Benefit (Cost) compared to No Action			+37.7	-9.6	+31.9

Table K-37 shows the assumed unit costs used to calculate survey costs.

Table K-37
Assumed Parameters for Survey Cost Calculations

Survey Cost Components	Cost ($/ton)
Trash survey for baseline	-50.00
Steel survey for baseline	-176.00
Concrete survey for baseline	-26.00
Trash survey for 1 mrem/yr dose option	-74.00
Steel survey for 1 mrem/yr dose option	-41.85
Concrete survey for 1 mrem/yr dose option	-35.94

Table K-38 show net survey costs and benefits in sample year 2020 for the Alternatives in 2020$.

Note that for survey activities, the net benefit of each Alternative compared to No Action is exactly the same, $3.3 million. This equality seems counter intuitive, as the number of tons surveyed under each Alternative in the year 2020 is different. The incremental net benefit of one Alternative compared to another Alternative is the same (relative to No Action) because the unit costs for surveying material going to a landfill are the same as those going to a LLW facility. The extra material released for the Limited Dispositions Alternative compared to the Unrestricted Release Alternative in 2020 is also assumed for the Limited Disposition No Action baseline compared to the Unrestricted Release No Action baseline. Thus, incremental amounts among Alternatives cancel each other out because the same increment is in both the Alternative and the baseline for that Alternative.

Limited Disposition survey costs are about $1 million more costly than Unrestricted Release survey costs in 2020 ($62.2 million compared to $61.2 million) due to more steel surveyed prior to release to a landfill. This added cost is offset by a lesser amount of steel going to a LLW facility in the baseline ($64.5 million compared to $65.5 million).

In summary, there are two conclusions from the survey cost sub-attribute:

- an approximate $3.3 million benefit in 2020 is obtained for each of the three Alternatives compared to No Action, and
- the benefit is due to the cost difference in surveying steel for the Alternatives, $41.85 per ton compared to $176.00 per ton for No Action, and to the quantity of concrete surveyed prior to LLW disposal for No Action compared to no tons for the Alternatives.

Table K-38
Calculation of Survey Costs (Year 2020)
(Millions 2020$)

		No Action Baseline	**Unrestricted Release**	**EPA/State-Regulated Disposal**	**Limited Dispositions**
Material Recycled					
Assumptions:	$ 35.94 cost per ton for concrete survey for 1 mrem/yr dose option $ 26.00 cost per ton for concrete No Action baseline survey $ 41.85 cost per ton for steel survey for 1 mrem/yr dose option $176.00 cost per ton for steel No Action baseline survey				
Steel		-21.2	-4.1	0	0
Concrete		-33.6	-56.2	0	-56.2
Trash		0	0	0	0
Material Disposed at EPA/State-Regulated Landfills					
Assumptions:	$41.85 cost per ton for steel survey for 1 mrem/yr dose option $35.94 cost per ton for concrete survey for 1 mrem/yr dose option $74.00 cost per ton for trash survey for 1 mrem/yr dose option $50.00 cost per ton for trash No Action baseline survey				
Steel		0	0	-5.9	-5.9
Concrete		0	0	-56.4	0
Trash		< -0.1	< -0.1	-0.1	-0.1
Material Disposed at LLW Facility					
Assumptions:	$41.85 cost per ton for steel survey $35.94 cost per ton for concrete survey $74.00 cost per ton for trash survey				
Steel	Unrestricted	0	-0.9		
	EPA/State	-0.9		0	
	Limited Disp	-0.9			0
Concrete	Unrestricted	-9.7	0		
	EPA/State	-10.0		0	
	Limited Disp	-9.7			0
Trash	Unrestricted	0	< -0.1		
	EPA/State	0		0	
	Limited Disp	< -0.1			0
Alternative Total $					
	Unrestricted	-64.5	-61.2		
	EPA/State	-65.7		-62.4	
	Limited Disp	-65.5			-62.2
Net Benefit (Cost) compared to No Action			+3.3	+3.3	+3.3

5. Paperwork Sub-Attribute

The Paperwork sub-attribute is exactly the same value each year for each of the three Alternatives. This sub-attribute cost is associated with the administrative technical labor hours required of the licensees in their preparation and submittal of information supporting the release of solid material from their facilities.

Eighteen facilities are involved in decommissioning activities in the year 2020.

As described in Section 2.2.2 of Appendix K, the number of administrative technical labor hours for each licensee per facility is assumed to be 200, and the labor rate cost is assumed to be $33.84 per hour.

Thus, the value of -$121,824 is assigned to each Alternative (Unrestricted Release, EPA/State-Regulated Disposal and Limited Dispositions) as a cost in 2020 compared to the No Action Alternative. Thus, as with the survey sub-attribute, the paperwork sub-attribute has no differentiation value in ranking the Alternatives compared to No Action.

6. Summary of Industry Operation Benefits and Costs

Table 4-3 in this draft GEIS shows the Industry Operation attribute is by far the most significant of the eight cost attributes quantified in the cost-benefit analysis of the Alternatives compared to No Action. Table 4-3 is in units of present value 2003$, with the analysis having been performed over the years 2003 through 2049.

This attachment provided a discussion of the assumed parameters used for calculations and the results of those calculations for the Industry Operation cost-benefit analysis in the year 2020. The dollar values in this attachment are in current year dollars (2020$). The cost-benefit is for the Unrestricted Release, EPA/State-Regulated Disposal, and Limited Dispositions Alternatives compared to No Action.

The methodology evaluates four cost sub-attributes within the Industry Operation attribute. Two of these -- transportation and disposal – are the significant drivers in the analysis. Table K-39 summarizes the results for the Industry Operation attribute in the year 2020 for the three Alternatives compared to No Action.

The transportation of about 270,000 tons of concrete by truck to a LLW facility (1,544 miles distant) under the No Action baseline is the most significant influence in the transportation costs. (More tonnage is released under the 1 mrem/yr Alternatives than under the No Action dose option.) For the three other Alternatives, this volume of concrete is assumed to be transported either to a concrete recycling facility (198 miles distant) or to a landfill (58 miles distant). For the Unrestricted Release Alternative, there is a larger cost of transporting steel a greater distance to a recycling facility (269 miles) compared to a landfill (58 miles) used in the EPA/State-Regulated Disposal and Limited Disposition Alternatives. As with concrete, the landfill is only 58 miles away, whereas the LLW facility is 1,544 miles. Also, the truck unit cost to the LLW facility is about double, at $0.12 per ton-mile, compared to $0.06 per ton-mile to the landfill.

Table K-39
Summary of Industry Operation Sub-Attribute Benefits and (Costs)
Year 2020 Compared to No Action
(Millions 2020$)

	No Action Baseline	Unrestricted Release	EPA/State-Regulated Disposal	Limited Dispositions
Transportation	0	+43.3	+66.9	+52.4
Disposal and recycle	0	+37.7	-9.6	+31.9
Survey	0	+3.3	+3.3	+3.3
Paperwork	0	-0.1	-0.1	-0.1
Net Benefit (Cost) compared to No Action		+84.2	+60.5	+87.5

For the disposal costs, both the Unrestricted Release and Limited Disposition Alternatives have significant benefits compared to No Action, but the EPA/State-Regulated Disposal Alternative is more costly than No Action. This is due to the EPA/State-Regulated Disposal Alternative having an additional $50 million expense in disposing of concrete in a landfill at $32.19 per ton compared to $5.00 per ton disposal cost at a concrete recycling facility for the other Alternatives. The disposal of steel by selling it as recycled scrap in the Unrestricted Release Alternative provides a benefit of about $8 million in 2020 compared to the other two Alternatives.

This section provided a discussion using year 2020 data. Since the unit costs remain constant and the volume of cleared material changes each year in the analysis, all other years in the analysis would provide similar results as the year 2020 relative to the number of facilities entering their dismantlement activities in that year. The number of facilities starting dismantlement is the basis of the tonnage of solid material available for clearance in 2020 and other years. Eighteen facilities are involved in decommissioning in 2020. In the years 2003 through 2049, the number of facilities entering dismantlement each year ranges from none to 18.

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APPENDIX L
GLOSSARY

Activation
The process of making a radioisotope by bombarding a stable element with neutrons or protons.

Agreement State
A state that has signed an agreement with the Nuclear Regulatory Commission under which the state regulates the use of by-product, source and small quantities of special nuclear material within that state.

Air sampling
The collection of samples of air to measure the radioactivity or to detect the presence of radioactive material, particulate matter, or chemical pollutants in the air.

ALARA
Acronym for "As Low As Reasonably Achievable," means making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as practical, consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest (see 10 CFR 20.1003).

Alpha particle
A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus that has a mass number of 4 and an electrostatic charge of +2. It has low penetrating power and a short range (a few centimeters in air). The most energetic alpha particle will generally fail to penetrate the dead layers of cells covering the skin and can be easily stopped by a sheet of paper. Alpha particles are hazardous when an alpha-emitting isotope is inside the body.

Anion
A negatively charged ion.

Atom
The smallest particle of an element that cannot be divided or broken up by chemical means. It consists of a central core of protons and neutrons, called the nucleus. Electrons revolve in orbits in the region surrounding the nucleus.

Atomic energy
Energy released in nuclear reactions. Of particular interest is the energy released when a neutron initiates the breaking up or fissioning of an atom's nucleus into smaller pieces (fission), or when two nuclei are joined together under millions of degrees of heat (fusion). It is more correctly called nuclear energy.

Attenuation
The process by which the number of particles or photons entering a body of matter is reduced by absorption and scattered radiation.

Background radiation
Radiation from cosmic sources; naturally occurring radioactive materials, including radon (except as a decay product of source or special nuclear material) and global fallout as it exists in the environment from the testing of nuclear explosive devices. It does not include radiation from source, byproduct, or special nuclear materials regulated by the Nuclear Regulatory Commission. The typically quoted average individual exposure from background radiation is 360 millirem per year.

Becquerel (Bq)
The unit of radioactive decay equal to 1 disintegration per second. 37 billion (3.7E+10) becquerels = 1 curie (Ci).

Beta particle
A charged particle emitted from a nucleus during radioactive decay, with a mass equal to 1/1837 that of a proton. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin bums, and beta emitters are harmful if they enter the body. Beta particles may be stopped by thin sheets of metal or plastic.

Bioassay
The determination of kinds, quantities or concentrations, and in some cases, the locations, of radioactive material in the human body, whether by direct measurement (in vivo counting) or by analysis and evaluation of materials excreted or removed (in vitro) from the human body.

Biological halflife
The time required for a biological system, such as that of a human, to eliminate, by natural processes, half of the amount of a substance (such as a radioactive material) that has entered it.

Biological shield
A mass of absorbing material placed around a reactor or radioactive source to reduce the radiation to a level safe for humans.

Boiling water reactor (BWR)
A reactor in which water, used as both coolant and moderator, is allowed to boil in the core. The resulting steam can be used directly to drive a turbine and electrical generator, thereby producing electricity.

British Thermal Unit (Btu)
A British thermal unit. The amount of heat required to change the temperature of one pound of water one degree Fahrenheit at sea level.

Byproduct
Byproduct is (1) any radioactive material (except special nuclear material) yielded in, or made radioactive by, exposure to the radiation incident to the process of producing or using special nuclear material (as in a reactor); and (2) the tailings or wastes produced by the extraction or concentration of uranium or thorium from ore (see 10 CFR 20.1003).

Calibration
The adjustment, as necessary, of a measuring device such that it responds within the required range and accuracy to known values of input.

Cask
A heavily shielded container used to store and/or ship radioactive materials. Lead and steel are common materials used in the manufacture of casks.

Cation
A positively charged ion.

Charged particle
An ion. An elementary particle carrying a positive or negative electric charge.

Cladding
The thin-walled metal tube that forms the outer jacket of a nuclear fuel rod. It prevents corrosion of the fuel by the coolant and the release of fission products into the coolant. Aluminum, stainless steel, and zirconium alloys are common cladding materials.

Clearance
Removal of material that meets certain release criteria from regulatory control.

Collective dose
The sum of the individual doses received on a given period of time by a specified population from exposure to a specified source of radiation.

Committed dose equivalent
This is the dose to some specific organ or tissue that is received from an intake of radioactive material by an individual during the 50-year period following the intake (see 10 CFR 20.1003).

Committed effective dose equivalent
The committed dose equivalent for a given organ multiplied by a weighting factor (see 10 CFR 20.1003).

Compact
A group of two or more States formed to dispose of low-level radioactive waste on a regional basis. Forty-two States have formed nine compacts.

Condenser
A large heat exchanger designed to cool exhaust steam from a turbine below the boiling point so that it can be returned to the heat source as water. In a pressurized water reactor, the water is returned to the steam generator. In a boiling water reactor, it returns to the reactor core. The heat removed from the steam by the condenser is transferred to a circulating water system and is exhausted to the environment, either through a cooling tower or directly into a body of water.

Containment structure
A gaslight shell or other enclosure around a nuclear reactor to confine fission products that otherwise might be released to the atmosphere in the event of an accident.

Control room
The area in a nuclear power plant from which most of the plant power production and emergency safety equipment can be operated by remote control.

Controlled area
At a nuclear facility, an area outside of a restricted area but within the site boundary, access to which can be limited by the licensee for any reason.

Cooling tower
A heat exchanger designed to aid in the cooling of water that was used to cool exhaust steam exiting the turbines of a power plant. Cooling towers transfer exhaust heat into the air instead of into a body of water.

Core
The central portion of a nuclear reactor containing the fuel elements, moderator, neutron poisons, and support structures.

Cosmic radiation
Penetrating ionizing radiation, both particulate and electromagnetic, originating in outer space. Secondary cosmic rays, formed by interactions in the earth's atmosphere, account for about 45 to 50 millirem of the 360 millirem background radiation that an average individual receives in a year.

Counter
A general designation applied to radiation detection instruments or survey meters that detect and measure radiation. The signal that announces an ionization event is called a count.

Crud
A colloquial term for corrosion and wear products (rust particles, etc.) that become radioactive (i.e., activated) when exposed to radiation. Because the activated deposits were first discovered at Chalk River, a Canadian nuclear plant, "crud" has been used as shorthand for Chalk River Unidentified Deposits.

Cumulative dose
The total dose resulting from repeated exposures of ionizing radiation to an occupationally exposed worker to the same portion of the body, or to the whole body, over a period of time (see 10 CFR 20.1003).

Curie (Ci)
The basic unit used to describe the intensity of radioactivity in a sample of material. The curie is equal to 37 billion (3.7E+10) disintegrations per second, which is approximately the activity of 1 gram of radium. A curie is also a quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second. It is named for Marie and Pierre Curie, who discovered radium in 1898.

Daughter products
Isotopes that are formed by the radioactive decay of some other isotope. In the case of radium-226, for example, there are 10 successive daughter products, ending in the stable isotope, lead-206.

Decay, radioactive
The decrease in the amount of any radioactive material with the passage of time due to the spontaneous emission from the atomic nuclei of either alpha or beta particles, often accompanied by gamma radiation.

Decommission
The process of closing down a facility followed by reducing residual radioactivity to a level that permits the release of the property for unrestricted use (see 10 CFR 20.1003).

Decon
A method of decommissioning in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed and safety buried in a low-level radioactive waste landfill or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations.

Decontamination
The reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by: (1) treating the surface to remove or decrease the contamination, (2) letting the material stand so that the radioactivity is decreased as a result of natural radioactive decay, or (3) covering the contamination to shield or attenuate the radiation emitted (see 10 CFR 20.1003 and §20.1402).

Derived air concentration (DAC)
The concentration of radioactive material in air and the time of exposure to that radionuclide, in hours. An NRC licensee may take 2,000 hours to represent one ALI, equivalent to a committed effective dose equivalent of 5 rem (0.05 sievert).

Detector
A material or device that is sensitive to radiation and can produce a response signal suitable for measurement or analysis. A radiation detection instrument.

Deterministic effect
The health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a deterministic effect (also called a non-stochastic effect) (see 10 CFR 20.1003).

Dose
The absorbed dose, given in rads (or the international system of units, grays), that represents the energy absorbed from the radiation in a gram of any material. Furthermore, the biological dose or dose equivalent, given in rems or sieverts, is a measure of the biological damage to living tissue from the radiation exposure.

Dose equivalent
The product of absorbed dose in tissue multiplied by a quality factor, and then sometimes multiplied by other necessary modifying factors at the location of interest. It is expressed numerically in rems or sieverts (see 10 CFR 20.1003).

Dose factor
Multiplier used to convert radionuclide concentrations to dose.

Dose rate
The ionizing radiation dose delivered per unit time. For example, rem or sieverts per hour.

Dose, absorbed
The amount of energy deposited in any substance by ionizing radiation per unit mass of the substance. It is expressed numerically in rads or grays.

Dosimeter
A small portable instrument (such as a film badge, thermoluminescent or pocket dosimeter) for measuring and recording the total accumulated personnel dose of ionizing radiation.

Dosimetry
The theory and application of the principles and techniques involved in the measurement and recording of ionizing radiation doses.

Effective dose
The quantity obtained by multiplying the equivalent dose to various tissues and organs by a weighting factor appropriate to each and summing the products.

Effective halflife
The time required for the amount of a radioactive element deposited in a living organism to be diminished 50% as a result of the combined action of radioactive decay and biological elimination.

Electromagnetic radiation
A traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiation range from x-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wave length.

Electron
An elementary particle with a negative charge and a mass 1/1837 that of the proton. Electrons surround the positively charged nucleus and determine the chemical properties of the atom.

Entomb
A method of decommissioning in which radioactive contaminants are encased in a structurally long-lived material, such as concrete. The entombment structure is appropriately maintained, and continued surveillance is carried out until the radioactivity decays to a level permitting decommissioning and ultimate unrestricted release of the property.

Exclusion area
That area surrounding the reactor, in which the reactor licensee has the authority to determine all activities, including exclusion or removal of personnel and property from the area.

Exposure
Being exposed to ionizing radiation or to radioactive material.

External radiation
Exposure to ionizing radiation when the radiation source is located outside the body.

Fiscal Year
The 12-month period, from October 1 through September 30, used by the Federal Government in budget formulation and execution. The fiscal year is designated by the calendar year in which it ends.

Fissile material
Although sometimes used as a synonym for fissionable material, this term has acquired a more restricted meaning. Namely, any material fissionable by thermal (slow) neutrons. The three primary fissile materials are uranium-233, uranium-235, and plutonium-239.

Fission (fissioning)
The splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation.

Fuel assembly
A cluster of fuel rods (or plates). Also called a fuel element. Many fuel assemblies make up a reactor core.

Fuel cycle
The series of steps involved in supplying fuel for nuclear power reactors. It can include mining, milling, isotopic enrichment, fabrication of fuel elements, use in a reactor, chemical reprocessing

to recover the fissionable material remaining in the spent fuel, re-enrichment of the fuel material, refabrication into new fuel elements, and waste disposal.

Fuel reprocessing
The processing of reactor fuel to separate the unused fissionable material from waste material.

Fuel rod
A long, slender tube that holds fissionable material (fuel) for nuclear reactor use. Fuel rods are assembled into bundles called fuel elements or fuel assemblies, which are loaded individually into the reactor core.

Full-time equivalent
A measurement equal to one staff person working a full-time work schedule for 1 year.

Gamma radiation
High-energy, short wavelength, electromagnetic radiation emitted from the nucleus. Gamma radiation frequently accompanies alpha and beta emissions and always accompanies fission. Gamma rays are very penetrating and are best stopped or shielded by dense materials, such as lead or depleted uranium. Gamma rays are similar to x-rays.

Gas Centrifuge
A uranium enrichment process that uses a large number of rotating cylinders in a series. These series of centrifuge machines, called trains, are interconnected to form cascades. In this process, UF6 gas is placed in a rotating drum or cylinder and rotated at high speed. This rotation creates a strong gravitational field so that the heavier gas molecules (containing U-238) move toward the outside of the cylinder and the lighter gas molecules (containing U-235) collect closer to the center. The stream that is slightly enriched in U-235 is withdrawn and fed into the next higher stage, while the slightly depleted stream is recycled back into the next lower stage. Significantly more U-235 enrichment can be obtained from a single unit gas centrifuge than from a single unit gaseous diffusion barrier.

Gaseous Diffusion Plant
A facility where uranium hexafluoride gas is filtered, uranium-235 is separated from uranium-238, increasing the percentage of uranium-235 from 1 to about 3 percent. The process requires enormous amounts of electric power.

Geiger-Mueller counter
A radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage, but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. It was named for Hans Geiger and W. Mueller, who invented it in the 1920s. It is sometimes called simply a Geiger counter or a G-M counter, and is the most commonly used portable radiation instrument.

Gigawatt
One billion watts.

Gigawatthour
One billion watt-hours.

Graphite
A form of carbon, similar to the lead used in pencils, used as a moderator in some nuclear reactors.

Gray (Gy)
The international system (SI) unit of absorbed dose. One gray is equal to an absorbed dose of 1 Joule/kilogram (one gray equals 100 rads) (see 20.1004).

Halflife
The time in which one half of the atoms of a particular radioactive substance disintegrates into another nuclear form. Measured half-lives vary from millionths of a second to billions of years. Also called physical or radiological halflife

Halflife, biological
The time required for the body to eliminate one half of the material taken in by natural biological means.

Halflife, effective
The time required for a radionuclide contained in a biological system, such as a human or an animal, to reduce its activity by one-half as a combined result of radioactive decay and biological elimination.

Head, reactor vessel
The removable top section of a reactor pressure vessel. It is bolted in place during power operation and removed during refueling to permit access of fuel handling equipment to the core.

Health physics
The science concerned with the recognition, evaluation, and control of hazards to health and the environment that may arise from the use and application of ionizing radiation.

Heat exchanger
Any device that transfers heat from one fluid (liquid or gas) to another fluid or to the environment.

Hot
A colloquial term meaning highly radioactive.

Hot spot
The region in a radiation/contamination area in which the level of radiation/contamination is significantly greater than in neighboring regions in the area.

Impacted Area
An area with some reasonable potential for residual radioactivity in excess of natural background or fallout levels.

Ion-exchange
A common method for concentrating uranium from a solution. The uranium solution is passed through a resin bed where the uranium-carbonate complex ions are transferred to the resin by exchange with a negative ion like chloride. After build-up of the uranium complex on the resin, the uranium is eluted with a salt solution and the uranium is precipitated in another process.

Isotope
Any two or more forms of an element having identical or very closely related chemical properties and the same atomic number but different atomic weights or mass numbers.

Kilovolt
The unit of electrical potential equal to 1,000 volts.

Leachate
An often toxic liquid that forms as water seeps down through waste in a landfill and collects contaminates from the waste.

Light water
Ordinary water as distinguished from heavy water.

Light water reactor
A term used to describe reactors using ordinary water as coolant, including boiling water reactors (BWRs) and pressurized water reactors (PWRs), the most common types used in the United States.

Loop
In a pressurized water reactor, the coolant flow path through piping from the reactor pressure vessel to the steam generator, to the reactor coolant pump, and back to the reactor pressure vessel. Large PWRs may have as many as four separate loops.

Low-level waste
A general term for a wide range of wastes having low levels of radioactivity. Industries, hospitals and medical, educational, or research institutions; private or government laboratories; and nuclear fuel cycle facilities (e.g., nuclear power reactors and fuel fabrication plants) that use radioactive materials generate low-level wastes as part of their normal operations. These wastes are generated in many physical and chemical forms and levels of contamination (see 10 CFR 61.2). Low-level radioactive wastes containing source, special nuclear, or byproduct material are acceptable for disposal in a land disposal facility. For the purposes of this definition, low-level waste has the same meaning as in the Low-level Waste Policy Act, that is, radioactive waste not classified as high-level radioactive waste, transuranic waste, spent nuclear fuel, or byproduct material as defined in section 11e.(2) of the Atomic Energy Act (uranium or thorium tailings and waste). See also High-level waste.

Material-independent dose factors
Dose factors that consider the most conservative dose factor for each radionuclide, regardless of the material.

Material-specific dose factors
Dose factors based on the most limiting scenario.

Megacurie
One million curies.

Megawatt (MW)
One million watts.

Megawatt hour (MWh)
One million watt-hours.

Metric ton
Approximately 2,200 pounds in the English system of measurements (Note: in the international system of measurements, 1 metric ton = 1000 kg.)

Microcurie
One millionth of a curie. That amount of radioactive material that disintegrates (decays) at the rate of 37 thousand atoms per second.

Mill tailings
Naturally radioactive residue from the processing of uranium ore into yellowcake in a mill. Although the milling process recovers about 93 percent of the uranium, the residues, or tailings, contain several naturally-occurring radioactive elements, including uranium, thorium, radium, polonium, and radon.

Millirem
One thousandth of a rem (0.001 rem).

Mixed oxide fuel
A mixture of uranium oxide and plutonium oxide used to fuel a reactor. Mixed oxide fuel is often abbreviated as "MOX." Conventional nuclear fuel is made of pure uranium oxide.

Monitoring of Radiation
Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in a region, as a safety measure, for the purpose of health or environmental protection. Monitoring is done for air, surface, & ground water, soil & sediment, equipment surfaces, and personnel (for example, bioassay or alpha scans).

Nanocurie
One billionth (10-9) of a curie.

Natural uranium
Uranium as found in nature. It contains 0.7 percent uranium-235, 99.3 percent uranium-238, and a trace of uranium-234 by weight. In terms of the amount of radioactivity, it contains approximately 2.2 percent uranium-235, 48.6 percent uranium-238, and 49.2 percent uranium-234.

Neutron
An uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.

Nonpower reactor
Reactors used for research, training, and test purposes, and for the production of radioisotopes for medical and industrial uses.

Nuclear energy
The energy liberated by a nuclear reaction (fission or fusion) or by radioactive decay.

Nuclear power plant
An electrical generating facility using a nuclear reactor as its heat source to provide steam to a turbine generator.

Nuclear waste
A particular type of radioactive waste, that is produced as part of the nuclear fuel cycle, i.e., those activities needed to produce nuclear fission, or splitting of the atom. These include extraction of uranium from ore, concentration of uranium, processing into nuclear fuel, and disposal of byproducts. Radioactive waste is a broader terms that includes all waste that contains radioactivity. Residues from water treatment, contaminated equipment from oil drilling, and tailings from the processing of metals such as vanadium and copper, also contain radioactivity but are not "nuclear waste" because they are produced outside of the nuclear fuel cycle. NRC generally regulates only those wastes produced in the nuclear fuel cycle (uranium mill tailings, depleted uranium, spent fuel rods, etc).

Nucleon
Common name for a constituent particle of the atomic nucleus. At present, applied to protons and neutrons, but may include any other particles found to exist in the nucleus.

Nucleus
The small, central, positively charged region of an atom. Except for the nucleus of ordinary hydrogen, which has only a proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge or atomic number. This number is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons is called the mass number.

Nuclide
A general term referring to all known isotopes, both stable (279) and unstable (about 2,700), of the chemical elements.

Parent
A radionuclide that upon radioactive decay or disintegration yields a specific nuclide (the daughter).

Parts per million (ppm)
Parts (molecules) of a substance contained in a million parts of another substance (or water).

Personnel monitoring
The use of portable survey meters to determine the amount of radioactive contamination on an individual, or the use of dosimetry to determine an individual's occupational radiation dose.

Photon
A quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.

Picocurie
One trillionth (10-12) of a curie.

Pig
A colloquial term describing a container (usually lead or depleted uranium) used to ship or store radioactive materials. The thick walls of this shielding device protect the person handling the container from radiation. Large containers used for spent fuel storage are commonly called casks.

Point source
Any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, landfill leachate collection system, vessel or other floating craft from which pollutants are or may be discharged. This term does not include return flows from irrigated agriculture or agricultural storm water runoff. (See 40 CFR 122.3).

Potentially Clearable Material
Solid materials that originate in restricted or impacted areas of NRC/Agreement State-licensed facilities, and have no, or very small amounts of, radioactivity resulting from licensed operations.

Power reactor
A reactor designed to produce heat for electric generation, as distinguished from reactors used for research, for producing radiation or fissionable materials, or for reactor component testing.

Pressure vessel
A strong-walled container housing the core of most types of power reactors. It usually also contains the moderator, neutron reflector, thermal shield, and control rods.

Pressurized water reactor (PWR)
A power reactor in which heat is transferred from the core to an exchanger by high temperature water kept under high pressure in the primary system. Steam is generated in a secondary circuit. Many reactors producing electric power are pressurized water reactors.

Proton
An elementary nuclear particle with a positive electric charge located in the nucleus of an atom.

Quality Factor
Factor by which the absorbed dose (rad or gray) is to be multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage (rem or sievert) to an exposed individual. It is used because some types of radiation, such as alpha particles, are more biologically damaging internally than other types.

Rad
The special unit for radiation absorbed dose, which is the amount of energy from any type of ionizing radiation (e.g., alpha, beta, gamma, neutrons, etc.) deposited in any medium (e.g., water, tissue, air). A dose of one rad means the absorption of 100 ergs (a small but measurable amount of energy) per gram of absorbing tissue (100 rad = 1 gray).

Radiation (ionizing radiation)
Alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Radiation, as used in 10 CFR Part 20, does not include non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light (see also 10 CFR 20.1003).

Radiation area
Any area with radiation levels greater than 5 millirem (0.05 millisievert) in one hour at 30 centimeters from the source or from any surface through which the radiation penetrates.

Radiation source
Usually a sealed source of radiation used in teletherapy and industrial radiography, as a power source for batteries (as in use in space craft), or in various types of industrial gauges. Machines, such as accelerators and radioisotope generators, and natural radionuclides may be considered sources.

Radiation standards
Exposure standards, permissible concentrations, rules for safe handling, regulations for transportation, regulations for industrial control of radiation, and control of radioactive material by legislative means.

Radiation Survey
In the context of the GEIS, "radiation survey" is used to define various types of surveys conducted to assess levels of residual radioactivity in or on material and equipment. Such surveys include the use of conventional radiation detection instrumentation, and sample collection and sample analysis using appropriate types of analytical equipment and procedures. The use of any one method or combination of methods are mandated by the type of material, radionuclide distributions and their relative mix, and detection limits in comparison to allowable dose criteria.

Radiation, nuclear
Particles (alpha, beta, neutrons) or photons(gamma) emitted from the nucleus of unstable radioactive atoms as a result of radioactive decay.

Radioactive decay
Large unstable atoms can become more stable by emitting radiation. This process is called radioactive decay. This radiation can be emitted in the form of a positively charged ALPHA particle, a negatively charged BETA particle, or GAMMA RAYS or X-RAYS.

Radioactivity
The spontaneous emission of radiation, generally alpha or beta particles, often accompanied by gamma rays, from the nucleus of an unstable isotope. Also, the rate at which radioactive material emits radiation. Measured in units of becquerels or disintegrations per second.

Radioisotope
An unstable isotope of an element that decays or disintegrates spontaneously, emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified.

Radionuclide
A radioisotope.

Reaction
Any process involving a chemical or nuclear change.

Reactivity
A term expressing the departure of a reactor system from criticality. A positive reactivity addition indicates a move toward supercriticality (power increase). A negative reactivity addition indicates a move toward subcriticality (power decrease).

Reactor coolant system
The system used to remove energy from the reactor core and transfer that energy either directly or indirectly to the steam turbine.

Reactor, nuclear
A device in which nuclear fission may be sustained and controlled in a self-supporting nuclear reaction. The varieties are many, but all incorporate certain features, including fissionable material or fuel, a moderating material (unless the reactor is operated on fast neutrons), a reflector to conserve escaping neutrons, provisions of removal of heat, measuring and controlling instruments, and protective devices. The reactor is the heart of a nuclear power plant.

Reference man
A person with the anatomical and physiological characteristics of an average individual which is used in calculations assessing internal dose (also may be called "Standard Man").

REM
The acronym for Roentgen Equivalent Man is a standard unit that measures the effects of ionizing radiation on humans. The dose equivalent in rems is equal to the absorbed dose in rads multiplied by the quality factor of the type of radiation (see 10 CFR 20.1004).

Restricted area
Any area to which access is controlled for the protection of individuals from exposure to radiation and radioactive materials.

Risk-informed regulation
Incorporating an assessment of safety significance or relative risk in NRC regulatory actions. Making sure that the regulatory burden imposed by individual regulations or processes is commensurate with the importance of that regulation or process to protecting public health and safety and the environment.

Rubblization
A decommissioning technique involving demolition and burial of formerly operating nuclear facilities. All equipment from buildings is removed and the surfaces are decontaminated. Above-grade structures are demolished into rubble and buried in the structure's foundation below ground. The site surface is then covered, regraded and landscaped for unrestricted use.

Runoff
Water from precipitation or irrigation that flows over the ground and does not infiltrate the ground surface. It may collect pollutants from the land and carry them into receiving water bodies.

Sealed source
Any radioactive material or byproduct encased in a capsule designed to prevent leakage or escape of the material.

Secondary radiation
Radiation originating as the result of absorption of other radiation in matter. It may be either electromagnetic or particulate in nature.

Sievert (Sv)
The new international system (SI) unit for dose equivalent equal to 1 Joule/kilogram. 1 sievert = 100 rem.

Somatic effects of radiation
Effects of radiation limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent unexposed generations.

Source material
Uranium or thorium, or any combination thereof, in any physical or chemical form or ores that contain by weight one-twentieth of one percent (0.05%) or more of (1) uranium, (2) thorium, or (3) any combination thereof. Source material does not include special nuclear material.

Special nuclear material
Plutonium, uranium-233, or uranium enriched in the isotopes uranium-233 or uranium-235.

Spent (or depleted) nuclear fuel
Fuel that has been removed from a nuclear reactor because it can no longer sustain power production for economic or other reasons.

Steel slag
A solid made of the silicate and oxide components found in iron, which are considered undesirable in steel. It is a by-product formed during the removal of excess quantities of carbon and silicon from iron in the production of steel.

Stochastic effects
Effects that occur by chance, generally occurring without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose. In the context of radiation protection, the main stochastic effects are cancer and genetic effects.

Storm water discharge associated with industrial activity
Discharge from any conveyance that is used for collecting and conveying storm water and that is directly related to manufacturing, processing or raw materials storage areas at an industrial plant (see 40 CFR 122.26(b)14).

Survey meter
Any portable radiation detection instrument especially adapted for inspecting an area or individual to establish the existence and amount of radioactive material present.

Terrestrial radiation
The portion of the natural background radiation that is emitted by naturally occurring radioactive materials, such as uranium, thorium, and radon in the earth.

Thermal neutron
Neutrons that have been slowed to the degree that they have the same average thermal energy as the atoms or molecules through which they are passing. The average energy of neutrons at ordinary temperatures is about 0.025 eV, corresponding to an average velocity of 2.2 × 103 m s-1.

Thermal power
The total core heat transfer rate to the reactor coolant.

Thermal reactor
A reactor in which the fission chain reaction is sustained primarily by thermal neutrons. Most current reactors are thermal reactors.

Transuranic Element
An artificially made, radioactive element that has an atomic number higher than uranium in the Periodic Table of Elements such as neptunium, plutonium, americium, and others.

Transuranic Waste
Waste containing more than 100 nCi/g of alpha-emitting transuranic isotopes per gram of waste, with half-lives greater than 20 years.

Turbine
A rotary engine made with a series of curved vanes on a rotating shaft, usually turned by water or steam. Turbines are considered the most economical means to turn large electrical generators.

Turbine generator (TG)
A steam (or water) turbine directly coupled to an electrical generator. The two devices are often referred to as one unit.

Unrestricted area
The area outside the owner-controlled portion of a nuclear facility (usually the site boundary). An area in which a person could not be exposed to radiation levels in excess of 2 millirem in any one hour from external sources (see 10 CFR 20.1003).

Uranium fuel fabrication facility
A facility that (1) manufactures reactor fuel containing uranium for any of the following (I) preparation of fuel materials; (ii) formation of fuel materials into desired shapes; (iii) application of protective cladding; (iv) recovery of scrap material; and (v) storage associated with such operations; or (2) conducts research and development activities.

Uranium hexafluoride production facility
A facility that receives natural uranium in the form of ore concentrate; processes the concentrate and converts it into uranium hexafluoride (UF6).

Waste, radioactive
Radioactive materials at the end of a useful life cycle or in a product that is no longer useful and should be properly disposed of.

Watt
An electrical unit of power. 1 watt = 1 Joule/second. It is equal to the power in a circuit in which a current of one ampere flows across a potential difference of one volt.

Watt-hour
An electrical energy unit of measure equal to 1 watt of power supplied to, or taken from, an electrical circuit steadily for 1 hour.

Whole-body counter
A device used to identify and measure the radioactive material in the body of human beings and animals. It uses heavy shielding to keep out naturally existing background radiation and ultrasensitive radiation detectors and electronic counting equipment.

Whole-body exposure

For purposes of whole body exposure includes at least the external exposure, head, trunk, arms above the elbow, or legs above the knee. Where a radioisotope is uniformly distributed throughout the body tissues, rather than being concentrated in certain parts, the irradiation can be considered as whole-body exposure (see also 10 CFR 20.1003).

Wipe sample

A sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area. It is also known as a "swipe or smear" sample.

X-rays

Penetrating electromagnetic radiation (photon) having a wavelength that is much shorter than that of visible light.

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