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Alternative Transuranic Waste Management Strategies at Los Alamos National Laboratory

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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L. J. Walker
W. R. Hansen
D. C. Nelson
G. Maestas
W. J. Wenzel
F. A. Guevara
J. L. Warren
J. C. Rodgers
J. M. Graf

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

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ALTERNATIVE TRANSURANIC WASTE MANAGEMENT STRATEGIES AT LOS ALAMOS NATIONAL LABORATORY

by

L. J. Walker, W. R. Hansen, D. C. Nelson, G. Maestas, W. J. Wenzel,
F. A. Guevara, J. L. Warren, J. C. Rodgers, and J. M. Graf

ABSTRACT

As an integral part of the ongoing U.S. Department of Energy (DOE) waste management programs, several strategies have been identified and evaluated for the long-term management of defense transuranic (TRU) waste now buried or stored at the Los Alamos National Laboratory. The 14 alternatives evaluated are combinations of the following operations: (1) Continue present practices (CPP), (2) Engineered improvements (EI), (3) Exhume the buried waste and retrieve the stored waste, (4) Segregate the TRU from the low-level (LL) wastes with reburial of the LL wastes, (5) Resize and package the TRU wastes, (6) Process the TRU wastes, and disposal either by (7) Burial in a deeper pit or pits at Los Alamos, or (8) Emplacement in a federally owned deep geological repository.

TRU wastes are located in six waste disposal areas with an estimated volume of wastes, backfill materials, and projected accumulations to the year 1990 totalling ~330 000 m^3 (~12 000 000 ft^3).

Estimated costs in dollars, environmental, radiological and other impacts are generally proportional to the amount of handling, processing, transportation over the short term (15 yr), and the institutional control period (100 yr). Possible long-term impacts, over several thousands of years, are dependent upon the possible uses of the disposal site lands over these prolonged time periods. The higher estimates of impacts relate to urbanization and commercial uses and the lower estimates stem from agricultural and undeveloped land uses. Man-caused changes in erosion produce the greatest long-term contact possibility of waste by humans and release of wastes to the biosphere.

This document provides the public and government agencies with possible alternative waste management strategies and serves as the basis for discussion and comment.

1. SUMMARY

As an integral part of the ongoing U.S. Department of Energy (DOE) waste management programs, several strategies for the long-term management defense transuranic (TRU)* wastes currently buried and stored at the Los Alamos National Laboratory have been identified and evaluated.

The strategy list was reduced because of local conditions, engineering, and economic constraints, to 14 alternatives for the long-term management of the Los Alamos TRU wastes. No preselection or prejudgment was made on one or another of the alternatives; instead data are presented to allow comparison of the alternatives and to solicit comments and suggestions leading to selection of an alternative or combination for possible future implementation.

The alternatives studied are various combinations of the following operations: (1) Continue present practices (CPP); (2) Engineered improvements (EI); (3) Exhume buried waste and retrieve stored waste; (4) Segregate TRU from the low level (LL) wastes; (5) Resize and package TRU wastes; (6) Process TRU wastes, and dispose of the TRU waste by (7) Burial in a deeper pit at Los Alamos; or, (8) Dispose of the TRU waste in a federally owned, deep, geological repository. The 14 alternatives comprise selected combinations of these 8 operations.

This assessment considers that those options leaving the TRU wastes in their present locations could represent permanent disposal. However, the intent is not to abandon the wastes but rather to allow a base for future social-political decisions.

Removal of the stored TRU from Los Alamos to a repository could result in a reduction of ~90% or more of the TRU material buried and stored in the wastes at Los Alamos.

Typical TRU wastes at Los Alamos include tools, instruments, equipment, sludge and cement, building materials (from the decontamination and decommissioning of older facilities), and general refuse (such as paper, plastics, rubber, glassware, etc.). Before mid-1971, TRU wastes were not segregated nor retrievably stored. Therefore, some earlier waste burials contained both TRU and LL wastes mixed together. These wastes are located in six waste disposal areas at Los Alamos. The estimated volume occupied by these wastes, the backfill used to cover the wastes when the wastes were placed into the disposal area, and the TRU wastes accumulated to the year 1990, total ~330 000 m^3 (~12 000 000 ft^3). This estimate includes (1) unknown amounts of backfill cover that were used and (2) possible contamination of the backfill by its being mixed with the wastes. Low-level wastes were not included in this study, even though many of the buried wastes are known to contain both TRU and LL wastes.

Costs, including possible impacts, the commitment of resources, and the radiological assessment of each of the alternatives and options were estimated, using the best data available. Numerous engineering estimations were required for analysis although many subjects were incompletely covered. Possible environmental and radiological consequences of both normal and accident scenarios were calculated. Projections for human exposure included occupationally exposed workers, the general population in 22.5° sectors to a distance of 80 km (50 mi), and the population of Albuquerque.

Comparisons of the 14 alternatives are given in the text and in Table 1-1. For ease of comparison, the CPP alternative is used as a common base, with the dollar cost assigned the value of unity (1.0) and the other alternatives then listed as multiples of the value for the CPP alternative. Possible radiological risks are compared to the local natural background level.

Strict comparisons must consider that differing time periods were used in the options. That is, the CPP and EI options assume 100 yr of continuing institutional control, as opposed to options based on 15 yr of Los Alamos operations, after which the TRU wastes are removed to a federal repository. The 100-yr period includes periodic site maintenance and surveillance. However, at any time during or at the end of 100 yr, other options could be reconsidered. The wastes would not simply be abandoned. In many cases, the cost estimates may be off by as much as a factor of ~2 because of the lack of data in areas such as estimated volumes, inventories, other unknowns requiring gross estimations to perform the calculations, and possible conditions when exhumation is started. The dollar-cost estimates are in April 1980 dollars, with no allowances

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*A Glossary of Abbreviations and Terms is presented in Appendix A.

TABLE 1-1

COMPARISON OF ALTERNATIVES

				Relative			
Alternative No.	Buried	Stored	Time (yr)	Dollar Costs[a]	Radiological Risk[b]	Advantages	Disadvantages
1	Continue Present Practices (CPP)	Continue Present Practices (CPP)	100	1.0	0.1	Least cost	No improvement
2	Engineered Improvement	Engineered Improvement	100	1.1	0.1	Least risk; some improvement	TRU wastes still in 6 separate areas
3	Continue Present Practices	Retrieve, package TRU, deep pit at Los Alamos	100	1.1	1.0	Stored TRU all buried and in one place	Does nothing for the buried TRU wastes
4	Continue Present Practices	Same as No. 3 except except federal repository	100	1.5	1.2	Stored TRU removed to offsite	Does nothing for the buried wastes, and higher risk
5	Continue Present Practices	Retrieve, package TRU, deep pit at Los Alamos	100	1.7	2.0	Stored TRU wastes reduced in volume and better contained at site	Does nothing for the buried TRU, higher costs and risk. Deep pit required
6	Continue Present Practices	Same as No. 5, except to offsite	100	1.8	1.9	Same as No. 5; no deep pit required. Stored TRU offsite	Higher costs and risks
7	Engineered Improvement	Retrieve, package TRU, deep pit at Los Alamos	100	1.1	0.9	Buried and stored; better confined. All stored in one location	Required a deep pit and resources
8	Engineered Improvement	Same as No. 7 except offsite	100	1.5	1.2	Stored TRU removed to offsite. No deep pit required.	Buried TRU still in 6 separate locations
9	Engineered Improvement	Retrieve, process TRU, deep pit at Los Alamos	100	1.8	2.0	Volume reduction and better fixation of stored TRU wastes	Buried TRU wastes still in 6 separate locations. Requires deep pit
10	Engineered Improvement	Same as No. 9, except offsite	100	1.9	1.9	Volume reduction and better immobilization. Stored TRU removed to offsite. No deep pit required	Buried still in 6 separate locations
11	Exhume, package TRU, deep pit at Los Alamos	Retrieve, package TRU deep pit at Los Alamos	15	3.4	7.0	All TRU into one location	Deep pit required. Higher costs and risks
12	Same as No. 11, except disposal offsite	Same as No. 11, except disposal offsite	15	5	8.7	All TRU wastes removed to offsite	Higher costs and risks
13	Exhume, package, and process TRU and dispose in deep pit at Los Alamos	Retrieve, package, and process TRU, and dispose in deep pit at Los Alamos	15	6	11.5	All TRU wastes better immobilized and in one location	Higher costs and risks. Deep pit required
14	Same as No. 13 except disposal offsite in federal repository	Same as No. 13 except disposal offsite in federal repository	15	7	13.5	All TRU wastes better immobilized and removed. No deep pit required	Higher costs and risks

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[a] Multiples of the value for the CPP alternative.

[b] Compared to local natural background external dose (98 mrem). See Sec. 7 and Appendix D for details, and Table 7-12 for comparative risk perceptions.

for inflation. Many of the accident or upset conditions are based on "worst case" conditions rather than on historical experience in waste handling at the Laboratory.

The possible long-term effects over prolonged time periods and various land usages were also estimated. The possible effects over several hundreds to thousands of years of land use under the first alternatives resulted in smaller doses than did alternatives requiring more extensive waste handling.

Alternative 1 is Continue Present Practices or CPP. Under this strategy, the buried and the stored wastes would be left in their locations, and surveillance and maintenance would continue for an assumed period of 100 yr of Laboratory control. Among the major advantages of this strategy are commitment of the least number of dollars, low estimated population risk, and the possibility of switching any of the other alternatives in the future. For comparison, the dollar costs of this alternative have been arbitrarily assigned a value of unity. This strategy covers 100 yr. Among the major disadvantages are that the buried and stored wastes would remain in six separate disposal sites, and no improvement is made in their disposal.

Alternative 2 is Engineered Improvement or EI, of both the buried and the stored wastes. The amount of cover over the existing waste sites would be increased, and a final riprap cover would be added. The dollar cost for this strategy is ~1.1 times that of the CPP alternative, and the estimated total radiation risk (to workers, to the public within a radius of 80 km, and to Albuquerque residents) is 0.1 times the local external background dose. The time required for covering the waste sites is probably <10 yr, but the time base includes 100 yr of surveillance and maintenance. Among the major advantages possible are increased protection from possible intrusion and erosion and increased radiological risk protection. Radiological risk is decreased because the wastes would not be uncovered or contacted, but rather additional cover would be added. Among the possible disadvantages are a slightly greater (1.1 times more) commitment of resources, such as equipment, manpower, fuel and utility costs, additional fill material and riprap, and the wastes would still be located in the six separate disposal sites.

Alternative 3 is a combination of strategies. The buried waste would be left as is, that is, CPP, whereas the stored waste would be retrieved and the TRU wastes packaged and buried deeper than conventional shallow land burial at Los Alamos. Retrieval and packaging would be completed within a short period of time, but the costs still include the 100 yr of institutional control, because of the buried waste. The main advantages for this alternative are that all of the stored TRU wastes would be in one location and that they would be more permanently buried rather than retrievably stored. The dollar cost of this alternative is ~1.1 times that of the CPP alternative, and the relative radiological risk is about equal to the background dose. Among the possible disadvantages are that the buried wastes would still be in the six separate sites, they would still require 100 yr of surveillance and maintenance, a deeper pit or pits would be required, and all of the TRU wastes would still be at Los Alamos.

Alternative 4 involves CPP for the buried waste, whereas the stored TRU wastes would be retrieved, packaged (with resizing as necessary), and disposed of offsite at a federally owned deep geological repository. The dollar costs for this alternative are ~1.5 times those of the first alternative with a relative radiological risk of ~1.2 times background. Among the possible advantages are presently stored TRU wastes would be disposed of at a national repository, remote from Los Alamos, thus removing 90% or more of the TRU. Among the possible disadvantages are the higher cost and radiological risk and the buried TRU wastes would remain at Los Alamos. Resizing, processing, and/or repackaging may be required for repository acceptance.

Alternative 5 also uses CPP for buried wastes, while retrieving stored TRU wastes, processing them, and disposing of them in a deeper pit at Los Alamos. The processing includes incineration of combustibles, decontamination of metals, immobilization of residuals and unprocessed wastes, and packaging. The dollar cost for this alternative is ~1.7 times that for CPP, with a radiological risk of about twice background. While processing operations are estimated to require only ~15 yr for completion, the CPP of the buried wastes would still require 100 yr of surveillance and maintenance. The advantage of this alternative is locating the stored TRU waste in one location. Among the possible disadvantages are higher cost, higher radiological risk, commitment of additional resources, such as manpower, fuel and utilities, a deep pit, and continued storage of the TRU wastes at Los Alamos.

Alternative 6 is the same as Alternative 5, except that the wastes currently stored would be transferred to a federal deep geological repository instead of a deep pit at Los Alamos. The relative dollar cost is ~1.8 times higher, and the radiological risk factor is ~1.9 times higher than background. The main advantages include those listed under alternative 5 and removal of wastes currently stored (which contain most of the TRU) from Los Alamos. The possible disadvantages include higher cost and radiological risk during transport.

Alternative 7 is to provide EI for the buried wastes while retrieving and packaging the stored TRU wastes, with disposal in a deep pit at Los Alamos. The time periods are the same as previously described, 15 yr or less for the retrieval, etc., and 100 yr of institutional control. The costs of this alternative are ~1.1 times the CPP dollars and ~0.9 times the normal background dose. The possible advantages include those listed under Alternative 5 and removal of wastes currently stored (which contain most of the TRU) from Los Alamos. The possible disadvantages include higher cost and radiological risk during transport, construction of a deeper pit, the higher radiological risk associated with retrieval and handling, and keeping all of the TRU at Los Alamos.

Alternative 8 provides for EI for the buried wastes while the stored TRU wastes are retrieved, resized as necessary, and packaged (as in Alternative 4), with disposal in a federal repository within 15 yr. Relative costs are ~1.5 and the radiological risks are 1.2 times background. The main advantage is removal of most of the TRU wastes from Los Alamos. The main disadvantages include greater commitment of dollars, resources, and higher risks.

Alternative 9 provides for EI over the buried wastes and retrieval, processing, and deep pit burial at Los Alamos for stored TRU wastes. The relative costs are ~1.8 times the dollars and about twice background for the radiological risk. The main advantages include better immobilization and reduction of the amount of stored TRU wastes. The possible disadvantages include TRU remaining at Los Alamos and higher costs and risks associated with waste handling.

Alternative 10 also provides EI for buried wastes, while disposing of stored TRU wastes at the federal repository. The relative costs are ~1.9 times the dollars and ~1.9 times higher radiological risks. The main advantage is removing stored wastes from Los Alamos. The possible disadvantages include the higher dollar costs and greater risks.

Alternative 11 would handle both the buried and the stored TRU wastes in the same manner. After exhumation and retrieval, the TRU would be segregated out and the LL wastes buried. The TRU wastes would be repackaged and buried in a deep pit at Los Alamos. The relative costs are ~3.4 times the dollars and ~7.0 times the relative radiological risk. Among the possible advantages are removal of all of the buried and stored TRU wastes to one disposal site. The disadvantages include the higher commitment of dollars and greater risk, caused by exhumation operations, as well as the greater commitment of manpower, equipment, fuel and utilities, and other resources, and keeping the wastes onsite. Field operations are estimated to require ~15 yr.

Alternative 12 is the same as Alternative 11, except that the TRU wastes might require resizing for acceptance at a federal repository. The estimated time for completion of the operation is ~15 yr. The costs are ~5 times the dollar costs and ~8.7 times the relative risk. Among the possible advantages are removal of all of the TRU wastes from Los Alamos. The possible disadvantages include the higher costs in dollars and other resources, plus the increased risk.

Alternative 13 is to exhume the buried waste, retrieve stored waste, and segregate TRU from the LL wastes, which would be reburied onsite. The TRU wastes would be processed, as described for the stored wastes under Alternative 5, and the processed TRU wastes would be buried in a deeper pit at Los Alamos. The relative dollar costs are ~6 times higher and the radiological risk ~11.5 times higher. The advantages include better immobilization of the TRU wastes and location of all the TRU wastes in one place. The possible disadvantages include increased costs, higher risk factor, keeping TRU wastes onsite, digging a deeper pit or pits than those onsite, and a greater commitment of resources.

Alternative 14 is the same as Alternative 13, except that the disposal would be to an offsite, federally owned deep geological repository. Field work is estimated to require ~15 yr. The relative dollar costs are ~7 times higher and the radiological risk ~13.5 times background. The advantages are that the TRU wastes would be better immobilized, reduced in volume, and removed from Los Alamos. The disadvantages include the higher cost in dollars, the increased relative risk, and the commitment of resources for field operations, such as manpower, equipment, fuel, and utilities.

A more complete evaluation for each of these alternatives is presented in the text of the document.

2. INTRODUCTION

2.1 Purpose of the Study

This document provides the public and government agencies with possible alternatives for the long-term management of TRU wastes at Los Alamos National Laboratory.

Implementation technology is described for the 14 alternatives that were studied. Preliminary estimates present the benefits of each alternative, the estimated costs in dollars, possible radiological dose risks, and commitment of resources.

Estimated radiological doses were calculated for the operations required for each alternative under both normal and accident scenario conditions. The exposed population included (1) occupationally exposed workers, (2) the total population within each 22.5° sector to a distance of 80 km (50 mi), and (3) the population of Albuquerque. Albuquerque was included primarily because of its much larger population. These calculated doses were based upon the time period for each of the alternatives, either 100 or 15 yr, and the lifetime dose commitment for all exposed groups. Methodology is more fully explained in Sec. 7.

One hundred years is a reasonable estimate of the period of continuing institutional custody (Sec. 7.3.2). It is expected that a more permanent disposal or site closure method would be implemented during this 100 yr rather than abandonment of the waste sites after the 100 yr.

This document considers several options along with the advantages, costs, and other pertinent data on each alternative. No attempt is made to advocate any alternative. Instead, this document solicits comments to be considered in the selection of an alternative or combination of alternatives for further consideration and possible implementation.

2.2 Scope

This Alternatives Document, based on current information, identifies the possible locations of the TRU wastes, provides volume estimates of TRU waste buried and stored at Los Alamos, and describes possible alternative strategies for the long-term management of these wastes. Long-term management of the LL wastes is not included in the Alternatives Document.

Several TRU waste management strategies were considered. Because specific information was not always available, several engineering judgments had to be made, as described more fully in Sec. 4. Fourteen alternatives were selected for more detailed study and analysis, as described in Sec. 5 and Appendix B. Alternatives considered but not selected for this study are presented in Sec. 5.4, along with an abbreviated discussion of each.

During the study, it was not known whether a federally owned deep geological repository would be available by 1990, when field operations for several of the alternatives might be started. Therefore, the evaluation had to assume that (1) disposal would be at Los Alamos in a deeper pit or (2) a federal repository would be available and wastes would be accepted for disposal. To estimate transportation costs and risks, it was assumed the federal facility would be located in southeastern New Mexico.

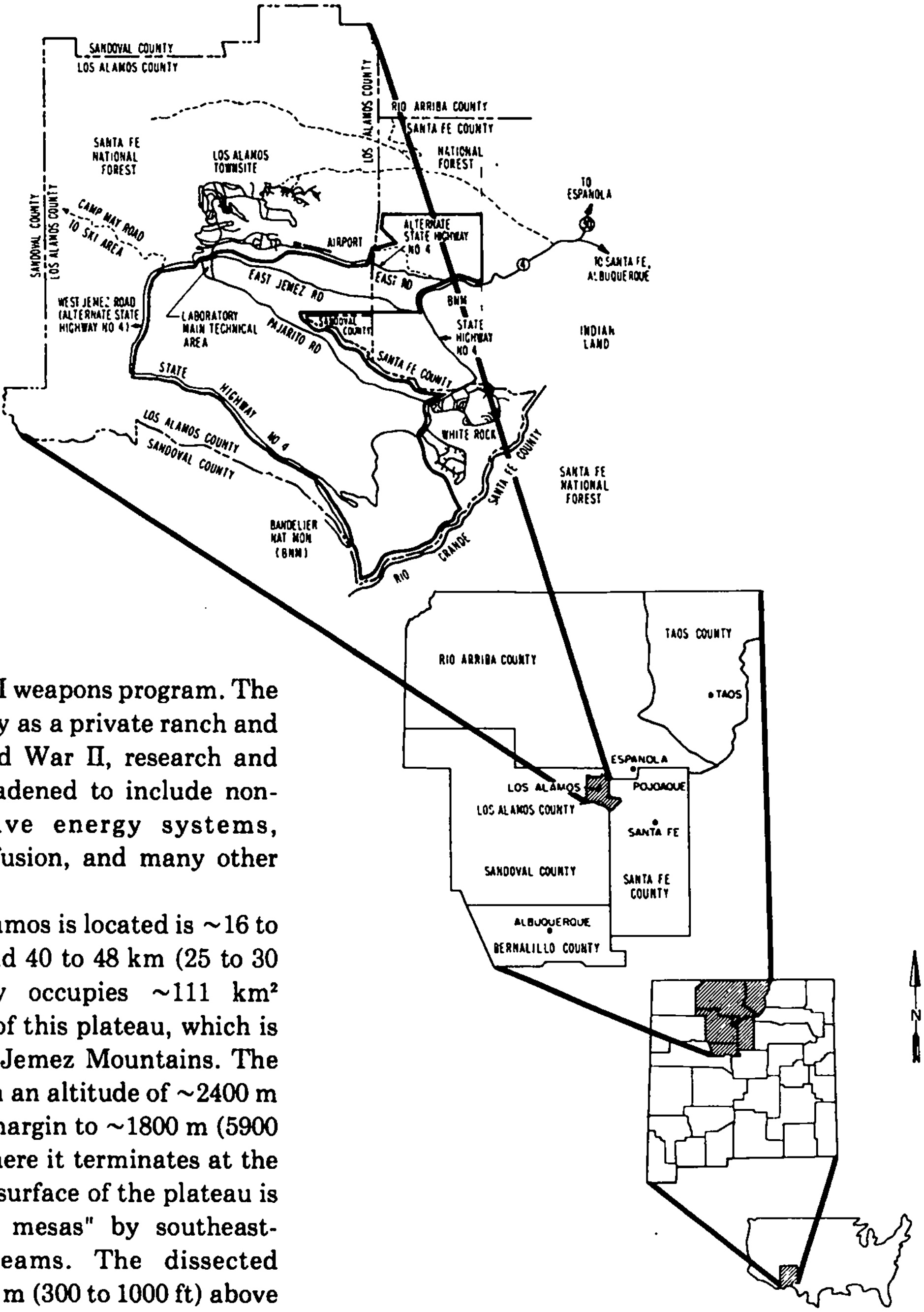
3. BACKGROUND INFORMATION

3.1 Description of Los Alamos National Laboratory and Vicinity

The Los Alamos National Laboratory is located on a mountain plateau 40 km (25 mi) by air northwest of Santa Fe, New Mexico, as shown in Fig. 3-1. This figure and much of the text in Sec. 3 are summarized from Ref. 3-1.

This site was chosen in the interests of safety and security when the Laboratory was established in the early 1940s for the design of nuclear weapons as a

Fig. 3-1.
Los Alamos location.



part of the U.S. World War II weapons program. The site had been used previously as a private ranch and school for boys. After World War II, research and development work was broadened to include nonnuclear work (alternative energy systems, biomedical research, laser fusion, and many other nonweapons programs).

The plateau where Los Alamos is located is ~16 to 24 km (10 to 15 mi) wide and 40 to 48 km (25 to 30 mi) long. The Laboratory occupies ~111 km^2 (~27 500 acres or ~43 mi^2) of this plateau, which is on the eastern flank of the Jemez Mountains. The plateau slopes eastward from an altitude of ~2400 m (7900 ft) along the western margin to ~1800 m (5900 ft) on its eastern margin, where it terminates at the rim of the Rio Grande. The surface of the plateau is cut into numerous "finger mesas" by southeast-trending intermittent streams. The dissected eastern margin is ~90 to 300 m (300 to 1000 ft) above the Rio Grande. Los Alamos has a semiarid continental mountain climate, and rainfall in the area is sparse; evapotranspiration exceeds annual precipitation. Water from rainfall and snowmelt infiltrates the surface, providing moisture to the soil zone and supporting plant growth. This moisture penetrates no more than a few meters into the tuff on the mesa tops. The tuff, as a result, has a low moisture content (generally <5% by weight)—too low for most plants to extract water.

Ground water (subsurface water) occurs as perched water in alluvia and basalts, in the saturation zone, and in sediments of the Los Alamos area main aquifer. These units relate as shown in Fig. 3-2, which is taken from Ref. 3-1.

As water perched in the alluvium moves downgradient, it is lost by evaporation, transpiration, and infiltration. Vegetation is lush where surface or perched water is present in the alluvium.

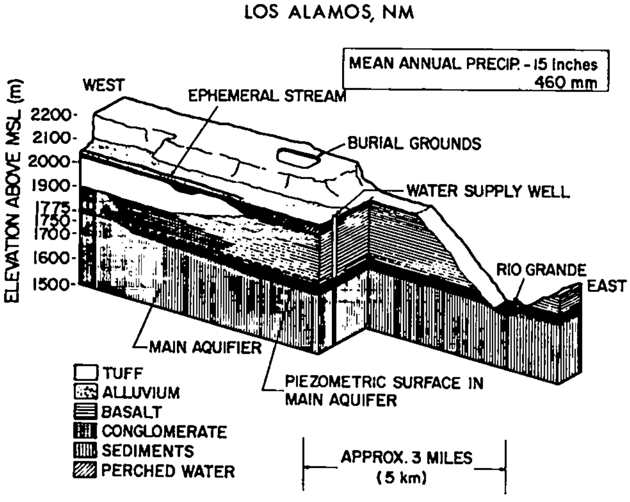


Fig. 3-2.
Hydrological cross section.

Water moving from the alluvium into volcanic debris in the lower reach of Pueblo Canyon and the midreach of Los Alamos Canyon recharges local perched water within the basaltic rock of Chino Mesa. Water from this perched aquifer discharges at the base of the basalt in Los Alamos Canyon west of the Rio Grande.

Perched water is not found in the tuff, volcanic sediments, or basalts above the main aquifer in the central and western portions of the plateau. Test holes in these areas penetrated numerous rock units that could have perched water above the main aquifer. Absence of water in these test holes indicates that the infiltration of surface water through the alluvium and the tuff is limited. Age dating of water from the main aquifer further supports the inference of insignificant infiltration of surface water through the alluvium and tuff to the main aquifer.

Water depths (in the main aquifer) below the mesa tops range from ~360 m (1200 ft) along the western margin of the plateau to ~180 m (600 ft) along the eastern part of the plateau.

3.2 Description of TRU Wastes

From the earliest days of Laboratory operations until mid-1971, common practice was to dispose of radioactive wastes by burial in designated locations. Transuranic wastes had not been defined as a separate category and did not require any special handling or treatment. The Atomic Energy Commission then defined TRU and required that they be segregated and retrievably stored for a 20-yr period. Thus, many of the burial facilities used at Los Alamos before this ruling contain some TRU wastes mixed with LL wastes.

The radioactivity in the pre-1971 wastes included TRU materials, uranium, Mixed Fission Products (MFP), Mixed Activation Products (MAP), and tritium. Typically, the wastes with the higher levels of radioactivity were associated with beta and gamma radiation emitted from MFP and MAP activities.

During the first few years of Laboratory operations, radioactive wastes were handled by the best available methods. Relatively little was known about disposal methods for some of the wastes. Time and manpower were limited, and national security required strict control of the materials. Solid radioactive wastes were buried in pits dug into the tuff on mesa tops or in shafts drilled vertically in the mesa surfaces.

Experience, extensive research, continuous environmental surveillance, and drilling around and under waste buried pits have shown that these methods, with refinement, are the most effective method of waste disposal in this area (Refs. 3-1 through 3-4).

The radioactive wastes are buried and stored at several sites located on the plateau between the woodlands of the Jemez Mountains to the west and the desert grasslands of the Rio Grande Valley to the east.

Typical wastes include tools, instruments, equipment, building materials (from the decontamination and decommissioning of older facilities), sludge, cement, and general refuse (such as paper, plastics, rubber, glassware, etc.) that are lightly contaminated or that came from areas where TRU was in use.

Before mid-1971, solid radioactive wastes were buried in common pits, trenches, and shafts. Wastes containing higher levels of radioactivity were usually placed in the shafts, but this generalization may be too simple. Pits typically are ~8 to 11 m deep by 8 to 30 m wide by 120 to 180 m long (25 to 40 ft deep by 25 to 100 ft wide by 400 to 600 ft long); however, these dimensions vary greatly. The wastes were placed in layers in the pits, and the usual practice was to cover each day's addition with clean fill. When the top layer of the wastes came to within ~1 m (3 ft) of the surface of the adjacent undisturbed terrain, the pit was closed by covering the surface with a minimum of 1 m (3 ft) of clean fill material (tuff or soil). Where subsidence has occurred, additional fill has been or will be added to level the surface with the surrounding terrain.

Shafts were drilled vertically to depths of a few meters to ~20 m (65 ft) and from ~0.6 to 2.5 m (2 to 8 ft) in diameter. Although a few shafts were lined with concrete or metal, most were not. Wastes were periodically placed in the shafts. If the radiation dose rates at the surface deemed it advisable, additional fill (dirt) was added above the wastes for shielding. In some cases cement was added. When the wastes filled the shaft to no closer than ~1 m (3 ft) of the surface, a thin layer of dirt was usually added and then cement poured to seal the shaft.

The ruling that TRU wastes were to be handled in a different manner, that is, retrievably stored for a 20-yr period, required that they be segregated, separately packaged, and placed into specifically designated locations for storage. Storage of retrievable TRU wastes started in mid-1971.

TRU wastes have been defined as waste materials contaminated with certain alpha-emitting radionuclides of long half-life and high specific radiotoxicity, to >10 nanocuries (nCi, or 10^{-9} Ci) per gram (g) of waste (Ref. 3-5).

These radionuclides include ^{233}U and its daughter products, plutonium, and transplutonium nuclides (except ^{238}Pu and ^{241}Pu). At Los Alamos, solid wastes contaminated with only ^{238}Pu are not considered to be TRU wastes until the concentration of ^{238}Pu is greater than 100 nCi/g of waste (Ref. 3-6).

To provide the 20-yr retrievability of solid TRU wastes requires segregation and special packaging. These packages include 210-ℓ (55-gal) DOT 17C drums and plywood boxes coated with fiber glass reinforced polyester (FRP). These TRU containers are placed in designated, recorded locations, on special storage pads that are backfilled or bermed with a minimum cover of 1 m (3 ft) when filled. Some TRU wastes, because of waste form or higher activity, have been stored in concrete casks located in trenches, in vertical sections of Corrugated Metal Pipe (CMP), and in shielded casks placed in shafts. The CMPs are sections of metal pipe, cut to length and placed vertically in a surface excavation. These CMPs are used only for stored, not buried wastes. Each CMP has a lower concrete plug 0.3 m (1 ft) thick. The wastes are mixed with cement paste and placed in the vertical CMP. A concrete plug 0.3 m (1 ft) thick is poured in place to seal the top.

Continued monitoring of all of the waste disposal areas over the years has shown that no safety or environmental violations have resulted from Laboratory waste management practices. For additional details, see the Final Environmental Impact Statement (Ref. 3-1).

3.2.1 The Six Los Alamos Burial and Storage Areas. The stored and buried TRU wastes discussed in this document are located in six waste disposal areas (Fig. 3-3). Five of these areas contain TRU-contaminated wastes, and the sixth area contains alpha-contaminated wastes (^{226}Ra and ^{227}Ac). A brief description of these areas and their estimated volumes are given below and summarized in Table 4-1 in the next section.

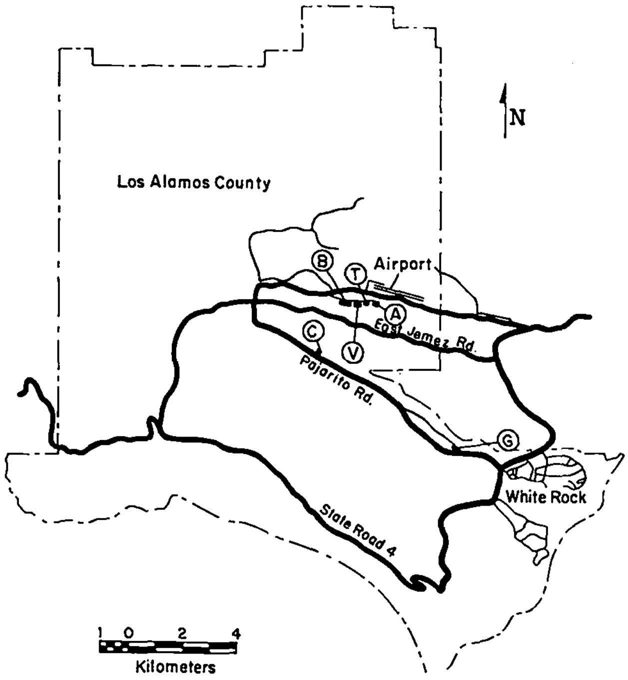


Fig. 3-3.
Map of TRU or potential TRU-waste disposal and storage areas.

The total volume of the pits, trenches, shafts, and storage from these six areas is estimated from existing records and documents and TRU wastes projected to the year 1990, total ~330 000 m^3 (~12 000 000 ft^3). However, not all of this material is TRU waste. Significant amounts of LL and backfill or cover material have been mixed with the buried TRU wastes. This backfill material may have been contaminated by mixing and may, therefore, also require treatment or processing. Conversely, the backfill material may have diluted the TRU concentrations to levels below the definition of TRU wastes. The estimated volume includes the total volume of the burial pits, trenches, and shafts, minus the top 1 m (3 ft) of final cover above the wastes and the volume of the retrievably stored TRU waste. The following descriptions of the six disposal areas are summarized from Refs. 3-1 and 3-7.

- ***Area A*** (operated with four burial pits from 1945-1946). A fifth pit was opened in April 1969 and used until mid-1978 for building decontamination and decommissioning (D&D) wastes. Area A covers 5000 m^2 (1.25 acres or 53 800 ft^2) with the actual waste pits occupying ~2600 m^2 (28 000 ft^2) of surface area. The total volume of the waste pits in Area A is ~14 000 m^3 (500 000 ft^3). The first four pits in Area A were also used for the disposal of some chemical wastes.

- ***Area B*** (used from 1946-1948). Area B encompasses 24 000 m^2 (6.0 acres or 258 250 ft^2). Buried waste pits occupy ~4 700 m^2 (50 000 ft^2) of surface area with an estimated total volume of ~21 000 m^3 (750 000 ft^3). The wastes may contain small amounts of TRU and some hazardous wastes such as chemicals and gas cylinders. A search of Laboratory records leads to an estimate that 100 g of plutonium may be contained in these buried wastes.

- ***Area C*** (pits opened in 1948 with six burial pits used through 1964, and ~100 shafts used through 1969). The surface area is ~48 000 m^2 (11.8 acres or 516 500 ft^2) with a pit surface area occupying 21 000 m^2 (225 000 ft^2) and an estimated total waste pit volume of 103 000 m^3 (3 650 000 ft^3).

- ***Area C Shafts*** (wastes containing larger quantities of radioactive material placed in vertical shafts beginning in 1958). Laboratory records show that 107 shafts were excavated. It is known that a few of these were lined with CMP or cement, but most were not. The total volume of TRU wastes in these shafts is estimated to be ~140 m^3 (5 000 ft^3). It is estimated that 42 of the unlined shafts and 6 of the lined shafts may contain TRU wastes, while 55 of the unlined shafts and 4 of the lined shafts probably do not contain TRU wastes.

- ***Area G*** (the primary solid waste disposal and storage area at Los Alamos, in use since 1957, with 21 pits used or in use as of 1980). The larger pits are typically 30 m (100 ft) wide by 180 m (600 ft) long by 8 to 11 m (25 to 36 ft) deep with smaller pits of varying dimensions. Additionally, several shallow trenches are used for the retrievable storage of TRU wastes in concrete casks. Pits number 1 through 6 probably contain some TRU waste disposed of before 1971, and, therefore mixed with LL wastes. Pit 1 is known to contain ~600 g of plutonium mixed with sand in about thirty 114 ℓ (30-gal) drums. Pit 2 contains drums of sludge with >10 nCi/g of TRU waste. This sludge is mixed in concrete. These first six pits occupy a surface area of ~33 000 m^2 (360 000 ft^2), with an estimated total pit volume of ~170 000 m^3 (6 000 000 ft^3). In addition, pit 8 contains several drums of TRU waste. The waste volume in Pit 9 (used for storage from 1974 to 1979) is ~1 300 m^3 (47 000 ft^3), whereas the storage trenches contain ~240 m^3 (8 400 ft^3). All the other pits and trenches contain only LL wastes.

- ***Area G Shafts*** (~120 vertical shafts are now located in Area G, with an estimated surface area of ~580 m^2 (6 000 ft^2) and total volume of ~430 m^3 15 000 ft^3). Some of the shafts used before 1971 are thought to contain mixed TRU, MFP, MAP, and other LL wastes. Generally, wastes with higher levels of radioactivity have been disposed of in shafts rather than in pits.

Area G burial pits and shafts contain tritium, mixed fission products, uranium, activation products, ^{239}Pu, ^{241}Am, and small amounts of other nuclides (such as ^{238}Pu, ^{237}Np, ^{230}Th, ^{232}Th, curium isotopes and others).

- ***Area T.*** Four absorption beds were used from 1945 to 1952 for the disposal of untreated liquid wastes from plutonium processing, which contained low levels of plutonium and americium. The total surface area of the site is ~1 900 m^2 (20 000 ft^2). The absorption beds are trenches ~35 m long by 1.2 m deep by 6 m wide (115 by 4 by 20 ft), excavated into the tuff. The beds were backfilled with coarse material, grading from 0.2-m (8-in.) boulders in the bottom, through gravel, to fine sand at the surface. The total volume of the four beds is ~2 700 m^3 (96 000 ft^3).

  A treatment plant was installed in 1952 for removal of plutonium and other radionuclides from liquid wastes. Residues from this treatment plant were mixed with cement and buried in Areas C and G. The beds were used infrequently between 1952 and 1967 for the disposal of a few hundred gallons of treated liquid wastes.

  A new treatment plant was built in 1967. Since mid-1968, treated waste residues were mixed with cement in a pug mill and pumped down shafts augered between the two beds to the south side and the two beds to the north side. About 62 of these shafts were used for the disposal of mixed cement and neutralized americium strip, alkaline fluoride, and plant sludge. The shaft dimensions are typically 1.2 to 2.4 m (4 to 8 ft) in diameter and up to 24 m (80 ft) deep. These dimensions vary depending upon conditions found when they were augered. The volume of these 62 shafts is ~3 800 m^3 (135 000 ft^3). About 56 of these shafts contain TRU wastes, but 6 do not. These wastes were buried in the shafts before the 1971 decision regarding segregation and retrievability of TRU wastes.

  Retrievable storage of TRU wastes is also conducted in Area T. Treated TRU wastes are mixed with cement and pumped into sections of CMP placed vertically in a pit. This pit is ~37 m long by 7 m wide by 6 m deep (120 by 24 by 19 ft). Plutonium- and americium-contaminated aqueous waste from a holding tank is taken into a pug mill, mixed with cement, and the mixture pumped into the vertical CMP sections ~6 m by 0.75 m (20 ft by 30 in.). The estimated volume of the CMPs is 480 m^3 (17 000 ft^3).

  Aqueous wastes received at the treatment facility adjacent to Area T may be TRU wastes for retrievable storage, or nonretrievable wastes for burial. Retrievable wastes are mixed with cement and placed in the CMP sections; wastes for burial are mixed with cement and placed in the shafts.

- ***Area V*** (used from 1945 to 1961 with three absorption beds receiving waste water from a laundry). These absorption beds were also similar to those described in Area T. The estimated surface area is 1 400 m^2 (15 000 ft^2) with an estimated volume of contaminated material of 4 300 m^3 (150,000 ft^3). Area V contained ~3 Ci ^{90}Sr, ^{140}Ba, ^{140}La, and also 0.1 Ci plutonium at concentrations that meet the 10 nCi/g definition of TRU wastes. The barium and lanthanum have half-lives measured in days and hours, and therefore, have all decayed.

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6. "Radioactive Solid Waste Management," Administrative Requirements 7-1, Los Alamos Scientific Laboratory manual LA-7940-M (October 1979).

7. M. A. Rogers, "History and Environmental Setting of LASL Near-Surface Land Disposal Facilities for Radioactive Wastes," Los Alamos Scientific Laboratory report LA-6848-MS, Vol. I (June 1977).

4. ESTIMATES USED IN THE STUDY

Guidelines and engineering judgments presented herein have been established to provide a common baseline for identifying, developing, and evaluating engineering alternatives for the long-term management of TRU waste buried and stored at Los Alamos. Some of the estimates have been made with limited information, but they are required for the continuation of this study and should be understood in that context. These estimates facilitate completion of the study. Assumptions made affected each of the options considered and should not be considered as binding or as final answers.

4.1 General Estimates

First, this study addresses buried and stored TRU waste and radioactive liquid waste receiving areas formerly used at Los Alamos. LL wastes are not considered in this Alternatives Document. Small quantities of remote-handled TRU waste, that is, high MFP activity waste, are also present in some burial pits, in shafts, and in some of the stored wastes.

Second, alternatives for the TRU waste include concepts to retain the waste at Los Alamos and to ship it to an offsite federal repository assumed to be located ~540 km (335 mi) from Los Alamos, New Mexico.

Third, after exhuming the waste and removing the TRU waste, the remaining LL waste would be returned to the pit from which it came, except for the LL waste from Area B, which would be transported to another Los Alamos site for disposal. All LL waste would be retained at Los Alamos.

For purposes of this study, the exhumation proposal applies to all locations containing TRU waste. However, additional research may indicate that some of the areas suspected of containing TRU waste may, in fact, contain LL waste only, and, therefore, exhumation would not be required.

Operations involving waste retrieval, exhumation, processing, and shipment of waste are to begin in 1990 and would be completed within 15 yr. For any plan that proposes leaving the TRU waste at Los Alamos, maintenance and surveillance activities would continue for 100 yr after implementation of the concept.

Next, plans that require development of new technology before their implementation would not be considered. (Assay techniques now under development would be expected to be operational by exhumation time (Refs. 4-1, 4-2, and 4-3).

For plans that include exhumation of the buried waste, any soil intermixed with TRU waste would be separated from the waste, where practical. Soil that cannot be separated readily from the TRU waste would be processed in the same manner as the TRU waste.

Buildings proposed for exhumation of the *buried* TRU waste would provide double containment of the waste during exhumation, to safely dispose of any deteriorated containers. *Stored waste* containers will probably be intact during retrieval; therefore, additional containment beyond that provided by the waste package would not be required. However, a structure would be provided for weather protection. Also, areas of the Waste Processing Facility (WPF) containing more than 500 g of TRU elements would be designed in accordance with DOE Manual, Appendix 6301, Part II, Plutonium Facilities.

Methods for transporting waste offsite would conform to Department of Transportation regulations. Waste shipments from Los Alamos would be made by truck to the federal repository.

Finally, a record of fissile material content for criticality control would be maintained by assaying the exhumed or retrieved waste before and, as necessary, during treatment operations and/or after packaging for transport. No plan would be considered that proposes the recovery of any exhumed material (fissile material, precious metals, etc.). These materials have already been processed through treatment and recovery operations. Because TRU waste disposal criteria have not been finalized, alternative plans are considered that assume the repository would accept either processed or unprocessed waste (Ref. 4-4).

4.2 Waste Description Estimates

This study uses volumes, locations, and characteristics of waste projected through FY 1990 (Table 4-1). The following combustible/noncombustible volume ratios are used: stored waste 1 to 8 and buried TRU waste 1 to 16 (includes soil intermixed with waste). For TRU waste exhumation plans, if it is known or suspected that a pit or shaft contains TRU waste, the entire pit or shaft would be excavated unless records exist to verify that only some sections of the pit or shaft contain TRU waste. If it is known that only a given portion contains TRU, only that portion would be exhumed.

A waste disposal pit or shaft suspected of containing TRU waste is estimated to contain ~5% TRU waste by volume and 95% LL waste, unless Laboratory documents show otherwise. The following average waste densities were used: buried waste (intermixed waste and soil) 1120 kg/m^3 (70 lb/ft^3); stored waste 1280 kg/m^3 (80 lb/ft^3); concrete waste in CMP, shafts, and drums 2000 kg/m^3 (125 lb/ft^3); and contaminated soil in liquid disposal absorption beds 1600 kg/m^3 (100 lb/ft^3).

4.3 Cost Analysis Estimates

Cost analyses should be considered as only approximate because the engineering design is based on concepts rather than on proven technology. These cost estimates are for comparison of the various alternatives, not for budgeting purposes. Any decision to select one option would also be based on social and political considerations, not simply cost.

Cost estimates are based on April 1980 costs (no escalation). Unpredictable inflation rates and unstable time preclude assuming a given escalation value; therefore, these exercises would be entirely academic and soon outdated.

For plans that propose shipment of TRU waste to a federal repository, costs include (a) capital and operating and maintenance (O&M) costs of the facilities and equipment, (b) shipment costs, (c) an assessed cost of \$3180/m^3 (\$90/ft^3) for long-term management at the federal repository, and (d) maintenance and surveillance costs of the LL wastes for a 100-yr period. Costs of meeting possible additional regulations are not included.

Plans that propose leaving the waste in place, with or without engineered improvements, include (a) implementation costs, and (b) maintenance and surveillance costs for a 100-yr period.

Plans that propose exhumation or retrieval, processing, and disposal within Los Alamos, include (a) capital and O&M costs of facilities and equipment, (b) capital and O&M costs of the disposal structure and waste emplacement, (c) onsite shipment costs, and (d) maintenance and surveillance costs of the disposal site(s) for a 100-yr period.

Costs associated with D&D of all facilities except the disposal structures are included. Also, the cost of approved shipping containers are included where such containers are required.

Plans that involve disposal by shipment to an offsite repository (Alternatives 4, 8, and 12, for example) may require resizing, such as cutting, of some of the larger TRU waste items, to fit these wastes into smaller packages acceptable at the offsite repository. Conversely, plans involving disposal in a deeper pit at Los Alamos (Alternatives 3, 7, and 11, for example) probably would not require resizing of the larger TRU waste items.

4.4 Radiological Impact Estimates

Radiological impact analysis for the 14 alternatives is based on the following guidelines and estimates.

1. The quantities of waste are estimated from Laboratory records and projections of anticipated waste generation to the year 1990.

2. Radiation doses to the workers and the population were analyzed according to the operations postulated for the exhumation of buried waste and the retrieval of stored wastes. Estimates of radiological impacts are based on each of the work tasks associated with each of the 14 alternatives.

TABLE 4-1

LOS ALAMOS TRU-WASTE DISPOSAL SITES INFORMATION

Disposal Area	Disposal System	Disposal Method	TRU Waste	Waste Form	Waste Volume[a] [m^3 (ft^3)]	Surface Area[b] [m^2 (ft)]	Remarks
A	Pits (5)	Buried	Possibly small quantity	Combustible and noncombustible	14 000 (500 000)	2 600 (28 000)	Contains hazardous chemical wastes in the 4 original pits.
B	Pits	Buried	Probably small quantity	Combustible and noncombustible	21 000) (750 000)	4 700 (50 000)	Number and location of pits within area unknown. Contains hazardous chemical wastes. Estimated to contain 100 g of plutonium.
C	Pits (6)	Buried	Yes (6)	Combustible and noncombustible	103 000 (3 650 000)	23 000 (250 000)	Contains hazardous chemical wastes.
C	Unlined shafts (97)	Buried	Yes (42) No (55)	Combustible and noncombustible	140 (5 000)		
C	Steel/cement lined shafts (10)	Buried	Yes (6) No (4)	Combustible and noncombustible	5 (175)		
G	Pits (6)	Buried	Yes (6) No	Combustible, noncombustible, sludge, concrete	170 000 (6 000 000)	33 000 (360 000)	Pit numbers 1-6. Pits used for waste disposal before directive requiring segregation of TRU waste. About 600 g ^{239}Pu in 20 drums in Pit 1. Drums with sludge and concrete in Pit 2 contain TRU >10 nCi/g.
	Pit 8 contains about 10 drums containing TRU waste placed among about 1500 drums of non-TRU waste sludge.						
G	Pit No. 9	Stored	Yes	Combustible, noncombustible, and sludge	1 300 (47 000)	1 000 (12 000)	

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[a] Estimated volume of intermixed waste and soil in pits [pit volume less top 0.9 m (3 ft)], as of Dec. 31, 1979.

[b] Surface area of wastes only, not total area of the waste disposal site.

TABLE 4-1 (Continued)

Disposal Area	Disposal System	Disposal Method	TRU Waste	Waste Form	Waste Volume^a [m^3 (ft^3)]	Surface Area^b [m^2 (ft)]	Remarks
G	Trenches	Stored	Yes	Combustible and noncombustible	240 (8 400)	3 300 (35 000)	Volume includes casks. Actual waste is about 64 m^3 (2250 ft^3). Waste is ^{238}Pu and ^{233}U-contaminated in 114 liter (30-gal) drums, 2 drums per concrete cask.
G	Shafts (66)	Buried	Yes	Combustible, noncombustible, liquids, and asphalted tritium	430 (15 000)	580 (6 200)	TRU waste with considerable β-γ activity.
G	Shafts	Stored	Yes	Combustible and noncombustible	5 (175)	Nil	Waste is from hot cells. Volume includes sealed casks.
T	Absorption beds (4)	Buried	Yes	Contaminated soil	2 700 (96 000)	890 (9 600)	About 10 Ci of ^{239}Pu.
T	Unlined shafts (62)	Buried	Yes (56) No (6)	Concrete monoliths	3 800 (135 000)	840 (9 000)	1.8- and 2.4-m (6- and 8-ft)-diam shafts up to 20 m (65 ft)
T	CMP shafts (175)	Stored	Yes	Concrete monoliths	480 (17 000)	140 (1 500)	0.8 m (2-1/2 ft) diam × 6.1 m (20 ft) long.
V	Absorption beds (3)	Buried	Yes	Contaminated soil	4 300 (150 000)	1 400 (15 000)	Liquid waste from DP-Site laundry.
			Projected Volume of Additional TRU Waste to be Generated from 1980 to 1990				
G	Trenches	Stored	Yes (1)	Combustible and noncombustible	510 (18 000)	2 900 (31 000)	Volume includes casks. Actual volume about 136 m^3 (4800) ft^3) of ^{238}Pu-contaminated waste.
G	Pads	Stored	Yes (2)	Combustible noncombustible,	7 100 (250 000)	4 700 (50 000)	Future storage will be on asphalt pads above ground.
G	Shafts	Stored	Yes	Combustible and noncombustible	150 (5 300)	14 (500)	Volume includes sealed casks. Waste from hot cells. Surface dose rates greater than 200 mR/h and less than 100 R/h. Sealed casks to be removed with waste.

3. Waste volumes and radioactivity inventories listed in Table 4-2 for buried waste and in Table 4-3 for stored waste are the basis for the analysis.

4. Many radionuclides are present as contaminants in parts of the waste studied. For example, tritium, MFP, MAP, ^{230}Th or ^{232}Th, several of the uranium nuclides, ^{237}Np, several of the plutonium nuclides, ^{241}Am, and ^{252}Cf can be found in some fraction of the waste. Based on the inventories reported in Tables 4-2 and 4-3, the radiological impact presented by buried radionuclides other than ^{239}Pu are relatively minor and special handling procedures would be used to prevent significant exposures.

5. Radiological impacts are estimated for normal operating conditions and accidents.

6. Occupational doses for normal operations and accident or "worst case" scenarios are based on averaged Laboratory film badge or thermoluminescent dosimeter (TLD) data for external exposures. Internal occupational exposures in this case are considered insignificant.

TABLE 4-2

EXHUMATION DATA FOR BURIED WASTE DOSE ASSESSMENT

Burial Site		Volume (m³)	TRU[a] Nuclide Inventory (Ci)	Total Nuclide Inventory (Ci)
TA-21	A (pits)	1.4×10^4	Undetermined	(1.1×10^1)[b]
	B (pits)	2.1×10^4	7.0×10^0	(7.0×10^0)[c]
	T (beds)	2.7×10^3	1.0×10^1	1.4×10^1
	T (shafts)	3.8×10^3	4.0×10^3	4.0×10^3
	V (beds)	4.3×10^3	1.0×10^{-1}	(3.1×10^0)[d]
TA-50	C (pits)	1.0×10^5	1.8×10^2	2.0×10^2
	C (shafts)	1.4×10^2	5.7×10^1	(3.9×10^4)[e]
TA-54	G (pits)	1.7×10^5	2.4×10^3	(5.8×10^3)[f]
	G (shafts)	4.3×10^2	5.3×10^1	(1.3×10^5)[e]

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[a] Taken from data reported in Los Alamos EIS (Ref. 4-5), RW management (Ref. 4-6), or Ref. 4-7.

[b] Assumed value. Some TRU waste could be buried here (even though we have no conclusive evidence either way). Therefore, to perform the required calculations, 5% of the waste volume is considered to be TRU waste, although this value is probably far too high.

[c] Value deduced from 100 g Pu that is estimated on page B-4 of Ref. 4-7. On the basis of 10 nCi/g, 2% of the volume is estimated to be TRU waste.

[d] This value is taken from Ref. 4-5, and includes about 3 Ci of short half-life nuclides.

[e] Activity is principally ^{3}H and some MFP.

[f] The principal additional radioactivity is made up of 2683 Ci of ^{90}Sr and 600 Ci of MFP.

TABLE 4-3

RETRIEVAL DATA FOR STORED WASTE DOSE ASSESSMENT

Storage Site	Waste Form	m^3/Unit	Units[a]	Major Radionuclides	Approx. R/h Gamma at Contact
TA-21 Area T	Corrugated Metal Pipe (CMP) Filled With Concrete	2.8	180	^{241}Am	0.05 - 0.15
TA-54 Area G	55 Gal Drums:				
	Sludge Drums	0.21	2 500	^{239}Pu, ^{241}Am, MFP	<0.001
	Cemented Waste Drums	0.21	1 000	^{239}Pu, ^{241}Am, MFP	<0.001
	Misc: Waste Drums	0.21	8 400	^{239}Pu	<0.001 - 0.2
	FRP Boxes:				
	Standard	3.2	990	^{239}Pu	<0.001 - 0.05
	Oversize	varies	190	^{239}Pu	<0.001 - 0.05
	Concrete Casks Containing Two 114-gal Drums	0.85	480	^{238}Pu, ^{233}U	<0.01
	Steel Shafts	1.3	100	^{239}Pu, ^{235}U, MFP	0.2 - 100

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[a] These values include projected additional wastes to the year 1990. As of 1980, there were ~1500 drums of sludge and 1000 drums of cemented waste. Modifications to the waste treatment operations are expected to reduce the generation of sludge to ~100 drums/year and the cemented waste to negligible amounts.

7. The frequency of the events resulting in occupational or population dose commitments and the magnitude of the consequences are based on Laboratory experience whenever possible.

8. The released plume resulting from an accident is assumed to disperse into a 22.5° sector. Population doses were calculated for the population residing in the sector.

9. The maximally exposed population within a 22.5° sector out to an 80-km radius of Los Alamos is included in the analysis. Albuquerque is located 96 km from Los Alamos but is also included because it is the largest population center near Los Alamos. The population value is a projection to 1998.

The analysis for each stored waste option included the five major types of stored waste listed in Table 4-3, because of the large variation in geometry and dose rate among the different types.

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5. ALTERNATIVES

This section summarizes the 14 alternatives selected for long-term management of the Los Alamos radioactive wastes. Other alternatives were identified but not analyzed for the reasons discussed in Sec. 5.4. Figure 5-1 shows the selected options that combine for 14 alternatives as shown in Table 5-1.

Alternative 1 involves leaving the buried and stored waste in place and includes continuation of current practices for a period of 100 yr. By the end of this period, it is expected that one or more of the other alternatives would be implemented, that is, the waste sites would not be abandoned. Alternative 2 is the implementation of engineered improvements at the disposal sites. Alternatives 3 through 10 involve leaving the buried waste in place while retrieving the stored TRU waste. Alternatives 11 through 14 involve exhuming the buried TRU wastes and retrieving the stored TRU wastes. An assay and sorting operation separates the TRU waste from the LL waste, which is returned to the pits. The exhumed and retrieved TRU waste is either packaged for final disposal without further treatment or processed through a WPF before final disposal. The WPF has the capability to incinerate the combustible waste, decontaminate the metallic waste, and immobilize the dispersible waste forms. Disposal options include deeper pit disposal at Los Alamos and offsite disposal at a federally owned, deep, geological facility.

5.1 Description of Alternatives

This section describes the alternatives evaluated for the long-term management of the Los Alamos radioactive waste as identified in Fig. 5-1 and Table 5-1. For Alternatives 3 through 10, the stored waste and the buried waste follow different options, whereas for Alternatives 1, 2, and 11 through 14, the options are the same.

In Area G, some of the retrievable storage is located on top of the buried waste pits. Adding cover over these wastes would not present a problem. However, exhumation of the buried wastes would require retrieval of those wastes stored above, before gaining access to the buried wastes.

5.1.1 Alternative 1. Buried and Stored Waste—Continue Current Practices. For this alternative, current waste management practices or improvements thereof will continue for existing and future radioactive wastes buried and stored at Los Alamos. For this study, it was estimated that maintenance and surveillance practices would continue for 100 yr, at which time the decision would be reconsidered. Implementation of this alternative allows the final decision to be deferred until some future time when the national waste management program is more precisely defined. Initial selection of this alternative does not preclude the implementation of any other alternative at some future date.

5.1.2 Alternative 2. Buried and Stored Waste—Engineered Improvement. For this alternative, the waste would be covered with compacted tuff and overlaid with a layer of riprap to enhance the long-term confinement of the waste.

For disposal pits suspected or known to contain TRU waste, the semicompacted soil currently covering the waste would be removed to within ~0.3 m (1 ft) of the waste. (Note: There may be an exception for pits where up to 6.1 m (20 ft) of soil and tuff now

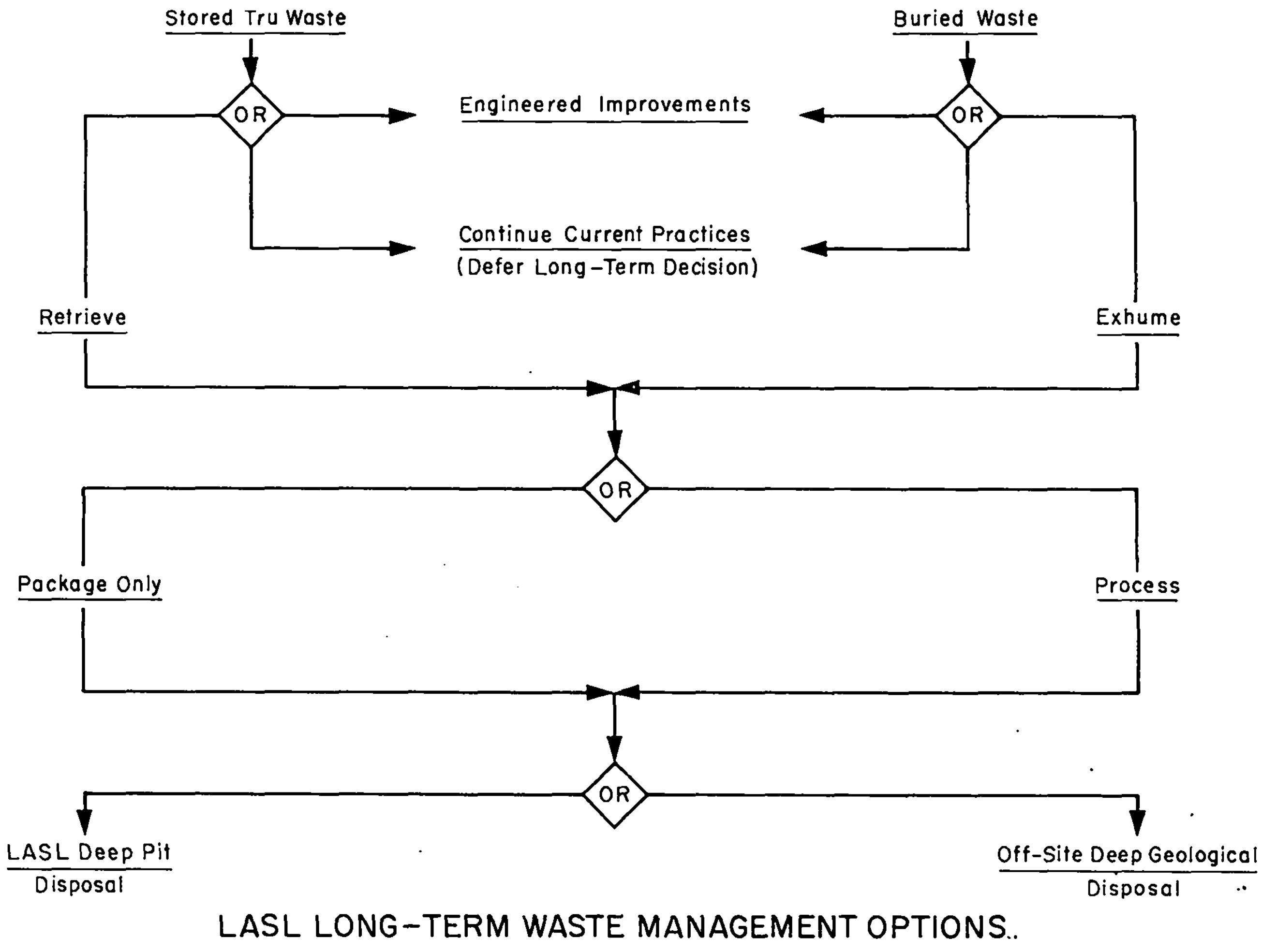

Fig. 5-1.
Los Alamos long-term waste management options.

cover the waste.) After removal of the cover soil, a 1.5-m (5-ft) minimum thickness of tuff would be spread and compacted over the waste. The compacted tuff would be built up to at least the level of the undisturbed tuff surrounding the pit (but in no case <1.5 m (5-ft)), and it would be sloped to provide drainage. The compacted tuff would be covered with a 0.3-m (1-ft)-thick overlay of 20 to 30 cm (8- to 12-in.) riprap, which would be a native material, such as river rock or basalt. The riprap would provide increased waste protection and isolation by adding additional cover and protection from erosion and intrusion.

Stored TRU waste would be handled in a manner similar to the buried waste, except that the existing cover soil would not be removed, and the waste would be covered by a minimum of 4.5 m (15 ft) of tuff. The additional tuff overburden would provide more protection for the waste if the soil subsided because of deterioration of the waste packages. The TRU waste stored in shafts and trenches would be covered with a minimum of 1.5 m (5 ft) of compacted tuff plus a riprap cover.

5.1.3 Alternative 3. Buried Waste—Continue Current Practices. The buried waste for this alternative would be handled the same as for Alternative 1.

TABLE 5-1

LOS ALAMOS LONG-TERM WASTE MANAGEMENT OPTIONS AND ALTERNATIVES

	Alternatives													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Buried Waste Options														
Continue current practices	X		X	X	X	X					a	a	a	a
Engineered improvements		X					X	X	X	X				
Exhume											X	X	X	X
Package											X	X		
Process													X	X
Los Alamos deep-pit disposal											X		X	
Off-site disposal												X		X
Stored Waste Options														
Continue current practices	X													
Engineered improvements		X												
Retrieve			X	X	X	X	X	X	X	X	X	X	X	X
Resize and package				X				X				X		
Process					X	X			X	X			X	X
Los Alamos deep-pit disposal			X		X		X		X		X		X	
Off-site disposal				X		X		X		X		X		X

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[a] The LL waste remaining after TRU waste has been separated would be returned to the pits where current waste management practices would be continued, except for the LL wastes from Area B, which would be buried at another Los Alamos disposal area.

5.1.3.1 Stored Waste—Retrieve, Package, and Dispose in Los Alamos Deep Pit. These options consist of retrieving the stored TRU waste from the pits, trenches, shafts, and pads; overpacking, repackaging or packaging, as necessary to satisfy disposal criteria; and disposing of the TRU waste at Los Alamos in a deeper pit than those used for shallow land burial (SLB). The retrieval operation consists of recovering the waste containers stored in a retrievable fashion since 1971. The containers consist primarily of 210-ℓ (55-gal) drums; varying sized FRP boxes [most commonly 1.2 by 1.2 by 2.1 m (4 by 4 by 7 ft)]; CMP sections, typically 6 m (20 ft) long by 0.8 m (2-1/2 ft) in diameter; and concrete and metal casks. Where necessary, retrieval operations would be conducted inside a weather-protected structure. First, the soil would be removed from the top of the waste to within ~0.3 m (1 ft) of the waste containers. Then the structure would be placed over the waste, excavation and retrieval equipment placed inside the structure, and the retrieval operation initiated. Waste containers would be surveyed for contamination as they were uncovered, and any that were found to be contaminated would be repackaged. The containers would then be transferred to and placed in a deeper disposal pit.

5.1.4 Alternative 4. Buried Waste—Continue Current Practices. The buried waste for this alternative would be handled the same as for Alternative 1.

5.1.4.1 Stored Waste—Retrieve, Resize as Necessary, Package, and Dispose in Offsite Deep Geological Repository. The stored waste options are the same as for Alternative 3 except that the TRU waste containers would be packaged for offsite shipment by truck to a federally owned deep geological repository such as the proposed Waste Isolation Pilot Project (WIPP). Necessary processing, including dividing larger TRU items to fit into smaller packages, will be done to prepare the waste for packaging and shipping in compliance with federal and state regulations. The operator of the federal repository would charge the disposing organization (the Laboratory, in this case) a one-time user's fee for each waste shipment and would assume custody of the waste upon receipt.

5.1.5 Alternative 5. Buried Waste—Continue Current Practices. The buried waste for this alternative would be handled the same as for Alternative 1.

5.1.5.1 Stored Waste—Retrieve, Process, and Dispose in Los Alamos Deep Pit. The options for the stored waste are the same as for Alternative 3, except that the waste would be immobilized before being packaged for disposal. The waste would be transported from the retrieval site to a nearby WPF where the containers would be opened, and the TRU waste recovered. The TRU combustibles would be incinerated, metals decontaminated, and the dispersible TRU-waste forms immobilized in concrete. Disposal would be in a deeper pit at Los Alamos.

5.1.6 Alternative 6. Buried Waste—Continue Current Practices. The buried waste for this alternative would be handled as in Alternative 1.

5.1.6.1 Stored Waste—Retrieve, Process, and Dispose in Offsite Deep Geological Repository. The stored waste would be retrieved and processed as described in Alternative 5 and disposed of offsite in a federally owned repository as in Alternative 4.

5.1.7 Alternative 7. Buried Waste—Engineered Improvements. The buried waste sites would be protected in the method described in Alternative 2.

5.1.7.1 Stored Waste—Retrieve, Package, and Dispose in Los Alamos Deep Pit. The stored waste would be handled in the same manner as described for Alternative 3.

5.1.8 Alternative 8. Buried Waste—Engineered Improvements. The buried waste sites would be protected in the method described in Alternative 2.

5.1.8.1 Stored Waste—Retrieve, Package, and Dispose in Offsite Deep Geological Repository. The stored waste would be handled as in Alternative 4.

5.1.9 Alternative 9. Buried Waste—Engineered Improvements. The buried waste sites would be protected by the method described in Alternative 2.

5.1.9.1 Stored Waste—Retrieve, Process, and Dispose in Los Alamos Deep Pit. The stored waste would be handled as in Alternative 5.

5.1.10 Alternative 10. Buried Waste—Engineered Improvements. The buried waste sites would be protected as in Alternative 2.

5.1.10.1 Stored Waste—Retrieve, Process, and Dispose in Offsite Deep Geological Repository. The stored waste would be handled as in Alternative 6.

5.1.11 Alternative 11. Buried Waste—Exhume, Package, and Dispose in Los Alamos Deep Pit. For Alternatives 11 through 14, the buried waste would be exhumed from designated solid-waste disposal pits, shafts, and liquid-absorption beds. The waste would be assayed as it is removed to determine if it is TRU waste. The waste classified as LL waste would be returned to an excavated portion of the pit, except for the LL waste from Area B, which would be packaged and transferred for burial at another existing burial site at Los Alamos.

For Alternative 11, the TRU waste would be packaged and transferred to the Los Alamos deep pit for disposal as described for stored waste in Alternative 3.

5.1.11.1 Stored Waste—Retrieve, Package, and Dispose in Los Alamos Deep Pit. The stored TRU waste would be handled as in Alternative 3.

5.1.12 Alternative 12. Buried Waste—Exhume, Package, and Dispose in Offsite Deep Geological Repository. The buried waste would be handled as in Alternative 11 except disposal would be at the offsite geological repository.

5.1.12.1 Stored Waste—Retrieve, Package, and Dispose in Offsite Deep Geological Repository. This alternative is the same as Alternative 11 except that the waste would be disposed of at an offsite repository as in Alternative 4.

5.1.13 Alternative 13. Buried Waste—Exhume, Process, and Dispose in Los Alamos Deep Pit. The buried waste would be exhumed, the TRU waste sorted, and the LL waste handled as described in the previous alternatives. The TRU wastes would be processed in the WPF as described in Alternative 5 for stored waste and followed by deeper pit disposal at the Laboratory.

5.1.13.1 Stored Waste—Retrieve, Process, and Dispose in Los Alamos Deep Pit. This alternative is the same as Alternative 11 except that the TRU waste would be processed through a WPF as in Alternative 5.

5.1.14. Alternative 14. Buried Waste—Exhume, Process, and Dispose in Offsite Deep Geological Repository. The buried waste would be exhumed and sorted as in previous alternatives. The TRU wastes would be processed through the WPF as in Alternative 5 for stored wastes and sent offsite to a federally owned repository.

5.1.14.1 Stored Waste—Retrieve, Process, and Dispose in Offsite Deep Geological Repository. This alternative is the same as Alternative 13 except that the processed waste would be disposed of offsite at the federally owned repository as in Alternative 4.

5.2 Description of Processes

This section describes processes for removing wastes from their current locations in storage or burial sites and subsequent processing, transportation, and disposal options. These descriptions, along with descriptions for the leave-in-place options, are supplemented in Appendix B.

The facilities for carrying out these processes are adopted from conceptual designs done elsewhere. For this document, it has been assumed that these processes would be directly applicable to Los Alamos. Specific site conditions may, however, necessitate some pilot operations to demonstrate the technologies for safe exhumation and processing of the wastes.

As used herein, retrieval refers to the recovery of the stored waste, whereas exhumation applies to the excavation of the buried waste.

5.2.1 Exhumation. The six burial areas are A, B, C, G, T, and V (see Fig. 3-2). Areas A, B, T, and V are all located at TA-21. Areas C and G are both located off Pajarito Road but are separated by 6-1/2 km (4 mi). Several methods were used for disposal of wastes at these sites as shown in Table 5-2.

The approximate volume of intermixed waste and soil (as described in Sec. 3) that would be exhumed or retrieved is estimated to be ~42 000 m^3 (~2 000 000 ft^3) from TA-21 (Areas A, B, T, and V); 104 000 m^3 (~4 000 000 ft^3) from TA-50 (Area C); and 170 000 m^3 (6 000 000 ft^3) from TA-54 (Area G).

The totals of these estimated volumes are 320 000 m^3 (~11 000 000 ft^3). Projected estimates to 1990 indicate an additional 8 700 m^3 (27 000 ft^3) for a grand total to 1990 of ~330 000 m^3 (11 600 000 ft^3).

These volumes could be reduced if future investigations reveal that sites such as Areas A and B do not contain TRU waste, or that the specific location of TRU waste within a pit can be more precisely identified. Because of the wide separation of the disposal areas and the large volume of waste, three exhumation facilities would be required: one each for TA-21, Area C, and Area G.

Waste exhumation would involve excavating the buried waste known or suspected to contain TRU waste, segregating TRU waste from LL waste, returning LL waste to the pits, and resizing large items

TABLE 5-2

BURIED WASTE AREAS DISPOSAL TECHNIQUES

Waste Disposal Area[a]	Buried Waste Disposal Techniques: Solid-Waste Pits	Liquid-Waste Absorption Beds	Shafts
A	X		
B	X		
C	X		X
G	X		X
T	X	X	X
V		X	

[a] Areas that contain or are assumed to contain TRU waste.

classified as TRU waste to fit the transport containers for transfer to the WPF or the disposal site.

The waste exhumation facility would be similar to that proposed for use at the Idaho National Engineering Laboratory (INEL) as described in Appendix B and Refs. 5-1 and 5-2. The facilities are based on conceptual designs with the first actual tests of such technology in the future. The containment building consists of a double-walled metal structure about 90 m (300 ft) long by 30 m (100 ft) wide. Attached retracting wheels can be lowered to lift the structure off the ground so that it can be moved. The structure has attached enclosures for airlocks for workers, equipment, and supplies. A control room and a ventilation (air supply and exhaust) system with High-Efficiency Particulate Air (HEPA) filters are also part of the facility.

Waste exhumation and sorting equipment would include heavy-duty excavation equipment, size reduction equipment, assay equipment, conveyors, packaging systems, waste container handlers, maintenance vehicles, and other associated services and equipment.

The waste excavation structures would be erected on or adjacent to the waste burial sites. After erection and checkout of all systems and equipment, the top layer of soil over the pit would be removed to within about 0.3 m (1 ft) of the waste. This depth could vary because the structure requires a flat surface and some burial pits are uneven.

All operations within the exhumation building would be performed by workers directly controlling the exhumation equipment from environmentally protected cabs located on the equipment. If shielding of operators is necessary, removable shields would be mounted on the exhumation equipment. Current personnel protection procedures would be used for personnel performing special operations or maintenance.

Specific exhumation procedures would vary with the dimensions of the waste pits and shafts and with the type or condition of the waste. For exhumation from pits, each pit would be enlarged to provide room for maneuvering the exhumation equipment and for placement of LL wastes to be returned to the pit. For exhumation from concrete-filled shafts [up to 2.5-m (8-ft) diam by 19 m (62 ft) deep], special concrete-cutting and breaking equipment would be used.

The waste and contaminated soil would be removed from the pits and shafts and moved to the waste assay station. The assay equipment is still under development, but it is expected to be capable of measuring the level of transuranics in the waste to determine LL or TRU waste classification (Refs. 5-3, 5-4, and 5-5). LL wastes would be returned for disposal to an area of the pit already excavated. The TRU waste would be diverted to a packaging station where it would be placed in transfer containers. When full, each container would be closed and moved to a transfer vehicle. The waste transfer containers would be monitored for radioactivity. If higher activity is detected (>200 mR/h at the surface), the container would be placed in a shield for transfer.

In addition to soil intermixed with waste, the soil located immediately below and around the waste would be examined to ensure adequate removal of all TRU waste. Intact drums would be removed, assayed, and placed in transfer containers if they contain TRU waste. Damaged drums and other loose or partially contained waste would also be assayed and placed directly in these transfer containers if they contain TRU waste. Large items would be assayed on an individual basis and, if classified as TRU waste, they would be resized or specially packaged if possible. Backfilling of the excavated area with the LL wastes would be performed continually during exhumation. Contamination in the backfilled areas would be avoided by using special procedures and uncontaminated soil as cover material.

Inventory records and interviews conducted with retired Laboratory personnel indicate that a few waste items, which had elevated surface radiation dose rates, were buried. These rates were as high as 1000 R/h at the surface of the container at the time of disposal. Continuous radiation measurements would be made during exhumation, and when the radiation measurements during exhumation indicate such items, they would be left in place with sufficient soil to shield personnel. Exhumation of these few items would be as a special effort.

When as much of the waste has been exhumed as can be excavated without moving the exhumation building, the building interior would be surveyed for contamination. Contamination would be removed or fixed in place with an impermeable coating. All exhumation equipment inside the building would be positioned near the forward wall of the building and covered to prevent contamination. The face being excavated would be covered with plastic sheeting, and the separated LL wastes replaced in the pit would be covered with a layer of uncontaminated soil.

Before moving the building to the next exhumation position, the mobile auxiliary support systems would be disconnected from the exhumation building and moved separately to the new location. To move the building, the retractable wheels would be lowered to lift the building off the ground, and tractors would tow the building to the next exhumation position. As the wheels are raised, the building would settle and be sealed to the ground. The support systems would be reconnected, and exhumation operations would resume. Exhumation operations would be coordinated so that exhumed waste would flow continuously from the exhumation areas to the processing or disposal facilities. Moving the exhumation facility from one disposal area to another at TA-21 would require a more extensive decontamination effort on the building and equipment. The exhumation equipment would be removed from the building during the move and must, therefore, be thoroughly decontaminated. Because of the uneven terrain to be crossed, the building may be partially disassembled or commercial moving techniques used.

After a pit has been exhumed and the building has been moved off the pit, the LL wastes would be covered with 1 to 1.5 m (3 to 5 ft) of tuff.

5.2.2 Retrieval. Stored waste at Los Alamos in 1990 will be located in one underground pit, in several above-ground asphalt pads, in buried CMPs, and in concrete casks placed in trenches. TRU waste intermixed with MFP waste will be stored in casks and in shafts. Containers are expected to be intact during the 1990-2005 time frame; therefore, enclosing the retrieval operation would not be necessary from a containment standpoint. However, an enclosure is proposed for weather protection during year-round operation. Larger-sized containers would be provided for the few questionable containers that have marginal integrity.

The oldest storage location, and, therefore, the one requiring the most care, is the underground storage pit. The 1.5 to 3 m (5 to 10 ft) of overburden would be removed, followed by removal of soil from one end of the pit until the stacked waste containers are exposed. They would be removed and placed on the transport vehicle. Similarly, waste stored on pads would be retrieved by carefully removing the soil cover and then removing the containers. If the retrieved waste is to be sent to an offsite disposal facility, oversized boxes will be delivered to the WPF or a resizing and packaging facility (RPF). If the alternative to dispose onsite without processing is selected, resizing of retrieved waste would probably not be required.

Retrievable ^{238}Pu-contaminated waste is stored in 114-ℓ (30-gal) drums placed inside concrete casks that are located in trenches. Retrieval would likely entail removal of casks intact by raising the entire cask for shipment to disposal.

Retrieval of MFP and TRU waste from shafts would require a shielded vehicle capable of lifting concentric steel pipes up to 0.75 m (2.5 ft) in diameter, filled with concrete. The pipes are up to 4.6 m (15 ft) long, capped at both ends with concrete and fitted with lifting devices. A shielded container might be required for shipping the waste. Retrieval of CMPs may require excavation around the concrete-filled pipes in order to remove them.

5.2.3 Resizing and Packaging Facility. A substantial number of FRP boxes used for TRU waste storage are larger than the maximum size specified by current federal repository criteria. Therefore, the waste would have to be resized and repackaged before shipment offsite. An RPF would be required for Alternatives 4, 8, and 12, which specify offsite disposal of stored waste without processing.

The containers would be opened at the facility and the oversized TRU items would be reduced in size to fit containers acceptable at the federal repository. The waste would then be packaged and shipped without further processing.

5.2.4 Waste Processing Facilities. All waste arriving at the WPF would be handled initially as TRU waste. Areas of the WPF that could contain >500 g of transuranic elements would conform to criteria in DOE Manual, Appendix 6301, Part II. For Alternatives 5, 6, 9, and 10, the WPF would be designed to handle ~9 600 m^3 (340 000 ft^3); whereas for Alternatives 13 and 14, the WPF would be designed to handle ~28 000 m^3 (1 000 000 ft^3) as shown in Table 5-3.

Waste arriving at the WPF would come from both retrieval and exhumation operations. The containers would consist primarily of 210-ℓ (55-gal) and 114-ℓ (30-gal) drums and FRP-coated plywood boxes. The TRU waste would be unpacked and sorted for processing in the following manner.

5.2.4.1 Sorting. TRU waste would be separated into combustibles, noncombustibles/nonmetals, and metals. Containers with both TRU and high levels of MFP (>500 mR/h at surface) would not be opened, and the relatively small amount of such waste would go directly to packaging for shipment to permanent disposal. Combustibles would be incinerated, and metals would be decontaminated if assay indicates the activity can be reduced to a level <10 nCi/g. Assuming a decontamination factor of 1000, metals with activity levels above 10 μCi/g could not be rendered LL and would be packaged for disposal without attempting decontamination.

The nonmetal/noncombustible portion of incoming TRU waste might consist of materials such as process residues, filter media, absorbents, loose tuff, sludge, soil, and concrete. These materials may be compacted or sized, packaged, and transported to the fixation process.

5.2.4.2 Volume and Size Reduction. Some of the exhumed TRU waste and, to a lesser extent, retrieved TRU waste would require volume and size reduction to permit packaging or processing. For offsite shipment, the following equipment may be needed:

- filter press for HEPA filters,
- compaction press for drums and sheet metal ducts,
- hammermill,
- hacksaw for structures and pipes, and
- plasma torch for gloveboxes and hoods.

5.2.4.3 Fixation. The purpose of fixation is to immobilize radionuclides during handling and transportation. TRU wastes requiring fixation would be in the form of incinerator ash, broken concrete, tuff, soil, and a few pieces of noncombustibles. A concrete matrix would be an effective binder, and the WPF would have provisions for both a continuous and a batch process, assuming that wastes fixed in this manner would be acceptable for disposal in the federal repository.

TABLE 5-3

DESIGN WASTE THROUGHPUT FOR WPF

Stored TRU Waste	Volume [m^3 (ft^3)[a]]	
Metals	5 000 (175 000)	
Combustibles	1 100 (40 000)	
Corrugated metal pipes with concrete	570 (20 000)	
Other nonmetal/noncombustibles	3 000 (105 000)	
		9 670 (340 000)
Buried TRU Waste		
Concrete from shafts	4 000 (140 000)	
Metal	2 800 (100 000)	
Combustibles	1 100 (40 000)	
Noncombustibles/nonmetals	3 000 (110 000)	
Soil exhumed with TRU waste	7 700 (270 000)	
		19 000 (660 000)
Total		28 000 (1 000 000)

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[a] Estimates are rounded to two significant figures.

5.2.4.4 Assay. Assay systems in the WPF would be required for control of TRU element inventory, and for separating out LL material. Considerable savings in costs and risks could be realized by routing LL waste back to the disposal areas now designated for such waste. The large volume 28 000 m^3 (1 000 000 ft^3) of waste that would pass through the WPF would necessitate efficient assay systems and several process streams to complete the program in a 15-yr period.

5.2.4.5 Containers. FRP-coated plywood boxes and 210-ℓ (55-gal) and 114-ℓ (30-gal) drums would be used to package the waste before transporting it from the exhumation site to the WPF. Steel drums that hold 314-ℓ (83 gal) would be available to overpack smaller drums with marginal integrity exhumed from burial or retrieved from storage. Larger overpacks such as the DOT-7A M-111 Bin, which can hold up to eight 210-ℓ (55-gal) drums are also available. An approved overpack and transport vehicle would be required for shipment of waste to an offsite repository.

5.3 Disposal Options

Four disposal options in the 14 alternatives described in this document are (1) Continue present practices, (2) Engineered improvements, namely, exhumation of the buried TRU, retrieval of the stored TRU, and disposal with or without further processing, (3) Deeper pit burial at Los Alamos, or (4) Deep burial at a geological federally owned repository. Although the first two disposal options conceivable could be used for permanent disposal, this study intends that these would be interim options for a period of up to 100 yr. TRU wastes would not be simply abandoned in existing locations in Los Alamos.

5.3.1 Offsite Disposal For this study, it was estimated that the offsite deep-geological disposal facility would be in southeastern New Mexico about 540 km (335 mi) from Los Alamos. Should an alternate site eventually be selected, it will probably be farther away, resulting in higher transportation costs and possibly higher risks, depending upon the route. Acceptance criteria have not been approved for a disposal site; therefore, for this study, the acceptable waste forms range from as-generated (packaged only) to a treated waste immobilized in concrete. The offsite disposal facility is assumed to be similar to WIPP, as described in Ref. 5-6.

5.3.2 Deeper Pit Disposal at Los Alamos. Deeper pit disposal would mean relocating the TRU waste after appropriate processing and/or packaging to a pit similar in design, but at some greater depth than the shallow land burial pits, for greater confinement and isolation. Exhumed and retrieved wastes would be segregated, with LL wastes going back into shallow land burial. The TRU wastes would be placed in a deeper pit for disposal. The excavation would be closed by covering the wastes with enough clean fill material to prevent penetration by animals and plant roots, by trench and building foundation excavation equipment, and by water. If the centerline is mounded higher than the edges, precipitation will more efficiently run off and infiltration will be minimized.

The advantages of this disposal method are in eliminating risks of extensive offsite transportation, and increased protection against intrusion and erosion provided by the added overburden. One pit might contain all the TRU waste now buried and stored at Los Alamos, as well as the TRU wastes expected to accumulate by the year 2005. At present, no deeper pits exist at Los Alamos, so they would have to be constructed.

Additional compacted overburden to the existing burial pits would also reduce the probability of a vertical release. However, some of the pits are so close to the edge of the mesa that horizontal activity from erosion conceivably could occur before the plutonium decays. A deeper pit would be located far enough from canyon rims to decrease horizontal erosion over longer time periods.

5.4 Alternatives Not Selected

A number of alternatives or options were not analyzed in depth in this study. Some of those omitted from further consideration are

- transmutation,
- polar ice cap disposal,
- extraterrestrial space disposal,
- oceanic disposal,
- deep geological disposal at Los Alamos,
- variations of engineered improvement, including absorbents,
- treatment of waste by slagging pyrolysis incineration,
- recovery of plutonium and americium by chemical processing, and
- rail transportation to offsite repository.

The first four options were not analyzed because they would entail technology still in the development stage. To quantify these options now would require a number of assumptions based on limited information and lead to findings of questionable validity.

Deep geological disposal at Los Alamos is less desirable than deeper pit disposal from both an economic and an industrial safety standpoint, and it does not address the problems of short- or long-range radiological risk.

Options for engineered improvement of the waste burial sites were covering the waste with (a) compacted tuff, (b) compacted tuff plus a riprap overlay, (c) compacted tuff plus a concrete interface barrier, and (d) compacted tuff plus a concrete interface barrier and a riprap overlay. Calculations show that 1.5 m (5 ft) of compacted tuff cover could provide adequate protection against activity release mechanisms such as erosion, radionuclide migration, intrusion by animals, tornadoes, earthquakes, meteorites, and airplane crashes (see Sec. 7). Considering only these mechanisms, option (a) is adequate, and the other three are somewhat overdesigned. However, because a riprap overlay will provide additional protection against unknowns, option (b) was selected for the detailed cost and risk analysis. Protection against volcanic eruption and intrusion by man is virtually impossible; therefore, these were not analyzed.

Local hydrological and meteorological conditions mitigate the need for adding chemicals and/or absorbents to the waste disposal areas (Ref. 5-7).

Slagging pyrolysis incineration (SPI) was not included in this document because SPI is essentially an unproven process, and because the costs for SPI are considerably higher than for the proposed WPF. No significant difference emerged in the short-term industrial or radiological hazards between the two options. The final product from the SPI may be more stable than that from the proposed WPF, but the product of the WPF (waste immobilized in concrete) meets proposed criteria for terminal disposal as written at the time of this study.

Recovery of transuranic elements (primarily plutonium and americium) from the waste is not considered economically feasible because of the small quantity of these elements present in the large volume of waste at Los Alamos, the unjustified costs of recovery compared with either replacement value or waste treatment costs, and because most of these wastes have already been subjected to waste processing and recovery operations.

Truck transportation was chosen over rail transportation because the nearest railhead to Los Alamos is at Lamy, New Mexico, ~80 km (50 mi) away. If the waste were trucked to Lamy, it might as well be trucked all the way to the disposal site to avoid additional handling. Constructing a rail line to Los Alamos would be extremely expensive because of the terrain, and the acquisition of right-of-ways would be very difficult.

REFERENCES FOR SECTION 5

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2. "Environmental and Other Evaluations of Alternatives for Long-Term Management of Buried INEL Transuranic Waste," Department of Energy report IDO-10084 (Draft) (October 1979).

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6. "WIPP Conceptual Design Report," Sandia Laboratories report SAND77-0274, Albuquerque, New Mexico (June 1977).

7. W. V. Abeele, "Future Credible Precipitation Occurrences in Los Alamos, New Mexico," Los Alamos Scientific Laboratory report LA-8523-MS (September 1980).

6. COST ESTIMATES FOR LONG-TERM MANAGEMENT OF LOS ALAMOS TRU WASTES

6.1 Introduction

The cost estimates prepared for this study are considered appropriate for economic feasibility studies only. They are based upon flow sheets, sketches, and equipment lists and are *not sufficiently accurate for budgetary purposes*; they are suitable for comparing alternative concepts.

6.2 Bases of Estimate

The cost estimates for this alternative study include capital costs, O&M, and D&D. Transportation and storage costs for waste onsite and offsite are also included. All costs are based on April 1980 costs (no escalation, see Sec. 4.3).

Capital costs include estimated costs of materials and equipment, with the equipment modified as required to allow its operation in a radioactive environment. For example, the mechanical equipment used to exhume the buried waste would be fitted with environmental cabs to allow operators to work safely in a contaminated area.

The total construction capital cost comprises the following components.

- *Direct costs* consist of equipment, materials, and construction.
- *Indirect costs*, 35% of direct costs, consist of contractors' field overhead, temporary facilities, bonds, and insurance.
- *Engineering costs*, 40% of direct and indirect, consist of engineering, design inspection, management, procurement, and fee.
- *Contingency costs* equal 40% of the sum of the above except in some instances where a more refined description was available.

Items not included in the total construction cost are utilities outside of the 5-ft line surrounding the facilities, escalation, any research and development required for retrieval, and equipment for packaging or processing. Because of these exclusions, the final capital costs could be significantly higher than indicated in this study. However, in the absence of more accurate information, these estimates form a logical basis for comparing the various alternatives.

O&M costs consist of labor, equipment replacement, fuel consumption, materials, and road maintenance, where applicable. A contingency of 40% of the applicable O&M costs is added to arrive at the total O&M costs.

For the alternatives that involve continuation of current practices and engineered improvements, O&M costs are those anticipated for surveillance and maintenance for a 100-yr period.

D&D costs are included for processing, packaging buildings, and exhumation buildings. D&D costs for facilities are difficult to determine because the degree of contamination and D&D criteria many years in the future are unknown, and cost data for D&D operations are scarce. Actual data indicate that D&D costs vary between 4 and 12% of the initial capital cost without escalation, depending upon the degree of contamination. This study estimates that the D&D costs for the processing, packaging, and exhumation building are 10% of the total capital cost. Actual costs incurred could be significantly different at the time the D&D operations are required.

Transportation costs to the federal repository are based on shipping the waste by truck from Los Alamos to a repository near Carlsbad, New Mexico. The costs are also based upon existing commercial interstate rates for radioactive waste. These costs could also be significantly different, depending upon several factors, such as fuel costs and federal, state, or other regulations.

The onsite transportation costs are based on purchase (and replacement) of trucks, labor costs for drivers, and fuel.

The cost for disposal of the TRU waste at a federal repository is included at \$3180/m^3 (\$90/ft^3), which is the current estimated charge for the WIPP facility. This cost is uncertain because of the ultimate cost of a repository, the amount of waste that will be stored in the repository, and because the required waste forms and packaging specifications are not yet known.

6.3 Cost Estimates

The cost estimates for the 14 alternatives are shown in Table 6-1. Several alternatives can be grouped according to total costs, as follows: Alternatives 1-3 and 7 ($80 000 000 to 95 000 000), Alternatives 4-6 and 8-10 ($122 000 000 to 156 000 000), and Alternatives 12-14 ($420 000 000 to 600 000 000). Alternative 11 costs $280 000 000.

In addition to cost estimates presented in Table 6-1, three variations of Alternatives 11-14 were considered to determine the costs associated with Areas A and B. The quantity of TRU waste is believed to be very small for those areas, and further investigations may verify that they do not contain TRU waste. Therefore, cost estimates were made for Alternatives 11-14 assuming (1) Area A is not exhumed, (2) Area B is not exhumed, and (3) Areas A and B are not exhumed. These cost estimates are shown in Table 6-2. Because the waste volumes at Areas A and B represent a small percentage of the total buried waste volume, the capital costs are not significantly affected. For example, the WPF of the size proposed is still required even if slightly less waste volume is processed. However, O&M costs have been reduced proportionately to the volume of waste processed. The cost difference for any of these variations is relatively small.

Note that exhumation of Area B would involve transporting LL wastes away from the area rather than replacing it in the pit as proposed for other locations. Therefore, the cost reduction obtained by leaving Area B out of the exhumation plan would be greater than for Area A, which is approximately the same size.

7. RISK ANALYSIS

The following section discusses the radiological and the nonradiological risks associated with the alternatives under study.

Sec. 7.1 presents the methodology used for estimating the radiation doses to the occupationally exposed workers and the general population in the maximally exposed 22.5° sector out to a distance of 80 km (50 mi) plus that in Albuquerque. These dose estimates are summarized in Sec. 7.1.7 with supporting details in Appendix D.

Sec. 7.2 discusses the nonradiological impacts that could be expected from each of the alternative strategies. Included in Sec. 7.2 are brief statements concerning environmental impacts, and the commitment of resources for the various alternatives.

Sec. 7.3 discusses some of the longer-term (over 100 years) impacts possible for the selected alternatives.

7.1 Radiological Risks

The radiological risk analysis for the 14 alternatives was limited to the determination of radiation doses to the public and the workers. Calculations were performed for the hypothetical operations underlying the implementation of the alternatives. The methodology used is described in Sec. 7.1.1, and an example of a calculated dose impact is given in Sec. 7.1.7. Details concerning the determinations are tabulated in Appendix D.

The alternatives for TRU waste management at Los Alamos consist of four basic options: (1) leave in place, (2) leave in place with an improved cover, (3) transfer to a new onsite deeper pit, or (4) transfer to an offsite geological repository. In addition to a modification to allow suboptions of onsite or offsite disposal, the basic options are modified to permit processing or no processing of the buried or stored waste. A total of 18 modular options are defined, 9 for buried waste (B1 through) and 9 for stored waste (S1 through S9). The modular options are analyzed independently and then combined as required to generate the doses and subsequent radiological impacts for a given alternative. Table 7-1 lists the 18 modular options and their description. Table 7-2 lists the 14 alternatives and their corresponding modular options.

7.1.1 Dose Calculation Methodology. Estimated impacts (I) for accidents are presented as the product of population dose (D) in man-rem per event, the event frequency (fe), and time interval (T) as

I (man-rem) =

$$D \, \frac{\text{(man-rem)}}{\text{(events)}} \cdot \text{fe} \, \frac{\text{(event)}}{\text{(yr)}} \cdot T \text{ (yr)} \; .$$

TABLE 6-1

LOS ALAMOS LONG-TERM WASTE MANAGEMENT ALTERNATIVE COST ESTIMATES
(Dollars in Millions—April 1980)

Alternative	Buried (B) Stored (S) Waste	Option	Capital Cost	O&M Cost	Total Cost
1	B	Continue current practices	$ 3	$ 80	$ 83
	S	Continue current practices			
2	B	Engineered improvements	10	80	90
	S	Engineered improvements			
3	B	Continue current practices	6	76	88
	S	Retrieve, Los Alamos disposal			
4	B	Continue current practices	14	108	122
	S	Retrieve, resize, and package, offsite disposal			
5	B	Continue current practices	31	103	140
	S	Retrieve, process, Los Alamos disposal			
6	B	Continue current practices	29	121	150
	S	Retrieve, process, offsite disposal			
7	B	Engineered improvements	12	76	94
	S	Retrieve, Los Alamos disposal			
8	B	Engineered improvements	20	108	128
	S	Retrieve, resize, and package, offsite disposal			
9	B	Engineered improvements	37	103	146
	S	Retrieve, process, Los Alamos disposal			
10	B	Engineered improvements	35	121	156
	S	Retrieve, process, offsite disposal			
11	B	Exhume, package, Los Alamos disposal	79	182	280
	S	Retrieve, Los Alamos disposal			
12	B	Exhume, package, offsite disposal	86	317	421
	S	Retrieve, resize, and package, offsite disposal			
13	B	Exhume, process, Los Alamos disposal	138	354	511
	S	Retrieve, process, Los Alamos disposal			
14	B	Exhume, process, offsite disposal	136	437	592
	S	Retrieve, process, offsite disposal			

TABLE 6-2

COST ESTIMATES FOR VARIATIONS OF ALTERNATIVES 11-14
(Dollars in Millions—April 1980)

Alternative	Variation	Total Cost
11	None	$280
11A	Area A not exhumed	273
11B	Area B not exhumed	268
11AB	Areas A and B not exhumed	261
12	None	421
12A	Area A not exhumed	412
12B	Area B not exhumed	407
12AB	Areas A and B not exhumed	397
13	None	511
13A	Area A not exhumed	501
13B	Area B not exhumed	498
13AB	Areas A and B not exhumed	485
14	None	592
14A	Area A not exhumed	582
14B	Area B not exhumed	577
14AB	Areas A and B not exhumed	562

D is the sum of the doses received by a specific population:

$$D \frac{\text{(man-rem)}}{\text{(event)}} = \sum_{i=1}^{n} di ,$$

where n is the number of people in a specific population receiving a radiation dose, and di is the radiation dose in rem to a member of that population.

The radiation dose (di) was calculated for inhalation exposures to individuals with the aid of two computer codes. The code PATHFINDER (Ref. 7-1) listed the population density surrounding the three Laboratory sites; TA-21, TA-50, and TA-54. Wind dispersion data from Laboratory meteorological studies were used to derive particulate dispersion factors to calculate the radioactive particulate concentration at multiple intervals and in 22.5° sectors up to 80 km from the sites considered (Ref. 7-2). Using the code DACRIN (Ref. 7-3), a reference initial 70-yr accumulative dose to an individual from the inhalation of 1 nCi of radioactive particulates was calculated. Subsequently, di were calculated for internal exposures by estimating the radioactive particulate intake in nCi from inhalation and then scaling the reference inhalation doses calculated by DACRIN.

External di to Laboratory workers were calculated by estimating the mass flow of radioactive material handled during well-defined short interval (days) tasks. For some tasks, Laboratory experience and experimental data (Ref. 7-4) including measurements of the radioactivity of the waste types and forms, were used as a basis for calculating the listed doses.

The following doses are analyzed for the buried and stored waste options for each alternative.

A. Occupational Doses
  - External Dose from Normal Operations
  - Internal Dose from Accidents

B. Population Dose
  - Internal Dose from Accidents
  - External Dose from Offsite Shipments

TABLE 7-1

OPTIONS FOR LOS ALAMOS TRU WASTE MANAGEMENT

Option	Waste Category	Description	Option	Waste Category	Description
B1	Buried	CONTINUE PRESENT PRACTICE The areas that contain waste buried without segregation of TRU material are left as they exist and maintenance and surveillance are continued for 100 years.	S1	Stored	CONTINUE PRESENT PRACTICE TRU waste is left as currently retrievably stored and maintenance and surveillance are continued for 100 years.
B2	Buried	ENGINEERED IMPROVEMENTS Same as option B1 but top cover is improved to consist of 1.5 m of compacted tuff and 30 cm of rip rap.	S2	Stored	ENGINEERED IMPROVEMENTS Same as option S1 but top cover is improved to consist of 4.5 m of compacted tuff and 30 cm of rip rap.
B3	Buried	EXHUME. Areas with a potential for TRU waste are excavated, the material is assayed, TRU waste is separated and the LL is returned to burial pits.	S3	Stored	RETRIEVE. The segregated TRU waste that is retrievably stored is removed from storage.
B4	Buried	EXHUME AND PROCESS The TRU fraction is processed in the Waste Processing Facility.	S4	Stored	RETRIEVE AND PROCESS The retrieved waste is processed in the Waste Processing Facility.
B5	Buried	OPTION B4 WITH TRANSFER TO ONSITE DEEP PIT	S5	Stored	OPTION S4 WITH TRANSFER TO ONSITE DEEP PIT
B6	Buried	OPTION B4 WITH SHIPMENT TO OFFSITE REPOSITORY	S6	Stored	OPTION S4 WITH SHIPMENT TO OFFSITE REPOSITORY
B7	Buried	EXHUME AND PACKAGE WITHOUT WPF PROCESSING	S7	Stored	RETRIEVE AND REPACKAGE WITHOUT WPF PROCESSING
B8	Buried	OPTION B7 WITH TRANSFER TO ONSITE DEEP PIT	S8	Stored	OPTION S7 WITH TRANSFER TO ONSITE DEEP PIT
B9	Buried	OPTION B7 WITH SHIPMENT TO OFFSITE REPOSITORY	S9	Stored	OPTION S7 WITH SHIPMENT TO OFFSITE REPOSITORY

The concept of discounting radiation risks over future years was considered and rejected because it is not compatible with keeping all radiation doses as low as reasonably achievable.

7.1.2 Estimated Occupational Doses From Normal Operations.

7.1.2.1 Buried Waste Modular Options B1 through B9. Occupational doses for the nine buried waste options are calculated based on weighted Laboratory external radiation dosimetry data and engineering estimates of the required time and manpower for the operations. At the Laboratory, ~25% of the badged Laboratory-wide employees receive almost 100% of the recorded external exposures (Ref. 7-5). Laboratory dosimetry records (Ref. 7-6) indicate that internal exposures are relatively insignificant for normal operations. For the years 1976 through 1978, the weighted average at the Laboratory for the 25% of the badged work force receiving the exposures was 260 mrem/yr/man. This value is used as a guide for assigning the occupational exposures to the buried waste options and is believed to err on the high side, or "worst" situation.

TABLE 7-2

TRU WASTE MANAGEMENT ALTERNATIVES AND OPTIONS

Alternative	Description	Related Options
1	Buried and Stored Waste. Continue Present Practice.	B1,S1
2	Buried and Stored Waste. Engineered Improvement.	B2, S2
3	Buried Waste. Continue Present Practice. Stored Waste, Retrieve, Los Alamos Deep-Pit Disposal.	B1 S3, S7, S8
4	Buried Waste. Continue Present Practice. Stored Waste. Retrieve, Package, Offsite Geological Disposal.	B1 S3, S7, S9
5	Buried Waste. Continue Present Practice. Stored Waste. Retrieve, WPF Treatment, Los Alamos Deep-Pit Disposal.	B1 S3, S4, S5
6	Buried Waste. Continue Present Practice. Stored Waste. Retrieve, WPF Treatment, Offsite Geological Disposal.	B1 S3, S4, S6
7	Buried Waste. Engineered Improvements. Stored Waste. Retrieve, Los Alamos Deep-Pit Disposal.	B2 S3, S7, S8
8	Buried Waste. Engineered Improvements. Stored Waste. Retrieve, Package, Offsite Geological Disposal.	B2 S3, S7, S9
9	Buried Waste. Engineered Improvements. Stored Waste. Retrieve, WPF Treatment, Los Alamos Deep-Pit Disposal.	B2 S3, S4, S5
10	Buried Waste. Engineered Improvements. Stored Waste. Retrieve, WPF Treatment, Offsite Geological Disposal.	B2 S3, S4, S6
11	Buried Waste. Exhume, Package, Los Alamos Deep-Pit Disposal. Stored Waste. Retrieve, Los Alamos Deep-Pit Disposal.	B3, B7, B8 S3, S7, S8
12	Buried Waste. Exhume, Package, Offsite Geological Disposal. Stored Waste. Retrieve, Package, Offsite Geological Disposal.	B3, B7, B9 S3, S7, S9
13	Buried Waste. Exhume, WPF Treatment, Los Alamos Deep-Pit Disposal. Stored Waste. Retrieve, WPF Treatment, Los Alamos Deep-Pit Disposal.	B3, B4, B5 S3, S4, S5
14	Buried Waste. Exhume, WPF Treatment, Offsite Geological Disposal. Stored Waste. Retrieve, WPF Treatment, Offsite Geological Disposal.	B3, B4, B6 S3, S4, S6

In options B1 and B2, the buried waste is undisturbed; the occupational doses incurred by maintenance and surveillance crews under normal operating conditions are estimated as 11 and 9 man-rem, respectively, for the 100-yr period assumed for the surveillance of both buried and stored waste. In option B3, the exhumation operations lead to several suboptions with a potential for occupational exposures. The operational tasks, manpower, time requirements, and external exposure potential are the principal factors considered in the dose assessment.

Based on the Los Alamos weighted average of 260 mrem/yr/man as the norm for all nuclear material processes throughout the Laboratory, the buried waste operations are assigned external exposure values that are less than, equal to, or more than this value depending on the exhumation data presented in Table 4-2. For this purpose the following estimations are made.

- Exhumation of Areas A and B pits and Area V absorption beds would average an external exposure of 150 mrem/yr/man.

- Exhumation of Area T beds and Areas C and G pits would average an external exposure of 260 mrem/yr/man.

- Exhumation of Area T shafts would average an external exposure of 400 mrem/yr/man.

- Processing operations at the WPF would average an external exposure of 400 mrem/yr/man.

- Special handling operations for the fission product contaminated waste in Areas C and G would be controlled to <1 rem/yr/man. The estimated average external exposure of 1 rem/yr/man, errs on the side of increased safety.

Details and results of the occupational dose assessments for the nine buried waste modular options are presented in Appendix D. Buried waste inventory data for the six burial areas are taken from Los Alamos reports and are summarized in Table 4-2. A summary of the calculated doses is provided in Table 7-3.

7.1.2.2 Stored Waste Options S1 through S9. Normal operations at the Laboratory are designed to limit occupational exposures to external radiation. This section estimates the external gamma dose to the radiation workers during handling and processing of stored waste. Three sources of information

TABLE 7-3

SUMMARY OF OCCUPATIONAL[a] DOSES FOR BURIED WASTE NORMAL OPERATIONS

Option	Description	Total Man-days	Occupational Man-rem/Option
B1	Continue Current Practice		11[b]
B2	Engineered Improvements		8.8[b]
B3	Exhume Buried Waste	3.6×10^5	470
B4	Process Exhumed Waste	2.2×10^5	340
B5	Onsite Deep Pit Burial After Processing	9×10^3	9.2
B6	Offsite Deep Geologic Burial After Processing	1.4×10^4	13
B7	Package Without Treatment	6×10^3	6.2
B8	Onsite Deep Pit Burial for Packaged Untreated Waste	2.5×10^3	7.8
B9	Offsite Deep Geologic Burial for Packaged Untreated Waste	1.2×10^4	12

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[a] Occupational doses are from external radiation. Internal doses are relatively insignificant.
[b] Includes buried and stored waste contributions and a 100-yr surveillance and maintenance period.

were used to calculate the external doses. The first source was actual TLD measurements (Ref. 7-4) of the following three simple stored-waste tasks, including installing of lids on waste-loaded FRP boxes, stacking of TRU drums, and loading FRP boxes onto transport vehicles. The second source was film badge/TLD data for Los Alamos workers. The third source was estimates based on determinations of the time, task, and source strength of a given operation.

Basically, the stored waste forms described in Table 4-2 were followed through the options; external doses were calculated with the number of workers required to complete the handling and processing of these waste types. Operations defined in the options were broken down into handling or processing tasks required for stored waste. Doses were assigned based on waste form, task, and number of units handled or processed. Details of the occupational dose assessments for the nine stored waste options are presented in Appendix D, Table D-10. A summary of the results is provided in Table 7-4.

7.1.3 Population Doses From Normal Operations. Releases from normal operations were calculated and were relatively insignificant because retrievable waste is stored in high-quality containers, from which releases during normal operations are not credible. "Not credible" signifies an event with a probability of less than 10^{-7}, and, therefore, unlikely to happen. Exhumation and WPF operations would be housed in structures that exhaust to the atmosphere through HEPA filters. Conservatively, assuming a decontamination factor of 10^5, a dust loading of 100 μg/m^3, and an activity of 20 nCi ^{239}Pu/g, the concentrations in the ventilation exhaust from exhumation and processing facilities would be 2×10^{-17} μCi/cm^3. The Maximum Permissible Air Concentration (Ref. 7-7) of soluble ^{239}Pu in the unrestricted areas is 2×10^{-14} μCi/mℓ, more than 1000 times greater than the hypothetical release concentrations. Therefore, releases resulting in population doses from normal operations are not considered significant and are not addressed further.

TABLE 7-4

SUMMARY OF OCCUPATIONAL DOSES[a] FOR STORED WASTE NORMAL OPERATIONS

Option	Description	Total Man-days	Occupational Man-rem/Option
S1	Continue Present Practice	1.1×10^5	11.0
S2	Engineered Improvements	1.1×10^5	8.8
S3	Retrieve Stored Waste	8.3×10^3	45.0
S4	Process Stored Waste	1.8×10^4	44.0
S5	Onsite Deep Pit Burial	2.7×10^3	42.0
S6	Offsite Deep Geologic Burial After Processing	3.7×10^3	1.5
S7	Repackage Without Treatment	3.7×10^2	14.0
S8	Onsite Deep Pit Burial for Repackaged Nonprocessed Waste	3.6×10^3	14.0
S9	Offsite Deep Geologic Burial for Repackaged Nonprocessed Waste	4.0×10^3	2.0

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[a] Occupational doses are from external radiation. Internal doses are relatively insignificant.

[b] Includes buried plus stored waste contributions.

For shipments of TRU waste within Los Alamos, it is calculated there would be no detectable doses to the public. For shipments to an offsite repository, doses to the public from normal (nonaccident) operations have been calculated in the WIPP EIS (Ref. 7-8). Based on the WIPP estimate, the external doses attributable to the shipment of TRU waste from Los Alamos to a federal repository 540 km away, are listed in Table 7-5.

7.1.4 Postulated Accident Scenarios. Buried waste and stored waste options were analyzed for the release potential from accidents caused by tornado, airplane crash, operator error, or equipment failure. The analysis considered the volume of waste, the curie content, and events that could lead to a release. The natural phenomena mechanisms for releases from the Los Alamos burial grounds have been studied by M. L. Wheeler et al. (Ref. 7-9). Their conclusion is that the probabilities of occurrence of meteorite impacts, tornadoes, and earthquakes are too low and their mechanisms too ineffective to result in any release of the buried waste. A significant difference in our analysis is that in the exhumation and retrieval options, the waste cover is removed. Thus, the tornado and earthquake events present a comparatively higher potential for the release of very small quantities of radioactivity to the environment. Natural phenomena and other potential release events considered include the following.

- **Tornado**—There is an extremely low probability at Los Alamos (Ref. 7-8). Tornadoes with winds 158-206 mph are deemed impossible. Winds of 113-157 mph have a probability of about 1.5×10^{-6}/yr, a value on the borderline of credibility.
- **Airplane Crash**—Small releases postulated for an airplane penetrating the exhumation building and causing an aviation fuel-waste debris fire. The estimated probabilities range from 1.6×10^{-4}/yr to 2.3×10^{-7} yr.

These estimates are based upon Ref. 7-10 as calculated in Appendix C of the present study.

- *Operator and/or Equipment Failure*—Dropping containers of waste assay or an incinerator explosion are the most likely accidents that could lead to a release.
- *Earthquake*—This event was dismissed from consideration after careful scrutiny of available information. The Final Environmental Impact Statement for Los Alamos summarizes two studies (Refs. 7-11 and 7-12) that have been made of seismic risk in the Los Alamos area. The studies estimate that the Los Alamos area is subject to an earthquake of magnitude from 5 to 5.5 (Richter scale) once every 100 yr. An equally important consideration is what might occur in Los Alamos during earthquakes. In the design of the new plutonium facility, a modified Mercalli scale intensity of VII was chosen for the "Operating Base Earthquake" and an intensity value of VIII on the

TABLE 7-5

NORMAL POPULATION DOSES FOR BURIED AND STORED WASTE TRANSPORT TO OFFSITE REPOSITORY

Option	Operation	Dose per Shipment (man-rem)	Total Number Shipments	Risk Period (yr)	Cumulative Dose Commitment (man-rem)
B6	Truck transport offsite	0.034	2700	15	130
B9	Truck transport offsite	0.034	2700	15	130
S6	Truck transport offsite	0.034	1000	15	34
S9	Truck transport offsite	0.034	1000	15	34

same scale was chosen for the "Safe Shutdown Earthquake." While there is no single relationship between Richter magnitude and the modified Mercalli Intensity, the following is noted for purposes of illustration. A 5 to 5.5 magnitude, VII-VIII Intensity earthquake would probably cause nonseismically qualified structures considerable damage. For waste exhumation or retrieval operations, it is estimated the disturbance would cause damage severe enough to break containers. However, release of radioactively contaminated material is unlikely, and if it did occur, it would be confined to the immediate area with no significant release to the environment. In addition, because the most probable epicenter for an earthquake at Los Alamos is the Pajarito fault (5 to 12 km distant from the waste sites analyzed), the severity of the most probable earthquake at Los Alamos would be lessened by the distance from the waste site. The earthquake scenario does not present a credible mechanism for release of radioactive material from the waste burial or storage areas analyzed.

- *Volcano*—The probability for volcanic activity at any of the Los Alamos burial grounds is extremely low (Ref. 7-5), so it is dismissed from consideration.
- ***Flood***—No credible flood event would effect a release of Los Alamos buried waste (Ref. 7-5).
- ***Meteorite***—Dismissed from consideration because the estimated probability is 1 × 10^{-7}/yr (Ref. 7-9).
- ***Sabotage***—This analysis does not address sabotage.

Accident scenarios, event frequencies and consequences that could conceivably result in occupational and population doses are presented in the dose assessment sections that follow.

7.1.5 Estimated Occupational Doses From Accidents. In postulating occupational doses from accidents, exposures are mitigated by good health physics practices in effect in the radiation areas. Tasks that have a potential for release of radioactivity are recognized, and suitable controls are applied; for example, the use of anticontamination clothing and respirators, standard operating procedures, radiation work permits, and established, tested emergency procedures.

The accidents or upsets postulated in Sec. 7.1.4 are of interest for their occupational dose potential as well as for population dose. For either case, releases of radioactivity are regarded as abnormal occurrences and are caused by low- probability phenomena such as a tornado or an airplane crash, or by operational accidents in handling or processing. Definitive analyses of occupational exposures from radioactive waste processing accidents are not available.

For that reason, the postulated accidents, their frequencies, and consequences are based on engineering judgment. For the accidents analyzed, the workers are assumed to inhale a fraction of the very small quantities of airborne radioactivity. Each worker inhales airborne contamination at a rate of 20 ℓ/min, at a concentration of from 10 to 100 nCi/g of ^{239}Pu and the air dust loadings range from 30 to 200 mg/m^3, depending on the postulated accident. Fractions of the material at risk that become airborne, the fraction that is in the breathable particle size range, and the duration of the exposure are factors whose values are estimated from best available data. In particular, the studies (Refs. 7-13 and 7-14) by Mishima and Schwendiman to estimate the amount of material inhaled by individuals were used.

The scenarios resulting in population exposures as well as occupational exposures are described later in the population dose section. The accidents that do not result in releases to the environment, but only to the work area, are described here.

7.1.5.1 WPF Waste Incinerator Explosion. The accident scenario for the WPF would result in no population exposure because the facility would be built to DOE Manual, Appendix 6301, Part II, Plutonium Facility Standards. The occupational exposure is considered here. The highest operational exposure in the WPF building would involve an explosion of the waste incinerator. It is postulated that, as a result of an explosion, the incinerator ashes would be blown into the operating areas. The following assumptions estimate the resulting release to the occupational area.

- The concentration of the radioactivity in the ash is higher than that of the feed material by a factor of 33.
- The feed material averages 20 nCi/g.
- The hourly throughput of the incinerator is 8.3×10^{-4} m^3.
- About 12% of the hourly ash output, 1.0×10^{-4} m^3, becomes airborne as a result of the explosion.
- The density of the ashes is 0.7 g/cm^3.
- The respirable fraction is 0.01.
- The event frequency is 0.01/yr.

The release to the operating area is calculated to be 231 nCi of ^{239}Pu and 231 nCi of ^{90}Sr.

7.1.5.2 TRU Waste Handling Box Spill. The most likely operator error or equipment failure that could result in a release in the exhumation building is the spill of the contents of a box loaded with TRU waste that has been assayed and separated from the LL. To calculate the local release, the following assumptions are made.

- A 3.2-m^3 box 80% full of TRU waste is dropped and the contents spill out into the immediate area.
- The radioactive content is 0.55 Ci/m^3.
- A 1×10^{-5} fraction becomes airborne.
- A 5×10^{-3} fraction is respirable.
- The event frequency is 1/yr.

The postulated release is calculated to be 35 nCi of ^{239}Pu and 35 nCi of ^{90}Sr and is confined to the area inside the building.

7.1.5.3 Glove Box Pressurization in the WPF. A glovebox pressurization may be caused by a variety of circumstances. The following assumptions are made for the pressurization scenario.

- A glovebox pressurizes enough to blow out a glove.
- The release to the room air is 1 μCi of ^{239}Pu in the oxide form.
- Four operators inhale 3 nCi of ^{239}Pu.
- Operators are not wearing respirators at the time of the incident.
- The frequency of glovebox pressurization is once per 15 yr.

7.1.5.4 Glove Rupture in the WPF. Glove rupture and tears are a relatively common incident in industrial processing areas. However, major releases following a glove tear are uncommon with highly trained operators. The following assumptions were made for the analysis.

- Releases involving gloves occur 5 times a year.
- An operator experiencing a torn glove inhales about 0.1 nCi of ^{239}Pu oxide.

The occupational doses calculated are shown in Table 7-6 for buried waste and Table 7-7 for stored waste.

7.1.6 Estimated Population Doses Resulting from Accidents. The probability of population exposures from Los Alamos buried or stored waste operations is very low. For all normal operations except shipments to an offsite repository, calculations show that the doses to the general public will be negligible. Nevertheless, for purposes of comparison, releases from the hypothetical accidents described in Sec. 7.1.4 are the basis for the population doses estimated for the 18 modular options. Area G was selected for the analysis because it contains the most waste in volume or activity. For each option, the most likely events that could result in a release have been considered.

TABLE 7-6

OCCUPATIONAL DOSES FOR BURIED WASTE ACCIDENTS

Option	Event	Release Quantity[a]	Particulate Loading (mg/m^3)	Respirable (nCi/g)	Inhaled/ Worker (nCi)	No. of Workers	Dose/ Event (man-rem)	Event Frequency (yr^{-1})	Risk Period (yr)	Estimated Impact[b] (man-rem)
B1	None								100	0.0
B2	None								100	0.0
B3	Tornado	50 mCi	200	100	1.0	17	35	1.5×10^{-6}	15	7.8×10^{-4}
	Plane crash	9 mCi	200	100	1.0	17	35	2.3×10^{-7}	15	1.2×10^{-4}
	Box spill (inside)	35 nCi	30	100	0.1	17	3.5	1.0×10^{0}	15	5.3×10^{1}
B4	Incinerator explosion	230 nCi	200	660	3.0	4	25	1.0×10^{-2}	15	3.8×10^{0}
	Glove box pressurization	1 μCi	200	100	1.0	4	8.3	4.0×10^{-1}	15	5.0×10^{1}
	Glove box rupture	10 nCi	30	100	0.1	1	0.20	1.0×10^{1}	15	3.0×10^{1}
B5	Box spill (outside)	35 nCi	30	100	0.1	4	0.83	1.3×10^{-1}	15	1.6×10^{0}
B6	Truck accident	3.1 mCi 0.3 mCi*	200	100	1.0	2	4.2	7.3×10^{-7}	15	4.6×10^{-5}
B7	Box spill (inside)	35 nCi	30	100	0.1	17	3.5	1.0×10^{0}	15	5.3×10^{1}
B8	Box spill (outside)	35 nCi	30	100	0.1	4	0.83	1.3×10^{-1}	15	1.6×10^{0}
B9	Truck accident	3.1 mCi 0.3 mCi*	200	100	1.0	2	4.2	7.3×10^{-7}	15	4.6×10^{-5}

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[a] Release quantities are ^{239}Pu except for *, which denotes ^{238}Pu.

[b] The estimated impact is the product of the dose per event times the event frequency times the risk period.

TABLE 7-7

OCCUPATIONAL DOSES FOR STORED WASTE ACCIDENTS

Option	Event	Release Quantity[a]	Particulate Loading (mg/m^3)	Respirable (nCi/g)	Inhaled/ Worker (nCi)	No. of Workers	Dose/ Event (man-rem)	Event Frequency (yr^{-1})	Risk Period (yr)	Estimated Impact[b] (man-rem)
S1	None								100	0.0
S2	None								100	0.0
S3	Tornado	1 μCi	200	100	1.0	13	27	1.5×10^{-6}	15	6.1×10^{-4}
	Plane crash	91 μCi	200	100	1.0	13	27	2.3×10^{-7}	15	9.3×10^{-5}
	Drop and rupture (drum or FRP)	10 nCi	30	100	0.1	4	0.83	1.3×10^{-1}	15	1.6×10^{0}
	Drop and rupture (Cask + 114 ℓ drum)	1 μCi*	30	1000	1.0	4	6.8	6.7×10^{-3}	15	6.8×10^{-1}
	Drop and rupture (shaft)	1 μCi	30	1000	1.0	4	8.4	6.7×10^{-3}	15	8.4×10^{-1}
S4	Incinerator explosion	230 nCi	200	660	3.0	4	25	1.0×10^{-2}	15	3.8×10^{0}
	Glove box pressurization	1 μCi	200	100	1.0	4	8.3	2.0×10^{-1}	15	2.5×10^{1}
	Glove box rupture	10 nCi	30	100	0.1	1	0.20	5.0×10^{0}	15	1.5×10^{1}
S5	Box spill (outside)	10 nCi	30	100	0.1	4	0.83	1.3×10^{-1}	15	1.6×10^{0}
S6	Truck accident	3.1 mCi 0.3 mC*	200	100	1.0	2	4.2	2.7×10^{-7}	15	1.7×10^{-5}
S7	Waste spill (inside)	10 nCi	30	100	1.0	8	17	6.7×10^{-3}	15	1.7×10^{0}
S8	Drop and rupture (drum or FRP)	10 nCi	30	100	0.1	4	0.83	1.3×10^{-1}	15	1.6×10^{0}
	Drop and rupture (cask +114 ℓ drum)	1 μCi*	30	1000	1.0	4	6.8	6.7×10^{-3}	15	6.8×10^{-1}
	Drop and rupture (shaft)	1 μCi	30	1000	1.0	4	8.4	6.7×10^{-3}	15	8.4×10^{-1}
S9	Truck accident	3.1 mCi 0.3 mCi*	200	100	1.0	2	4.2	2.7×10^{-7}	15	1.7×10^{-5}

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[a] Release quantities are ^{239}Pu except for *, which denotes ^{238}Pu.

[b] The estimated impact is the product of dose/event times event frequency times the risk period.

7.1.6.1 Buried Waste Options B1-B9. The exhumation of buried waste presents the principal operation that could result in a release of radioactivity to the environment. Each modular option was analyzed for population exposure as discussed below, and the calculated doses are reported in Table 7-8.

7.1.6.2 Options B1 and B2. Continue Current Practice and Engineered Improvements. There are no credible natural phenomena, operator errors, or equipment failures that affect these options. Therefore, no population doses are postulated.

7.1.6.3 Option B3—Exhumation of Buried Waste. Exhumation would surface the buried contaminated debris, and several mechanisms can be postulated that could cause material to become airborne. However, operator errors and equipment failures would result only in occupational exposures. The exhumation operations are housed in a containment building equipped with high-reliability HEPA filters for its air exhaust system. The building would be operated in a negative pressure differential mode with respect to the outside so that any leakage is inward.

Natural phenomena or other events that could lead to a release have very low probabilities. Because there is some potential for a release from a tornado or airplane crash when the burial grounds are being excavated, an analysis of each event was performed.

7.1.6.4 Tornado. The probability for a tornado (Ref. 7-9) with winds from 113 to 157 mph is about 1.5×10^{-6}/yr. This type of tornado could destroy the exhumation building and scatter exposed contaminated waste into the environment. The following assumptions made calculate a release potential.

- The average concentration of the radioactivity is 34.3 mCi/m^3 of burial pit volume.
- The surface of the Area G pits is approximately 33 000 m^2.
- About 1% of total pit surface area is exposed because of exhumation operations when the tornado strikes.
- A 1-cm-layer thickness of the exposed area is scattered into the environment.

The estimated release to the environment from this event is 0.1 Ci and is estimated to be 0.05 Ci of ^{239}Pu and 0.05 Ci of ^{90}Sr.

TABLE 7-8

POPULATION DOSES FOR BURIED WASTE ACCIDENTS

Option	Event	Release Site	Release Magnitude	Dose/ Event[a] (man-rem)	Event Frequency (yr^{-1})	Risk Period (yr)	Estimated Impact (man-rem)
B1	None					100	0.0
B2	None					100	0.0
B3	Tornado	Area G	50 mCi ^{239}Pu	1.8×10^4	1.5×10^{-6}	15	4.1×10^{-1}
	Plane crash	Area G	9 mCi ^{239}Pu	3.2×10^3	2.3×10^{-7}	15	1.1×10^{-2}
B4	None					15	0.0
B5	Box spill (outside)	Area G	35 nCi ^{239}Pu	1.3×10^{-2}	1.0×10^0	15	2.0×10^{-1}
B6	Truck accident	Urban center	3.1 mCi ^{239}Pu 0.3 mCi ^{238}Pu	2.0×10^3	7.3×10^{-7}	15	2.2×10^{-2}
B7	None					15	0.0
B8	Box spill (outside	Area G	35 nCi ^{239}Pu	1.3×10^{-2}	1.0×10^0	15	2.0×10^{-1}
B9	Truck accident	Urban center	3.1 mCi ^{239}Pu 0.3 mCi ^{238}Pu	2.0×10^3	7.3×10^{-7}	15	2.2×10^{-2}

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[a] Population assumed is 3.6×10^5.

7.1.6.5 Airplane Crash. The highest probability of an airplane striking any of the burial sites is 1.6×10^{-4}/yr. This is the probability of a small aircraft hitting TA-21. At TA-21, Area T, the waste concentrations are high, but the form is either absorption bed stones, sand and gravel, or liquid waste/sludge fixed in cement. These forms are noncombustible and difficult to disperse; therefore, the area is dismissed from further consideration. Area G contains the maximum radioactively contaminated combustible debris. The scenario of a large aircraft strike, accompanied by a fire, presents the highest potential for a release, even though the probability is extremely low. To calculate a release, the worst case assumption is made that a large airplane crashes into and penetrates the exhumation building and a fire ensues. To calculate a release, the following assumptions are made.

- Area G pits are exposed by exhumation operations.
- About 5% of the total pit surface area is involved, that is, 1670 m^2.
- A depth of 0.3 m of waste debris in this area burns.
- The waste radioactivity concentration is 34.3 mCi/m^3.
- Ten per cent of the radioactivity involved is released.
- The radioactive respirable fraction is 0.01.

The calculated release is 17 mCi and is estimated to be 8.6 mCi of ^{239}Pu and 8.6 mCi of ^{90}Sr.

7.1.6.6 Option B4—Processing of Exhumed Waste. There is no credible release during transportation of the exhumed waste from the burial site to the WPF. The transfer is made in approved containers on trucks that would not travel at speeds great enough to compromise the integrity of the shipping containers in case of an accident. From within the WPF, there is no credible mechanism for a release to the environment, because the WPF building will be designed and built to the plutonium handling facilities standards required in DOE Manual, Appendix 6301, Part II, Plutonium Facilities. The consequences of an incinerator explosion are analyzed in the occupational dose section.

7.1.6.7 Option B5—Los Alamos Deep Pit Burial of Processed Waste. No credible release to the environment from a truck accident is possible because of the use of approved transport containers and the relatively slow speeds allowed onsite. The probability for a truck accident of the severity required to release any waste from its containment is estimated as 5×10^{-13}/km (Ref. 7-15). Assuming 2700 truckloads of buried waste have to be transported 16 km to a Los Alamos deeper pit, the overall probability for a release accident is 2.2×10^{-8}. Therefore, such a release is not considered credible. Except for the β-γ contaminated waste, the radiation levels are too low for a credible exposure to the population en route under normal conditions. The β-γ contaminated waste constitutes a very small volume of the total and is assumed to be handled remotely and shielded in a manner that will preclude any population exposure en route.

A box spill accident would have the same probability and consequences as in the case of options B3 (Exhumation) or B7 (Packaging), and the release to the environment would be 35 nCi of ^{239}Pu.

7.1.6.8 Option B6—Ship the Processed Waste to an Offsite Repository. A total of ~3700 truck shipments (2700 attributed to buried waste and 1000 to stored waste) would be required for transporting both the exhumed and the retrieved waste to a federal repository assumed to be 540 km away. The impact of this event is not calculated here but is addressed in the Waste Isolation Pilot Plant Environmental Impact Statement (WIPP EIS, Ref. 7-8), where estimates are made of hypothetical doses to the population from the trucking of Los Alamos TRU waste to WIPP. In the WIPP analysis, an upper limit of 2000 man-rem population dose to the bone is estimated for a shipment of Los Alamos TRU waste, assuming a severe accident in a small urban area. The frequency assumed for this event in the WIPP EIS is 4.3×10^{-6}/yr. Also, in the WIPP EIS, the calculated radiation dose to the population from normal transportation of Los Alamos TRU waste is 0.034 man-rem per shipment. For this analysis, the result is a total of 160 man-rem population dose to the bone. Of this dose amount, 130 man-rem is attributed to buried waste normal operations and 34 man-rem to stored waste normal operations.

7.1.6.9 Option B7—Package Waste Without Processing. Packaging operations have the potential for the same spill of a TRU waste-filled box described for Option B3 (Exhumation). Assuming the same frequency, 1/yr, the release is estimated as 35 nCi of ^{239}Pu and 35 nCi of ^{90}Sr and is confined to the area inside the exhumation building. Therefore, no exposure of the population occurs, and only the occupational exposure is considered.

7.1.6.10 Option B8—Transfer Nonprocessed Waste to a Los Alamos Deep Pit. As in Option B5, there is no credible release that would lead to an exposure attributable to a truck accident. A handling accident would consist of consequences equivalent to the box spill of Option B3 or a release of 35 nCi to the environment.

7.1.6.11 Option B9—Ship the Nonprocessed Waste to an Offsite Repository. As in Option B6, the impact from this operation is addressed in the WIPP EIS (Ref. 7-8). The estimated frequency for a severe accident during this operation is 4.3×10^{-6} per yr, and completion of the operation is estimated to require 15 yr. Based on WIPP estimates, a population dose to the bone of 2 000 man-rem is estimated for an accident.

Table 7-8 summarizes the estimated impact in man-rem for the buried waste modular options that would be used to determine the overall impact of each alternative.

7.1.6.12 Stored Waste Options S1-S9. Stored waste is routinely handled and stored outside with suitable containment. A weather protection structure will be provided for the retrieval operation. No physical injury caused by corrosion, or water damage to any of the stored waste forms within the pads is expected to be evident (Ref. 7-16). Rust inhibitors, surface water runoff, careful placement of the stored waste, and other precautions in effect for waste storage since 1974, have resulted in very good container integrity, and hence, low release potential during retrieval and handling operations.

The probability of population doses occurring from Los Alamos stored waste operations is lower than for buried waste because of the packaging design and storage controls. Each stored waste form was analyzed separately. Two general types of accidents are considered: operational incidents such as dropping, rupturing, and release of contents during retrieval and handling of stored waste; and accidents caused by less probable phenomena such as airplane crashes, fires, and explosions. The releases estimated for the events selected and the calculated population doses are discussed below.

7.1.6.13 Options S1 and S2—Continue Current Practice and Engineered Improvements. Current practices for storage of retrievable waste are designed to retain package integrity for at least 20 yr. When a pad is full, it is covered with a plastic tarp and bermed with at least a meter of packed tuff, graded, seeded, and maintained over the 100-yr surveillance period. For these leave-in-place options, there is no credible release mechanism.

7.1.6.14 Option S3—Retrieve. Retrieval of stored waste should proceed with very little probability of airborne release because of package integrity. Tornado and airplane crash scenarios, as well as a drop and rupture accident, are considered here.

7.1.6.15 Tornado. A tornado is assumed to involve the active retrieval area and causes damage to barrels and FRP boxes to such an extent that they rupture, leading to an airborne release. The following assumptions were made.

- The frequency of a tornado is 1×10^{-6}/yr at Area G.
- Two FRP boxes rupture.
- A release of 1 μCi ^{239}Pu occurs.

7.1.6.16 Airplane Crash. For this scenario, an airplane crashes into the stored waste working front at Area G. The probability of this happening is extremely low, about 2.3×10^{-7}/yr. However, the results of this scenario were analyzed using the following assumptions.

- Four FRP boxes are ruptured, and the fraction released from the initial impact and fire is assumed to be 10%.

- About 1% of the released contaminants are respirable and are dispersed downwind.

- Each FRP box contains 2270 kg of waste, and the ^{239}Pu contamination is 10 nCi/g.

The calculated release is 90 μCi of ^{239}Pu.

7.1.6.17 Drop and Rupture. This scenario involves dropping a retrieved waste container and damaging it to the extent that some of the contents are released and become airborne. The estimated release varies considerably depending on the waste type. The four major containers of stored waste most susceptible to release from dropping are drums, boxes, casks, and shafts. The following assumptions are made.

- Drum or box ruptures are equivalent, and either one releases 10 nCi of ^{239}Pu to the air. The event frequency is assumed to be 1.3×10^{-1}/yr.

- A cask and one of its 114-ℓ drums rupture, releasing 1 μCi ^{238}Pu of respirable particles to the air. The event frequency is 6.7×10^{-3}/yr. (The frequency is lower than for a drum or box rupture because the cask and the drum must both be breached.)

- A shaft ruptures and a fraction of its contained material spills onto the ground. One μCi of respirable particles of ^{239}Pu and 1 μCi of FP are released to the air. The event frequency is 6.7×10^{-3}/yr. (In this case, the concrete plug and lead shielding at the shaft end have to be breached for a release to occur.)

7.1.6.18 Option S7—Package Retrieved Waste Without WPF Processing. Oversize FRP boxes are assumed to be the only waste forms requiring repackaging to meet repository size restrictions. It is assumed the oversize FRP boxes would be retrieved intact, transferred to an enclosure for opening and size reduction, and repackaged into smaller containers. The repackaging would be performed within an enclosure equipped with HEPA filtration. Therefore, no releases to the atmosphere are predicted, and no population exposures are considered for this option.

7.1.6.19 Options S5 and S8—Deeper Pit Disposal. Stored waste would be transported to a deeper pit at Los Alamos, unloaded, and stacked in the pit. These options are considered to have a release potential similar to that of the retrieve option S3. The time needed to place packaged waste in the deeper pit would be much less than the retrieval operation, hence, only the drop and rupture scenarios are considered here. The release magnitude for drums, FRP boxes, casks, and shafts, are the same as for Option S3.

7.1.6.20 Options S6 and S9—Ship Offsite. The trucking accident scenario has been described in the buried waste section under Option B6 and is based on the WIPP EIS (Ref. 7-8).

Table 7-9 summarizes the estimated impact in man-rem for the stored waste modular options that will be used to determine the overall impact of each alternative.

7.1.7 Summary of Radiological Risks. In order to compare the radiological risk of the proposed alternatives, a Relative Risk Index was computed. The index represents the end point of the analysis and is made up of the cumulative dose equivalents that were estimated for the modular options. The index is useful for comparing the relative impact from the various alternatives but *should not* be considered an estimate of absolute risk. The Relative Risk Index for each alternative is listed in Table 7-10.

Determination of the Relative Risk Index for Alternative 14 is detailed in the following description. The modular options are the basis for the analysis. For Alternative 14 (maximum impact) the options are

- B3—exhume the buried waste,

- B4—process the TRU fraction of the exhumed waste,

- B6—ship the processed buried waste to a Federal repository offsite,

TABLE 7-9

POPULATION DOSES FOR STORED WASTE ACCIDENTS

Option	Event	Release Site	Release Magnitude	Dose per Event[a] (man-rem)	Event Frequency (yr^{-1})	Risk Period (yr)	Estimated Impact (man-rem)
S1	None					100	0.0
S2	None					100	0.0
S3	Tornado	Area G	1 μCi ^{239}Pu	2.7×10^{-1}	1.5×10^{-6}	15	6.1×10^{-6}
	Plane crash	Area G	90 μCi ^{239}Pu	2.5×10^{1}	2.3×10^{-7}	15	8.6×10^{-5}
	Drop and rupture (drum or FRP)	Area G	10 nCi ^{239}Pu	2.7×10^{-3}	1.3×10^{-1}	15	5.3×10^{-3}
	Drop and rupture (cask +114 ℓ drum)	Area G	1 μCi ^{238}Pu	2.3×10^{-1}	6.7×10^{-3}	15	2.3×10^{-2}
	Drop and rupture (shaft)	Area G	1 μCi ^{239}Pu	2.7×10^{-1}	6.7×10^{-3}	15	2.7×10^{-2}
S4	None					15	0.0
S5	Box spill (outside)	Area G	10 nCi ^{239}Pu	2.7×10^{-3}	1.3×10^{-1}	15	5.3×10^{-3}
S6	Truck accident	Urban center	3.1 mCi ^{239}Pu 0.3 mCi ^{238}Pu	2.0×10^{3}	2.7×10^{-7}	15	8.1×10^{-3}
S7	None					15	0.0
S8	Drop and rupture (drum or FRP)	Area G	10 nCi ^{239}Pu	2.7×10^{-3}	1.3×10^{-1}	15	5.3×10^{-3}
	Drop and rupture (cask +114 ℓ drum)	Area G	1 μCi ^{238}Pu	2.3×10^{-1}	6.7×10^{-3}	15	2.3×10^{-2}
	Drop and rupture (shaft)	Area G	1 μCi ^{239}Pu	2.7×10^{-1}	6.7×10^{-3}	15	2.7×10^{-2}
S9	Truck accident	Urban center	3.1 mCi ^{239}Pu 0.3 mCi ^{238}Pu	2.0×10^{3}	2.7×10^{-7}	15	8.1×10^{-3}

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[a] Population assumed is 3.6×10^{5}.

- S3—retrieve the stored TRU waste,
- S4—process the retrieved waste, and
- S6—ship the processed stored waste to a federal repository offsite.

Population and occupational cumulative dose equivalents have been estimated for each option and added into a "Combined Impact" (see Tables 7-2 through 7-9). For example, to obtain the Radiological Risk Index for Alternative 14, the Combined Impacts have been summed with the results shown in Table 7-11. The resultant relative risk for Alternative 14 is 1300 man-rem.

7.1.8 Radiological Risk Perspective. To obtain a perspective on the radiological risk presented by the alternatives, one must realize that the values of man-rem quoted in the index are, at best, maximum limiting values. The doses from postulated accidents are a very small portion of the doses for normal operations, and the major part of normal operation doses are those to the workers. Using the ICRP (Ref. 7-17) factor of 1×10^{-4} fatal cancers/rem/yr for an estimate of health effects, the 1300 man-rem/15 yr for Alternative 14 calculate to 0.009 deaths/yr. For contrast, using the same factor for the 41 000 man-rem/yr from background radiation (based on a population of 3.6×10^{6} and an average exposure of 110 man-rem/man/yr), four deaths/yr are calculated.

Although the results of the analysis for the alternatives can only be used in a relative sense, some perspective may be gained by comparing the calculated effect of the TRU strategies with the major causes of death that occur annually in the United States. The number of deaths adjusted to a population of 3.6×10^{5} is shown in Table 7-12.

TABLE 7-10

RELATIVE RISK INDEX FOR THE ALTERNATIVES AND THE CUMULATIVE DOSE EQUIVALENTS FOR THE OPTIONS

		Cumulative Dose Equivalents					
Alternative	Included Option	Population Dose Accidents (man-rem)	Population Dose in Normal Operations (man-rem)	Occupational Dose Accidents (man-rem)	Occupational Dose in Normal Operations (man-rem)	Combined Impact[b] (man-rem)	Relative Risk Index[c] (man-rem)
1	B1	0	0	0	11	11	11
	S1	0	0	0	a	a	
2	B2	0	0	0	8.8	8.8	8.8
	S2	0	0	0	a	a	
3	B1	0	0	0	11	11	
	S3,S7,S8	0.11	0	8.0	73	81	92
4	B1	0	0	0	11	11	
	S3,S7,S9	0.063	34	4.8	61	100	110
5	B1	0	0	0	11	11	
	S3,S4,S5	0.060	0	49	130	180	190
6	B1	0	0	0	11	11	
	S3,S4,S6	0.063	34	47	90	170	180
7	B2	0	0	0	8.8	8.8	
	S3,S7,S8	0.11	0	8.0	73	81	90
8	B2	0	0	0	8.8	8.8	
	S3,S7,S9	0.063	34	4.8	61	100	110
9	B2	0	0	0	8.8	8.8	
	S3,S4,S5	0.060	0	49	130	180	190
10	B2	0	0	0	8.8	8.8	
	S3,S4,S6	0.063	34	47	90	170	180
11	B3,B7,B8	0.24	0	110	480	590	
	S3,S7,S8	0.11	0	8.0	73	81	670
12	B3,B7,B9	0.064	130	110	490	730	
	S3,S7,S9	0.063	34	4.8	61	100	830
13	B3,B4,B5	0.24	0	140	820	960	
	S3,S4,S5	0.060	0	49	130	180	1100
14	B3,B4,B6	0.064	130	140	820	1100	
	S3,S4,S6	0.063	34	47	91	170	1300

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[a] Listed value includes both buried and stored waste.

[b] The Combined Impact is the sum of the collective doses of each option.

[c] Relative Risk Index is the sum of the buried and stored waste impact for each alternative.

TABLE 7-11

RELATIVE RISK INDEX CALCULATION FOR ALTERNATIVE 14

Option	Population Dose from Accidents (man-rem)	Population Dose from Normal Operations (man-rem)	Occupational Dose from Accidents (man-rem)	Occupational Dose from Normal Operations (man-rem)	Sum
B3	0.042[a]	0.0[c]	53[d]	470[f]	
B4	0.0	0.0	84	340	
B6	0.022	130	4.6×10^{-6}	14	
Sub Total	0.064	130	140	820	1100
S3	0.055[b]	0.0[c]	3.1[e]	45[g]	
S4	0.0	0.0	44	44	
S6	0.0081	34.0	1.7×10^{-5}	1.5	
Sub Total	0.063	34	47	91	170
Grand Total (Relative Risk Index man-rem)					1300

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[a] See Table 7-8, Population doses for buried waste accidents.

[b] See Table 7-9, Population doses for stored waste accidents.

[c] See Table 7-5, Normal population doses for buried and stored waste transport to offsite repository.

[d] See Table 7-6, Occupational doses for buied waste accidents.

[e] See Table 7-7, Occupational doses for stored waste accidents.

[f] See Table 7-3, Summary of occupational doses for buried waste normal operations.

[g] See Table 7-4, Summary of occupational doses for stored waste normal operations.

The radiological risks estimated indicate that the hazard to the public and to workers because of the alternatives are very small in comparison to either the natural background or to other risks voluntarily and involuntarily accepted daily by society.

7.2 Nonradiological Risks

The following section describes and estimates the nonradiological risks associated with various waste-management strategies. These are risks that exist even if the wastes do not contain radioactive materials. Examples of these types of risks include the presence of pyrophoric and toxic materials, industrial-type accidents (which could happen during the operations concerned with retrieval and processing of the wastes), transportation, impacts of the various alternatives on the environment, and resources that will be committed if one of these waste-management strategies is selected for implementation.

7.2.1 Industrial Accident Risks. Examples of industrial accident risks are equipment accidents during operations; exposure of personnel and the general public to toxic or otherwise harmful materials or fires; possible cave-ins of earthen walls; and similar construction and industrial accident scenarios. Examples of possibly toxic or otherwise harmful materials include the presence in some of

TABLE 7-12

CAUSES OF DEATH IN UNITED STATES[a]
(Total, 1977)

Cause of Death	Deaths per 3.6×10^5/yr	Individual Risk/yr
Total from all causes	3200	1 in 110
Heart disease	1200	1 in 300
Cancer	640	1 in 560
Stroke	300	1 in 1200
Total for all accidents	170	1 in 2100
Motor vehicle	83	1 in 4 300
Falls	22	1 in 17 000
Drowning	11	1 in 33 000
Fires—burns	11	1 in 33 000
Poison (solid, liquid)	7	1 in 50 000
Pneumonia	83	1 in 4 300
Diabetes mellitus	54	1 in 6 700
Cirrhosis of liver	50	1 in 7100
Arteriosclerosis	47	1 in 7700
Suicide	47	1 in 7700
Homicide	32	1 in 11 000
Emphysema	29	1 in 13 000

[a] Safety facts for 1979. National Safety Council, Chicago, Ill.

the wastes of uranium metal chips and turnings, and other pyrophoric or toxic materials. Some of the waste burial sites may also contain some chemical wastes.

CPP, the first alternative, involves the least amount of risk from industrial-type accidents because this option does not involve handling or contacting actual wastes, but only continuing present operations.

The 100-yr maintenance and surveillance could involve some small amount of risk; for example, the possibility of a vehicular accident, a monitoring employee being bitten by a rattlesnake, or similar types of scenarios.

However, most of the surveillance, monitoring, and maintenance work would be conducted during the summer months under optimal weather conditions. Present procedures at the Laboratory require field personnel to sign out and in with their supervising office and to carry portable two-way radios with them or mounted in the vehicle used. Therefore, this alternative would be expected to cause negligible additional probability for an industrial-type accident or risk, over and above what is currently being experienced.

The second alternative, EI, would involve removing the top 0.3 m (1 ft) of cover from above the waste. Clean tuff would be placed over the waste, then built up and compacted to at least 1.5 m (5 ft), followed by a 0.3-m (1 ft) final cover of 20- to 30-cm (8- to 12-in.)-diam riprap.

An exception would be those locations where the cover over the waste is already thicker than 1 m (3 ft). In these locations, the top cover would not be removed. Instead, additional clean tuff or dirt would be added to the existing cover to bring the total to the desired thickness; then a final layer of riprap added, as described above.

The EI alternative presents various accident scenarios involving earth moving and transportation equipment. Additional fill and riprap cover would be required; the fill material could be obtained locally, whereas the riprap would probably have to be transported to Los Alamos by truck.

These additional risks would add only slightly to the risks attributable to excavation and earthmoving operations.

Those alternatives involving retrieval of the stored TRU wastes could pose more serious risks, because workers will be removing the cover from the stored wastes and will be coming into closer contact with the waste containers. Postulated accidents would involve, for example, operation of the earth-moving equipment, transfer of large boxes and casks from the storage area onto trucks, and vehicular accidents during transport of the wastes from the storage area to the RPF or the WPF. The retrieval of stored TRU wastes would be by excavation. Because most of the stored TRU wastes are located on pads above ground, the possibility of a cave-in from side walls is very small. Precautions and procedures similar to those practiced on strip mining operations would probably be required to mitigate those small, but, nonetheless, actual hazards.

Exhumation of buried TRU wastes, similarly, would be by an end trench and thus would require the same precautions as dictated in surface mining operations. These could include the shoring up of sidewalls to minimize cave-ins, using sufficient slope to preclude cave-in of the walls, and advance planning and inspections to mitigate unsafe practices.

The RPF would include some risks from cutting larger objects into smaller pieces and placing these in standard-sized containers. Compaction by a standard hydraulic press might also be used. Cutting operations might use electrically powered saws, hand saws, and shears, as well as some flame-type cutters, such as a plasma torch.

Inside the WPF, exhumed and retrieved wastes would be sorted with the wastes separated into items suitable for combustion, wastes (principally metals) suitable for possible decontamination, and materials not suited for further processing.

Combustible wastes would be burned in an incinerator such as a rotary kiln. Decontamination might include commercial cleaning operations, electropolishing, or similar techniques. Following treatment, waste and other contaminated materials would be immobilized (for example, in cement) and packaged for transport to the disposal site.

Transportation of the wastes to either a deep pit at Los Alamos or to a federal deep geological repository would present some risk from transportation accidents and potential exposure to personnel from radiation emitted from the wastes. The radioactivity exposures were described in Sec. 7.1. Onsite transportation would be largely on federally owned and controlled roadways. Transportation to the federal repository is discussed in the WIPP EIS, previously referenced. The disposal of wastes into a deep pit at Los Alamos would require construction of such a pit and would present excavation-type hazards similar to those discussed earlier under exhumation and retrieval operational risks.

Each of the operations involved in these alternatives involves normal operations with modern machinery. Although the presence of the radioactive TRU wastes makes each operation more difficult because of such things as protective clothing, respirators, and possibly remote handling, each operation has been performed previously many times at many different facilities. A study of these nonradiological risks has been performed by the INEL (Ref. 7-18). The findings of this study were that the nonradiological risks are no greater than those in industries involved in similar operations, such as trucking, transportation, and earth-moving operations. Because of the presence of the TRU wastes, extra precautions to prevent the spread of contamination actually serve to make the nonradiological risks less hazardous.

7.2.2 Environmental Impacts.

7.2.2.1 Introduction and Approach. This section discusses the estimated impact of each of the alternative modules on air quality; noise; terrestrial environment; surface and groundwater; generation and disposal of nonradioactive wastes; land use; archeological and historical sites; environmentally sensitive areas; and environmental monitoring. Because of inadequate information and many uncertainties at the present time, estimates on the possible commitment of resources, such as the required amounts of gasoline and other fuels, would be far too speculative to have credibility.

These results are summarized in Table 7-13. Additional details in each of these subject areas, such as background regarding the present environmental monitoring programs at the Laboratory, are presented in the Refs. 7-5 and 7-19.

7.2.2.2 Air Quality. The first alternative, Continue Present Practices, would not be expected to cause any deterioration of air quality, because it is a continuation of what is currently being done.

The second alternative, Engineered Improvement, would be expected to have short-term, quite localized effects, caused by increased dust levels during the earth-moving operations. Some longer range effects might be expected at the locations where the additional cover and the rock riprap were obtained. These impacts at the borrow area would include localized dusts while operations were being conducted.

The alternatives involving exhumation of the buried wastes and/or retrieval of the stored wastes would involve removal of some dirt cover. Although this would cause some localized dust, these alternatives would involve the use of a structure over the waste pits. Therefore, dust from these operations would be filtered out before release of the air into the uncontrolled environment. Some localized dust could be produced while the structures were being set up, moved, or being dismantled.

Transportation of the wastes would require containers for the wastes, and therefore, would prevent the release of the waste materials to the environment. The exhaust fumes from the transport vehicles would be released to the immediate vicinity, resulting in some localized vehicular emissions over and above current levels. These would also be short-term, up to perhaps a few years, and localized.

The construction of a deeper pit or pits at Los Alamos than previous ones would be expected to add localized dust; however, this would also be local and relatively short-term.

7.2.2.3 Terrestrial Environment. Terrestrial environment includes the local flora and fauna in, on, and adjacent to the waste disposal areas.

The CPP alternative would cause no incremental damage, because it continues what is currently being performed. Several of the older waste disposal areas have undergone natural biotic progression, and thus have experienced terrestrial enhancement with time.

Several of the older parts of the waste disposal areas have been seeded with grass species, primarily for assistance in surface-water and wind-erosion control as well as for aesthetic purposes.

The addition of a cover, improved and deeper than previous covers, and riprap would also enhance the local flora and fauna by acting as a barrier to erosion and by entrapment of airborne materials including dirt and wind-borne seeds. Obtaining additional cover would require stripping of this material from some other location, which would denude that area. Landscaping and reseeding of the borrow area would probably be required to mitigate these impacts. Riprap would be obtained either from commercial sources or from a location such as river beds and thus have relatively minor additional impacts.

Exhumation, retrieval, resizing and packaging, and processing of the wastes would require removal of existing vegetation from the present waste disposal areas. Grade and fill as well as landscaping and reseeding of these areas would be required. Reseeding with selected species will require a period of a few years to become established but would enhance the terrestrial environment.

Construction of the deep pit would produce a similar denuding of the surface and destruction of the local flora and fauna in that specific location. Final grading and landscaping, which could take a few years, would be required to mitigate these very localized effects.

7.2.2.4 Water. No surface water is used at any of the Laboratory waste disposal sites now. The local potable water source is used for watering the planted species on the reseeded areas and for local dust control.

The first alternative would not change present operations and, therefore would not change present water conditions. As described in the Los Alamos FEIS, the waste repositories in use now are considered to have no impact upon local waters for any reasonable future time periods.

Similarly, the Engineered Improvement Alternative would not be expected to have any measurable effect upon either water use or local water quality or quantity. Additional cover and grading would improve surface runoff of what little precipitation does occur.

Those options requiring exhumation, retrieval, sizing and packaging, and processing of the TRU

TABLE 7-13

COMPARISON OF ENVIRONMENTAL IMPACTS BY ALTERNATIVE

Option	Estimated Impact Upon			
	Air Quality	Noise Levels	Terrestrial Environment	Water
1. Continue present practices	Negligible effect	Negligible effect	Probable enhancement	Negligible effect
2. Engineered improvement	Localized short-term dust probable	Localized short-term effects	Probable enhancement	Negligible effect
3. Exhume buried waste; retrieve stored waste	Localized short-term dust	Localized short-term effects	Estimated 15- to 20-yr localized effects, similar to a small strip-mining operation	Negligible effect
4. Resize and package	Localized short-term during erection and movement of RPF	Localized short-term effects (same as Air Quality)	Same as Air Quality effects	Negligible effect
5. Waste Processing Facility (WPF)	Same as RPF	Same as RPF	Same as Option 3 above	Negligible effect
6. Disposal in deeper pit at Los Alamos	Same as Options 3 and 4 or 5 or 4 and 5 plus short-term local dust during construction of the deep pit(s)	Same as Air Quality effects	Same as Air Quality effects	Negligible effect
7. Disposal at a federal repository	Same as Options 3 and 4 or 5, or 4 and 5	Same as Air Quality effects	Same as Air Quality effects	Negligible effect
8. Onsite transportation	Truck exhaust fumes	Localized to area	Increased truck exhaust fumes	Negligible effect

TABLE 7-13 (Continued)

	Estimated Impact Upon	
Option	Environmentally Sensitive Areas	Environmental Monitoring Program[a]
1. Continue present practices	Not applicable	100-yr institutional control program required in addition to present programs
2. Engineered improvement	Not applicable	Same as Option 1 above
3. Exhume buried waste; retrieve stored waste	Negligible effect	Increased short-term effort required
4. Resize and package (RPF)	Negligible effect	Same as Option 3 above
5. Waste Processing Facility (WPF)	Negligible effect	Same as Option 3 above
6. Disposal at a federal repository	Would require careful selection of area(s) for construction of pit(s)	Would require continuation of existing programs to cover the new pit(s)
7. Disposal in deeper pit at Los Alamos	Negligible effect	Not applicable
8. Onsite transportation	Not applicable	Negligible effects

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[a] Even if TRU waste are removed from Los Alamos, environmental monitoring will still be required for both continuing activities at Los Alamos and for the remaining LL wastes buried at Los Alamos.

TABLE 7-13 (Continued)

Option	Estimated Impact Upon: Generation and Disposal of Non-radioactive Wastes	Land Use	Archeological and Historical Sites
1. Continue present practices	Not applicable	No change	No change
2. Engineered improvements	Same localized impact at borrow pits	Would require some borrow pits	Negligible with proper care and procedural requirements
3. Exhume buried, retrieve stored	Localized short-term effects	Would require additional fill from borrow pits	Negligible effect
4. Resize and package (RPF)	Localized short-term effects	Negligible effect	Not applicable
5. Waste Processing Facility (WPF)	Same as 4 above	Negligible effect	Not applicable
6. Disposal in deeper pit at Los Alamos	Localized short-term effects	Would require construction on deep pit(s) at Los Alamos	Negligible with proper care and procedural requirements
7. Disposal at a federal repository	Not applicable	No change	Not applicable
8. Onsite transportation	Not applicable	Localized short-term effects possible	Not applicable

wastes could have some effect upon local groundwater in that some water would be withdrawn from the local potable water supply for use. Such use might include the decontamination of metals using water-based commercial cleansers, for example, and making cement paste for immobilization of wastes in the steel drums.

7.2.2.5 Generation and Disposal of Nonradioactive Wastes. The first alternative would not be different from current practices, and, therefore, would not contribute any incremental generation of wastes.

The Engineered Improvements alternative could produce some nonradioactive impacts in obtaining additional cover and riprap, transporting these to the waste disposal areas, and placing them there. These impacts are estimated to be quite localized, with local disposition of the relatively minor quantities fairly easily managed.

The other alternatives could add to the generation of nonradioactive wastes in that the erection of one or more temporary structures at the waste disposal areas would be required. Among these wastes would be dirt movement for leveling and laying of the building foundations as well as some construction wastes. Because these buildings could cover several hundred square feet of surface area, a few hundred cubic feet of earth would have to be removed and stored. However, this material is not actually waste, so it would eventually be put back into place.

Following completion of waste processing, the facilities would undergo D&D operations.

Exhumation and retrieval of TRU wastes would involve the removal of the top cover or overburden, 1 m (3 ft) from the waste pits, with clean fill material stored for later use. TRU wastes would be removed from the burial areas and the wastes returned to the disposal area. Additional fill would be needed to make up the volume of TRU wastes that would be removed. Such fill could be nonradioactive wastes or clean fill from other locations.

7.2.2.6 Land Use. The CPP alternative would not involve more additional lands or land use than current operations do. The Engineered In-place Improvement Alternative could require additional fill and rock materials from areas other than the waste disposal areas, and transport and emplacement over the waste disposal areas. As described earlier, this fill would require that an area of perhaps as much as 100 acres be quarried or strip-mined, which could produce some negative environmental impacts in that area. Restoration of the mined area by landscaping and revegetation would be required.

The alternatives involving exhumation and retrieval of the TRU wastes would require only minimal additional land use for a period up to 15 yr or less. Relatively small land areas adjacent to the present waste disposal areas would be involved while the RPF and WPF buildings were being erected, moved, or taken down.

The disposal of TRU wastes into a deeper pit at Los Alamos would require deeper pit construction on DOE land at Los Alamos. Such land is available but the land is not being used now for such purposes. Similarly, disposal of the Laboratory TRU wastes at a federally owned deep geological disposal facility would be predicated upon the availability of the facility.

7.2.2.7 Archeological and Historical Sites. As described in much greater detail in the Los Alamos FEIS (Ref. 7-5), many historical Indian ruins are located on and near the federally owned Laboratory site. Considerable effort has been made and is continuing to locate, record, and preserve these sites. Before any new construction, approval must be obtained to assure that these important archeological findings are preserved. In addition, excavations uncovering new findings are promptly reported and thoroughly investigated.

The alternatives of CPP or EI are expected to have no added impact. Because the other alternatives involve work at present locations, no additional impact is expected. Only if additional burial sites at Los Alamos were selected, for example, for the construction of an onsite deeper pit, would there be the possibility of digging into additional historical sites. Before selection of such sites, approval for excavation would be required, including review by the Laboratory Environmental Surveillance Group, the State of New Mexico Historic Preservation Officer, and the Historic Preservation Council. Obtaining additional fill from Los Alamos locations could require excavation of land sites not currently in use but would require advance approval before mining or excavation.

7.2.2.8 Environmentally Sensitive Areas. This term means that endangered species of flora or fauna might be present. As described in the Los Alamos FEIS (Ref. 7-5), a few endangered and protected species are present in the immediate vicinity but not in or near the waste disposal areas. Therefore, no impact would be expected from any of the alternatives under consideration. Before implementation of one or more of the possible alternatives (except CPP), a more thorough review would be required.

7.2.2.9 Environmental Monitoring. The CPP and EI alternatives would entail continued environmental monitoring over a 100-yr period of institutional control. This surveillance and maintenance will require a staff of 8 over the entire assumed 100 yr.

Sampling and analysis of air, water, soil, and vegetation, as well as surface and subsurface monitoring, would continue, as described more fully in the Los Alamos FEIS (Ref. 7-5) and the annual Los Alamos Environmental Surveillance report series (Ref. 7-19).

Should one or more of the other alternatives be selected, environmental monitoring would be increased substantially while the various operations (exhumation, retrieval, packaging, resizing, processing, transportation, and terminal disposal) are conducted. These probably require a much larger commitment in terms of manpower for a much shorter period of time, however (15 yr or less).

When the RPF or the WPF are in operation, standard practice at Los Alamos requires that health physics monitoring personnel be in full-time attendance with sampling and environmental monitoring equipment in use. Similarly, transportation of waste materials would require compliance with Los Alamos criteria, which are based upon federal and state transportation requirements.

7.2.3 Resource Commitments. The following section describes some of the resources that would be committed, should one or more of the alternatives be selected for implementation. Because much of the data required for a detailed and accurate estimation is not available, the estimates presented should be used for comparison of the alternatives, not for budgetary purposes. The following discussion does not consider the commitment of financial resources, because these are considered more thoroughly in Sec. 6.

The first alternative, CPP, would have the least commitment of resources, because it involves the least amount of contact or handling of the wastes. After 100 yr institutional control would be discontinued, because one or more of the other strategies probably would be implemented, that is, the wastes would not simply be abandoned.

Manpower (for monitoring, surveillance, and maintenance operations), a small amount of equipment, and materials required for upkeep are the resources needed for the CPP alternative.

A staff of 8 persons/yr will be needed over the 100-yr period. Equipment requirements include pickup trucks and equipment for site maintenance. Included in the costs estimated for surveillance (as presented in Sec. 6) are the cost of drilling an estimated 40 test wells in the vicinity of existing waste disposal sites. The commitment of resources in the form of dollars is estimated in Sec. 6 of this document.

Resources required for the second alternative, EI, include all of those required for CPP, plus some additional resources for added cover, clean fill and riprap. For estimating cost, it was assumed that these materials would not be available at Los Alamos but would be obtained elsewhere and brought to Los Alamos where they would be emplaced. This commits fill and riprap from some other location, withdrawing it from possible use elsewhere. Also committed are earth-moving equipment and funds to obtain and transport the material from its location to Los Alamos, plus funds and equipment for emplacing the material. Fuel and other supplies for equipment operation would be required.

These amounts and costs cannot be estimated now because of incomplete information.

Those alternatives requiring exhumation of the buried waste and/or retrieval of the stored wastes would require the commitment of considerably more dollars for manpower, facilities and equipment over a shorter time. Note, however, that retrieval and exhumation of just the TRU waste (leaving the LL waste in its present locations) would not release the commitment for continuing 100-yr institutional control over the LL wastes, because these wastes cannot be abandoned by the Laboratory.

Exhumation and retrieval would require manpower, facilities, equipment, electricity, and fuels for operation. Earth-moving equipment and an enclosed, weather-proof structure would be required over a period of 15 yr or less, depending upon scheduling. In addition, some additional fill material would be required to make up for the volume of TRU wastes removed. This could remove additional land sites (from the "borrow" area) for other uses for some time. Close-out of exhumation and retrieval operations would require D&D of the equipment and structures before disposal. These items may not have any recoverable value upon completion of the operation.

Those alternatives involving resizing, packaging, or processing of the waste will require much greater commitments of fiscal resources for facilities, manpower, equipment, fuel, and electricity, but few other resources.

If a deeper pit at Los Alamos is to be used for terminal disposal, ~100 acres of land not now in some other productive use would be committed for construction of the pit(s). In turn, this allocation would require a commitment of manpower, equipment, and fiscal resources.

Any of the alternatives except the first two would require substantial amounts of fuel and electricity for operation of the various pieces of equipment required. For example, retrieval of the stored waste would require ~40 000 gal of fuel and 200 000 kWh of electricity. More precise estimates of several of the other operations are not possible now because of the variability in conditions possible once one of the alternatives is implemented.

Finally, emplacement of Los Alamos TRU wastes in the federally owned deep geological repository would take up space, which can be considered a resource, because this space could be used for accepting wastes from other locations. There will be charges for federal repository disposal, which would therefore commit fiscal resources.

7.3 Possible Long-Term Effects

7.3.1 Introduction and Approach. The use of disposal site lands is severely restricted during the disposal and the institutional control periods, thus minimizing the risks over these relatively short times. Following these periods, is the long-term risk of release and subsequent human exposure, especially if these lands should become available for other uses. Although the methodologies for risk estimation are subject to considerable uncertainties, sound waste management planning requires that any selected technical option meet all radiation protection criteria at the time of burial and at site closure.

The position of the Interagency Review Group on Nuclear Waste Management (IRG) is that zero release of radionuclides cannot be assured for the time span when the wastes may be hazardous. Therefore, any potential releases should be within preestablished limits (Ref. 7-20).

An acceptable level of long-term TRU releases to the unrestricted environment has not been determined. The present assessment focuses on an analysis of the principal long-term release processes under normal land use of the shallow land burial sites at Los Alamos, the estimated quantities of TRU that could be released and distributed, and the calculated individual doses possible from specific land uses. Reasonable predictions of the actual population at risk, the use of the land, or possible future changes in the radiation protection standards are impossible. This assessment makes no comparisons to existing standards or criteria but instead reports the results of the modeling and calculations performed. A limited-sensitivity analysis of some of the critical parameters has been included for comparison of the effectiveness of the technical options.

Four disposal options have been evaluated in this document, including (1) CPP, which are leaving the stored and buried TRU in their present locations; (2) EI, in which additional cover material would be added to the existing trench and pit covers; and exhumation of the buried TRU and/or retrieval of the stored TRU and disposal with or without further processing into, (3) Deeper pit burial at Los Alamos, or (4) Entombment in a remote, federally owned deep geological repository.

The following assessment of possible long-term impacts does not address the deeper pit burial concept because this has not been sufficiently defined to permit assessment. Offsite disposal is not addressed because this has already been covered in the WIPP FEIS (Ref. 7-21). Greater confinement by deeper pit burial at Los Alamos is discussed to the extent that consideration is given to the possible consequences of encountering TRU wastes with localized spots of higher concentration, and the consequences of encountering TRU wastes with a higher average concentration. The focus of the assessment is on the first two disposal options, where the TRU wastes are left onsite at Los Alamos.

For the Los Alamos shallow land burial options, several release mechanisms may be postulated, including the following.

- Excavation into the trench cap cover and the waste materials could be caused by trenching for utility lines, building foundations, deep plowing for agricultural purposes, and similar digging operations, and could result in bringing contamination to the surface. Although the possible impacts could be lessened or the time to uncover the wastes lengthened by increasing the depth and cover materials, the impacts would be highly dependent upon time since burial, the kind of cover materials, depth of cover, erosion rates, and the depth of excavation.

- Erosional processes would result in a reduction in the depth of cover, which in turn, could allow greater probability of intrusion and penetration. The rate of erosion will depend greatly on the use and management of the land.

- Water infiltration into the wastes could have a profound effect upon the mobility and transport of the TRU wastes. Water infiltration will be proportional to variables such as the amount of irrigation, soil management practices, the extent of building and paving, etc.

- Plant intrusion into the wastes by native species or by agricultural crops could transport contamination into the plants, the soil surface, and into crops and animal products grown for consumption.

- Continued risk of catastrophic events such as a meteorite impact or an accidental event such as an airplane crash could result in penetration of the trench cap, followed by the release of TRU contamination. These are discussed in Sec. 7 and in Appendix C.

Each release mechanism can create a contamination source that could spread by various redistribution processes, posing the possibility of radiological doses to humans. Release and distribution mechanisms are summarized in Table 7-14.

These dominating factors are directly proportional to the amount and type of land use related to and caused by people. Radiation doses to people from the buried TRU wastes could result from (1) releases uncovered and brought to the surface over time and resuspended by wind or mechanical disturbance, (2) contamination of surface or ground water supplies used for agriculture or drinking water, and (3) direct contact with TRU contamination and contaminated soil.

A site-specific evaluation methodology has been developed to systematically assess the principal components of the problem. These include

1. evaluation of the potential of a specific site for normal land use;

2. assessment of the local ecosystem dynamics for biotic and abiotic processes that could disperse, dilute, translocate, or reconcentrate the radioactive materials in pathways to man, and

3. investigation of the consequences of long-term climatic and geologic processes that could greatly alter the release and transport conditions in the waste site environs.

The scenarios and possible consequences presented in this analysis are emphatically not meant to be predictions of what will happen but rather relative estimations of what could happen under certain specified conditions. Even these are not complete without consideration of the possible consequences of identifiable ranges in some of the critical variables.

7.3.2 Time Frame Considerations. This assessment assumes that the present institutional controls guaranteeing the acceptability of the TRU shallow land burial disposal will continue to be effective for a period up to 100 yr, consistent with the DOE estimate of the institutional control period appropriate for nuclear fuel cycle wastes (Ref. 7-22).

TABLE 7-14

POSSIBLE RELEASE AND DISTRIBUTION MECHANISMS FROM TRU SHALLOW LAND BURIAL

Process	Mechanism	Contributing Factors
Release	Man, land uses	Ability of land to support these uses
	Water, erosion and subsurface transport	Drainage patterns, irrigation, surface covering (pavement)
	Vegetation, root depth	Species grown, erosion, soil management practices
Redistribution	Water, TRU transport	Irrigation practices
	Saturated and unsaturated	Depth of cover, soil management
	Excavation and mechanical disturbance	Land uses, depth of cover
	Wind, resuspension and redistribution	Land uses, soil management

The position of the IRG (Ref. 7-20) is that waste management should not depend on the long-term stability or operation of social or governmental institutions for the security of waste isolation after disposal because there is no absolute way of determining a specified time following loss of institutional control when ordinary land use at waste sites is likely to commence, or may cease to be of concern.

Methods have been used to estimate the removal rate of the protective trench covers of soil and soil-like materials under certain types of land use and to predict when contact with the wastes might occur. Therefore, each situation postulated in the following assessment is analyzed in its own characteristic time.

7.3.3 Comparison of Dominant Radioisotopes at Selected Times After Burial. The principal long-lived radioisotopes of health concern in the TRU wastes are shown in Table 7-15. For each parent isotope, the half-life, principal emission, specific activity, the daughter isotope and its half-life, and the number of daughter Ci/parent Ci are shown. The daughter amount is shown at the time of maximum ingrowth; that is, when the daughter amount is at its maximum value.

Table 7-16 compares the fractional amount of the parent remaining at three selected time periods, 100, 500, and 5000 yr after burial. Also shown are the fractional amounts of the daughters present at these same time intervals.

Tables 7-15 and 7-16 reveal that during the first few hundred years, the dominant radioisotopes include the parents ^{239}Pu and ^{240}Pu, and the daughters ^{234}U, ^{241}Am, ^{238}Pu, and ^{240}Pu.

During later periods, the isotopes of concern include the parents ^{239}Pu and ^{240}Pu and the daughters ^{234,235,236}U and ^{237}Np. These daughter products are of greater concern later because of the long time required for the decay of the parent into the daughter and because the daughter product may be a different chemical element than the parent, therefore, it may have different chemical properties than those of the parent radionuclide.

Although ^{238}Pu is one of the major dose contributors in the present analysis, note that most of the ^{238}Pu and the ^{241}Am will have decayed away in 1000 yr after disposal, because of their half-lives.

TABLE 7-15

PRINCIPAL RADIONUCLIDES IN LOS ALAMOS TRU WASTES

Parent				Daughter		
Isotope	Half-Life (yr)	Emission	Specific Activity (Ci/g)	Isotope	Half-Life (yr)	Ci of Daughter[a]/ Ci of Parent
^{238}Pu	87.75	Alpha	17.1	^{234}U	2.445×10^{5}	3.6×10^{-4}
^{239}Pu	24 390	Alpha	6.13×10^{-2}	^{235}U	7.1×10^{8}	3.4×10^{-5}
^{240}Pu	6 537	Alpha	3.67×10^{-2}	^{236}U	2.34×10^{7}	2.8×10^{-4}
^{241}Pu	14.4	Beta	103	^{241}Am	433	3×10^{-2}
^{241}Am	433	Alpha	3.43	^{237}Np	2.14×10^{6}	2.0×10^{-4}

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[a] At time of maximum ratio.

TABLE 7-16

FRACTIONAL AMOUNT OF ORIGINAL ACTIVITY REMAINING AT SELECTED TIME PERIODS

Parent		Time Period		
Radioisotope	Half-Life (yr)	100 Yr	500 Yr	5000 Yr
^{238}Pu	87.75	4.5×10^{-1}	1.9×10^{-2}	7.1×10^{-18}
^{239}	24 390	8.97×10^{-1}	9.86×10^{-1}	8.7×10^{-1}
^{240}Pu	6 537	9.9×10^{-1}	9.5×10^{-1}	5.9×10^{-1}
^{241}Pu	14.4	8×10^{-3}	3.5×10^{-11}	0
^{241}Am	433	8.5×10^{-1}	4.5×10^{-1}	3.4×10^{-4}

			Time Period		
Parent	Daughter	Half-Life (yr)	100 Yr	600 Yr[a]	5600 Yr[b]
^{238}Pu	^{234}U	2.445×10^{5}	5.5×10^{-1}	9.9×10^{-1}	9.8×10^{-1}
^{239}Pu	^{235}U	7.1×10^{8}	2.8×10^{-3}	1.7×10^{-2}	1.5×10^{-1}
^{240}Pu	^{236}U	2.34×10^{7}	1.1×10^{-2}	6.2×10^{-2}	4.5×10^{-1}
^{241}Pu	^{241}Am	433	8.7×10^{-1}	4.0×10^{-1}	1.3×10^{-4}
^{241}Am	^{237}Np	2.14×10^{6}	1.5×10^{-1}	6.2×10^{-4}	1.0

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[a] 500 yr after the first 100 yr; in reality, it is 600 yr of burial.
[b] 5000 yr after the 100 and 500 yr; in reality, it is 5 600 yr of burial.

One thousand years represents 11.4 half-lives of the 87.8 yr ^{238}Pu, so that only 5×10^{-16} of the original activity remains. Further, weapons-grade plutonium produces only a small fraction of ^{241}Am and its precursor parent ^{241}Pu, and the Los Alamos wastes contain very little ^{238}Pu. Also, most of the americium and plutonium wastes are mixed with cement.

7.3.4 Land Use Assessment Methodology.

7.3.4.1 Conceptual Basis. A basic premise for the acceptable management of LL and TRU contaminated wastes by near-surface land burial practices is the long-term confinement of wastes. This entails planning for the possibility of controlled, predictable, low release rates and minimized intruder consequences under any expected normal land use, at any time following termination of site control (Ref. 7-20). The Nuclear Regulatory Commission (NRC) has proposed that any shallow land burial site be evaluated with respect to present and potential character and activities of the human population of the region (Ref. 7-23). Such evaluation should consider present and projected uses of land, water, and natural resources within the region, and must take into account any special characteristics that may influence the capacity of the site to contain the wastes (Ref. 7-23).

The approach used in the study to evaluate long-term land use of TRU waste management alternatives for the Los Alamos sites is to avoid prediction of future land uses of the site, an impossibility for the required hundreds or thousands of years. The tools and materials of urban and agricultural planning, mineral resource evaluation, and soil surveys are used to gauge what land-use potentials exist at a specific site, and to evaluate their relative impact.

A tool formulated for the task of land-use evaluation is a land-use classification system (Ref. 7-24). The major land-use classes in this system, shown in Table 7-17, reflect major subdivisions in the use a given parcel of land in a particular region might have, and emphasizes differences in land use reflected in types or degrees of potential interaction with buried wastes. There are many site-specific influencing factors or indicators of land-use potential that are useful for classification.

Not all land uses have equal potential for impacting on the capacity of a site to contain wastes over long times or equal potential for significant radiological exposures should the use involve direct intrusion into the wastes. The intuitive expectation is that undeveloped uses are least intrusive, whereas urbanization, commercialization, and resource recovery are potentially most intrusive. This expectation will be quantified below with applications of the universal soil-loss equation to various land use categories.

Significant implications of these concepts include the following. First, the initial phase of an activity sometimes may be more intrusive or damaging to confinement capability of a site than ongoing activities as in the case of planting/harvesting cycles leading to sustained high erosion rates. Second, although these activities are being scrutinized for their invasive potential, some stages of some land uses might have very effective stabilizing effects, such as the construction of large paved parking lots or concrete structures. Third, although the initial phase of an activity may create the greatest potential for acute exposure should the buried wastes be encountered, the redistribution of uncovered wastes can provide a continuing source of exposure that could create a large cumulative effect because of the long radioactive and biological half-lives of many TRU radionuclides. Fourth, although interactions between these categories such as the contamination of agricultural land or gardens by building construction are not generally shown, they must be taken into account. To unite these concepts and those in the preceding two tables, a set of land-use situations are described for a specific site based on available soils, resource and socioeconomic data, and on the use of dynamic computer simulation modeling of the interactions between atmosphere, biosphere, and geosphere at the site.

As a final note to the discussion of the conceptual basis for site land use evaluation, the matter of the deliberate scavenger/intruder is addressed. There can be no doubt that shallow land burial sites such as are located at Los Alamos and elsewhere, are an "attractive nuisance" because of burial of valuable and interesting artifacts and materials. In the very distant future, such sites may be sought out by archeologists (Ref. 7-25), or accidentally uncovered and systematically exploited by a scavenger. There are two considerations that bear on this case. First, the activities of individuals with special interests

TABLE 7-17

LAND USE ACTIVITIES AND THEIR SITE IMPACTS

	Intrusive Processes		Effects	
Activity	Initial Activity	Ongoing Activity	Effect on Confinement	Exposure Effects Inhalation/Ingestion
Building Construction and Use	Construct building and support utilities, water, sewer, power, gas lines, septic tanks and drain fields	Utilization of site, maintenance and replacement of utilities, demolition reconstruction	Reduction or acceleration of surface cap erosion, increase/decrease water infiltration locally, direct intrusion into waste pit with local and distributed contaminants	Inhalation of contaminated dusts, direct contact with contaminated artifacts
Transportation	Construction of road cuts and fills, roadbeds, digging local borrow pits or backfilling, water collection and channeling	Roadway maintenance reconstruction, water management	Reduction or increase in cap erosion, changes in local runoff and infiltration character	Inhalation of contaminated dusts
Resource Exploration and Removal	Exploratory drilling, excavation for resource recovery, road and facility construction, waste	Working of mine or mill, resource material removal, facility maintenance waste disposal	Cap alteration, direct intrusion into wastes by drilling or surface excavation	Inhalation of contaminated dusts direct contact with waste artifacts
Water	Exploratory drilling, water well installation	Water extraction and use	Creation of channels for water entry into waste	Ingestion of contaminated water
Planting/Harvesting Irrigation	Clearing, leveling, plowing, water management, introducing cultivated plant species	Cycles of plowing, planting and harvest irrigation	Plant invasion of waste, attraction of burrowing animals	Inhalation of contaminated dusts, ingestion of contaminated food

and activities, such as scavengers and archeologists, rank far down on a list of what may be termed normal, probable uses of land and its resources, which is the focus of the present evaluation. Second, whereas the consequences of the scavenger scenario are of legitimate concern, these are probably best dealt with by one of the techniques in the current literature (Ref. 7-26 and 7-27), whereby a certain contact time, dust loading during excavation, etc., are prescribed for dose calculation purposes. Using this approach, a scavenger scenario will be included in the discussion of impacts. The persistence of markers and warnings could be an attraction to deliberate intrusion, by directing the intruder to a specific burial area.

7.3.5 Application to Los Alamos TRU SLB Sites. The concepts outlined in Tables 7-16 and 7-17 are the basis for the land-use portion of the site evaluation. An application for the Los Alamos SLB sites is the base case, which considers the entire site, including the trenched areas, as homogeneous with the rest of the general area. That is, the signs, markers, monuments, and the tops of the concrete shafts are undistinguishable.

This covers the variety of circumstances intervening until a time distant in the future, when trench caps would be altered, or until land users bring the surface site condition back to a state nearly identical with surrounding soils. Under this condition, the user of the site would proceed without regard for the presence or absence of burial trenches, and any inherent advantages or limitations for particular categories of land use are those the site would have had if waste disposal had not taken place, with possible exceptions to be noted.

The basic environmental setting of the Los Alamos TRU waste disposal sites is common to all land-use classes, and, hence, will be briefly reviewed before turning to specific land uses to avoid repetition.

The SLB sites at Los Alamos are all located on the Pajarito Plateau, which occupies the eastern flank of the Jemez Mountains in northcentral New Mexico. The elevation ranges from ~1800 to 2400 m (5900 to 7900 ft). Wastes are emplaced in trenches located on a series of mesas separated by deep canyons. The plateau is distributed into mesa regions (slopes 0 to 5%) having limited width (hundreds to thousands of meters), and of considerable length (several kilometers). The side slopes of these mesas are quite steep (20% or greater), and the canyons are deep (several hundreds of meters). The canyon floors are quite wide in places and subject to periodic flooding. Building density and distribution, and utility and transportation corridors are limited and naturally constrained by this topography.

The native vegetation of the mesa environs includes piñon-juniper and ponderosa pine/piñon juniper with interspersed shrub-grass-forb components. These well-adapted, drought-resistant species are very successful competitors with species introduced by man.

The plateau region is classed as a semiarid continental mountain climate. Proceeding up the elevation gradient from near White Rock (~1944 m, or 6200 ft) to Los Alamos (~2259 m, or 7400 ft), the annual precipitation ranges from 34 to 49 cm (~13 to 19 in.). More than two-thirds of the yearly total falls during the interval May through October. The growing season (limited by last and first freeze) is confined to the same relatively short interval.

Water resources in the region are limited. Only the Rio Grande and a small creek, both situated in deep canyons, constitute perennial streams in the region. Other intermittent streams appear seasonally. Groundwater lies a considerable depth, over 500 m (~1600 ft) below the mesa tops (Ref. 7-28).

Soil associations in the plateau region are shallow, with nearly half including extensive rock outcrops. Both the quality of the soils and severe water limitations have resulted in historically limited agricultural use of the land.

For impact assessment and evaluation, a worst-case waste disposal site will be used. The site selected for this evaluation is Waste Disposal Area C, as shown in Fig. 3-3. This site was selected because of its central location, easy accessibility to nearby roadways and utilities, typical disposal methodology, representative soils and vegetation, and representative potentials for land use.

Area C is a 12-acre site located on Pajarito Road to the south of the Laboratory TA-50. The mesa slopes gently eastward, with canyons approximately 300 m (1000 ft) north and south of the site. Ten-site Canyon heads immediately northeast of the area, about 50 m (150 ft) north of the closest pit, and thus serves as the local drainage pattern for runoff. The soil covering is approximately 0.9 to 1.5 m (3 to 5 ft) deep above the Tshirege Member of the Bandelier Tuff. All of the six waste disposal pits and 107 shafts are dug into this member. The last radioactive wastes were placed in the pits in 1964 and in the last shaft in 1965. Because this was before the ruling requiring segregation of the TRU wastes, all of these buried wastes contain both TRU and LL wastes, intermingled.

Included in these wastes was radioactive trash, consisting mostly of materials removed from chemical laboratories, in cardboard boxes and 5-mil-thick plastic bags (Ref. 7-29). Other wastes routinely disposed of included 0.2-m^3 (55-gal) drums of vacuum-filtered sludges from waste treatment operations. Nonroutine wastes included debris from D&D operations, classified materials, and uranium chips from machining shops. Area C contains about 1560 kg of depleted and natural uranium, 2 kg of ^{239}Pu (about 26 Ci), 1 kg of ^{233}U, and 150 Ci of ^{241}Am.

The surface area of the pits and trenches is ~21 000 m^2 (225 000 ft^2), and represents about 44% of the total surface area of the site. The corresponding pit volume is ~100 000 m^3 (~3 700 000 ft^3).

From these data, it was estimated that the average plutonium concentration in these pits is less than 1 nCi/g, provided that the volume was uniformly mixed. However, the wastes placed into the pits and trenches were not homogeneous. There were localized containers bearing higher concentrations along with the majority of the volume at lower concentrations, and wastes only suspected of being contaminated. Localized pockets of higher concentration wastes are expected for a long duration.

A 9-month study was done of boxes of radioactive room trash taken from the Los Alamos Plutonium R&D Facility (Ref. 7-30). Of ~1800 boxes examined, 91% contained <1 nCi/g of plutonium, 5% were between 1 and 10 nCi/g, 2% were between 10 and 100 nCi/g, and <2% were in the 100 to 5000 nCi/g range. These results indicate an approximate log-normal distribution in concentrations, and when the wastes are uncovered, there is a small but finite chance that concentrations in excess of 10 nCi/g will be found.

The following land-use assessment is based on measured data, on engineering interpretation of a recent soil survey of Los Alamos County, and on the results of dynamic computer model simulations of biotic and abiotic radionuclide transport mechanisms in the Area C environs.

There are six mapped soil units in the Area C vicinity. In order of decreasing area they are Nyjack loam, Seaby loam, Hackroy-Rock outcrop complex, Carjo loam, local very fine sandy loam, and a series of rock outcrops. The soils of the burial site itself are of the Nyjack (60%) and Seaby loam (40%) soil units (Ref. 7-31).

Nyjack loam is a moderately deep, well-drained soil formed on nearly level to gently sloping mesa tops. Native vegetation includes piñon, juniper, and blue grama. Depth to tuff bedrock and effective rooting depth range from 50 to 120 cm (3 to 8 ft). Permeability is moderate (1.6 to 5.0 cm/h), and available water holding capacity is medium (13 to 19 cm water/cm of soil). Runoff erosion (soil loss during a 2-yr average 30-min precipitation event) on bare soil is slow (less than 0.13 cm). The soil erodability factor K, of the Universal Soil Loss Equation, has a value >50 T/acre/yr for the plateau. The wind erodability hazard for bare soils of this group is 67 to 118 T/acre/yr. The full implication of these factors for the erosion of this soil at this site strongly depends on the use of the site, as will be discussed below.

Nyjack soils are moderately limited for community development, primarily because of the shallow depths to bedrock. Moderate limitation means that some of the soil properties are unfavorable for this development, but they can be overcome by special planning and design. The shrink-swell potential is generally low to moderate, but slopes should be <4%. The soil has little strength to support roads and streets without special planning and design. Limitations on the construction of septic tanks and sewage lagoons are severe, because of the thin soil horizon. Severe means that the soil properties (in this case, depth to bedrock) are so unfavorable and so difficult to correct or overcome, that major soil reclamation, special design, or intensive maintenance would be required. Recreational use should be limited to camping and picnicking, because the soil is too shallow for playgrounds. Likewise, reclamation and revegetation considerations make this soil a poor choice for roadfill and topsoil uses. Also, it is not well suited for gravel and sand resources.

Seaby loam, the other major soil group of Area C (40%), is a shallow to moderately deep, well-drained soil, forming on gentle to moderately sloping mesa tops. Native vegetation includes ponderosa pine, Kentucky bluegrass, and annual grasses and forbs. Depth to bedrock is 25 to 66 cm. The available water holding capacity is low, ~9.5 to 13 cm. Runoff erosion hazard on the bare soil is moderate, ~0.14 to 0.51 cm. As with Nyjack soils, Seaby loam has moderate limitations for shallow excavations, foundations for low buildings without basements, and local roads and streets, because of the shallow depth to bedrock. There are severe limitations for septic tanks for the same reasons. Recreational uses are limited in the same manner as described earlier for the Nyjack soils. The Seaby soil is too rocky for use as topsoil, too shallow for sand and gravel recovery, and too difficult to revegetate for roadfill.

With these general preliminary soil data and interpretations, various land use scenarios can be constructed.

7.3.5.1 Urbanization. Although estimating the potential use that a given site will be put to in the far distant future is extremely uncertain, the preceding information regarding the site-specific characteristics may be used to provide clues as to possible limitations of land use and to estimate the consequences of intrusion.

7.3.5.2 Wellwater Extraction. The use of groundwater for irrigation and drinking water are possible exposure pathways to humans. The extreme depth of an aquifer makes this an unlikely event, however, there are existing water wells in the community. It is extremely unlikely that an attempt would be made to extract groundwater from a well drilled on the mesa in the vicinity of the waste disposal site, because it would be more cost effective to drill the well in the adjacent canyons and pipe the water to the mesa top.

7.3.5.3 Construction of Utility Trenches. The severe limitations of the soils for septic tank or lagoon drain fields indicate that urbanization of the site would require offsite community support for adequate treatment of the waste waters from the site.

The parcel of land could be developed into large, individually owned single-family plots of ~1011 m^2 (quarter-acre) lots, for example. Assuming further that the division of the acreage in Area C would be to produce ~30 such lots, with underground utilities located along a centralized access road and lots on either side, it is highly possible that utility construction as well as foundation and basement excavation work could penetrate into the upper layers of the wastes. Excavation work could, therefore, bring some contaminated soil and possibly even some of the wastes to the surface, mixing these with uncontaminated soils. Hazards presented include inhalation of contaminated soils by the workers, during excavation, and long-term exposure of the workers and the general population. An estimated 2 to 3 m^3 of soil per linear meter of trench length could be excavated. For a 400-m trench, the amount of excavated soil could be ~1200 m^3. Digging foundation footings to bedrock is unlikely to penetrate the waste trenches. Assuming that the utility trench excavation is entirely in the area of the trenches results in ~1% of the waste volume being excavated. Disturbing the soil to create the utility trenches and building foundations could significantly influence the site erosion rates (Ref. 7-32), leading to the more rapid removal of the trench covering over a period of several urbanization cycles, each lasting perhaps several hundreds of years. Once urbanized, the onsite soil erosion rate could be substantially retarded because of the presence of dwellings, paved areas, and lawns. These factors are shown in Table 7-18, and are based on application of the Universal Soil Loss Equation described in the table footnote.

The data from Table 7-18 can be used to estimate, for example, the higher than normal erosion rates to be expected during construction phases, as high as 3.7×10^{-2} cm/yr to 2.8×10^{-1} cm/yr, as well as the lower erosion rates once construction is complete. The erosion rates calculated for covering the soil with buildings, pavement, gardens, or gravel drives are 0, 3.2×10^{-4}, and 1.6×10^{-3} cm/yr, respectively. These imply exposure times of infinity, 500 000 and 90 000 yr, respectively.

Radiation exposure modalities exhibit a similar dependence on the urbanization phase, that is, during the construction phase, the workers are exposed to heavier concentrations of potentially contaminated dusts while the trenches are being dug and the utilities installed. During the urbanization phase, the primary exposures are caused by contact with contaminated soils excavated and left distributed on the surface, after being mixed with uncontaminated soils. Under certain circumstances, such as home gardening, soil preparation could

TABLE 7-18

APPLICATION OF THE UNIVERSAL SOIL EQUATION FOR AREA C EROSION LAND USE CALCULATIONS

	Factors						
	Slope Length			Crop Management		Soil Loss	
Scenario	S (%)	L (m)	LS	Treatment	Factor	T/acre/yr	Depth (cm/yr)
Urbanization:							
Commercialization and construction	0.2-4.0	200	0.11 - 0.82 0.11	bare soil	1.0	2.31 - 17.22	3.7×10^{-2} to 2.8×10^{-1}
Gardens and lawns	0.2	50	0.09	good	0.01	0.02	3.2×10^{-4}
Driveways and roadways	4.0	25	0.23	crushed stone	0.02	0.10	1.6×10^{-3}
Agriculture Crops	2.0	200	0.34	bare soil + sod	0.1	0.71	1.0×10^{-2}
Permanent pasture	4.0	200	0.82	sod	0.01	0.17	2.7×10^{-3}
Parks	4.0	200	0.82	grass, trees	0.04	0.68	1.0×10^{-2}
Undeveloped	4.0	200	0.82	trees, cover	0.003	0.05	8.3×10^{-4}

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[a] The basic Universal Soil Loss Equation is $A = R \times K \times L \times S \times C \times P$, where A is the erosion rate in T/acre/yr, R is the rainfall and runoff factor for the region, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover and management factor, and P is the erosion control support practice factor.

For the Area C case, R is approximately 75 (Ref. 7-33)) and $P = 1.0$. No specific contouring practices will be assumed. For the Nyjack and Seaby loam soils, $K = 0.2$ to 0.28, and the value of 0.28 will be assumed for the calculation. The other factors are estimated for specific scenarios as shown in the table. The slopes are taken to be in the 0 to 5% range typical of mesa tops in this area.

create additional dust loadings, and crops could accumulate contaminants into the edible portions and act as an additional pathway.

7.3.5.4 Commercial Land Use. Because of the relatively limited acreage of the site, and the narrow mesa where Area C and the other waste disposal sites are situated, the commercial use of the land is expected to be similar to home construction. Although the patterns of contact with the wastes may be somewhat different, the net results are very similar.

7.3.5.5 Agricultural Land Uses. There is a documented early use of Los Alamos County mesa tops for dryland farming (Ref. 7-31). With this precedent for agricultural land use, dry farming and pastureland scenarios are definite possible normal land uses of the disposal sites at distant future times. As with the previous scenarios of urbanization and commercialization, clearing and plowing of the land for agricultural uses could increase the erosion rates. Referring to Table 7-18 and the Universal Soil Loss Equation, and assuming a slope of 2% and alternating periods of bare soil, plowing, and cover crops along with relatively long field lengths (200 m), the soil loss may be an average of 0.7 T/acre/yr. Larger rates are possible in areas where the runoff is more channeled. This rate is within the range for midcontinent farmland, other than clean-tilled, of 0.5 to 6 ton/acre/yr (Ref. 7-34). The estimated soil loss rate is approximately maximum compatible with long-term productivity for shallow soils, such as those at the disposal sites (0.5 T/acre/yr). Therefore, agricultural use might lead to relatively rapid loss of the cover, resulting in a more rapid exposure of the wastes. At the calculated erosion and removal rates, it would require ~15 000 yr to remove the 1.5-m soil cover.

Maintaining the site as a pasture on a permanent basis (that is, good sod) could reduce the erosion rate to 0.17 T/acre/yr, and require ~56 000 yr for erosion to uncover the wastes.

Severe limitations in the availability of surface and groundwater on the plateau make it virtually impossible for water to reach the wastes and become a translocator mechanism by irrigation of surface crops. Water limitations dictate that the predominant large-scale land use is limited to dry land farming with only very limited productivity. Computer modelling simulations of crop production for Area C site-specific conditions have been performed (Ref. 7-35). Assuming regional planting and harvesting dates, and both dry land and irrigation water inputs, the biomass estimates for major crop categories were simulated, with the results shown in Table 7-19. The irrigated farming describes home garden productivity.

Agricultural use of the site includes the potential for some limited excavation, for example, for construction of farm buildings, utilities, fence posts, and livestock watering tanks. For calculational purposes, it was assumed that 5% of the pit contents that were estimated to be uncovered or contacted in the urbanization scenario are contacted in the

TABLE 7-19

BIOMASS PRODUCTIVITY OF AREA C UNDER DRY LAND AND IRRIGATED AGRICULTURAL LAND USES

	Irrigated		Nonirrigated	
Crops	Dry Biomass (g/m^2) Total Plant	Edible Portion[a]	Dry Biomass (g/m^2) Total Plant	Edible Portion[a]
Corn and sorghum	575	288	238	120
Warm season vegetables	345	173	138	69
Alfalfa	173.[b]	---	76	---
Beans, cool season vegetables, grains	225	112	33	17

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[a] Assumes 50% of the biomass is edible portion.

[b] Used to feed dairy animals.

agricultural scenario, that is, 5×10^{-4} of the pit volume. In the agricultural situation, any wastes or contaminated soil is evenly mixed with clean soil by plowing and erosive forces involved in cropland use. The potential exposures are presented later.

7.3.5.6 Park or Recreational Use. The existing shallow land burial sites at Los Alamos are already leveled, cleared mesa tops, located in an area noted for its natural scenic beauty. Furthermore, the Laboratory complex is a National Environmental Research Park (NERP) designated by the federal government, covering ~27 500 acres. Thus, park uses might continue for a considerable time.

It is very difficult to predict what effect recreational and park use might have on a disposal site. However, some surface soil compaction would occur. This, in turn, could reduce infiltration and increase surface runoff (Ref. 7-36). The disposal areas in this vicinity are noted for their sparse vegetation, shallow and poorly developed soils, and short growing season. They would, therefore, be subject to increased erosion effects with increased use as a recreational site. Nongrazed watersheds in the Colorado Plateau have exhibited 30% less runoff and 45% less sediment yield than similar grazed watersheds, indicating the severe negative impact of compaction and removal of cover in the region.

The estimated crop and management factor, used in Table 7-18 to calculate erosion rates at the site, lies in the upper range of values calculated for family picnic sites without shelters accommodating up to 10 persons in the Patapsco Valley State Park in the Maryland Piedmont (Ref. 7-36). Also, this approximates the idle land management factor for soils having ~60% cover under tall weeds, bushes, or trees. Compacted soil erosion rates of $\sim 10^{-2}$ cm/yr suggest that ~15 000 yr would be required to expose the upper surface of the buried wastes. Only a small portion of the waste pit would be expected to be exposed by this mechanism.

Deeply rooted plants such as certain of the native trees and shrubs could eventually penetrate the wastes and extract small amounts of the transuranic wastes along with other mineral components normally cycled. Simulations of these processes were modeled using the BIOTRAN code. Surface concentrations approximating present fallout levels (10^{-8} to 10^{-4} pCi/g) have been calculated (Ref. 7-37).

Translocated wastes could then be available for resuspension during the recreational use period, and for redistribution to a nearby watershed, by runoff. This situation will be addressed in the undeveloped land use discussion below. Resultant human exposures are presented later.

7.3.5.7 Undeveloped Land Use and Resource Exploration. There are no known mineral resources in the soils, tuff, or underlying basalts of the plateau. Hydrothermal resources exist in the region at extreme depths below the mesas, typically 3000 m (~9800 ft). Conceivably, a hydrothermal well in one or more of the disposal sites could inadvertently penetrate the wastes, but the consequences would likely be minimal, because the hole would be small, ~20 cm in diameter or less. Also, the hole would typically be cased in the upper hundred or so meters of depth.

Two drilling scenarios were presented in the WIPP FEIS (Ref. 7-21), which can be used to estimate similar drilling impacts in the Los Alamos situation. The first scenario involved oil or gas exploration, whereas the second involved mineral exploration, each at 100 yr after WIPP closure. In each scenario, it was assumed that the drill penetrated the wastes, bringing TRU-contaminated materials to the surface. Doses were calculated for the drilling crew, the geologist who examined the drilled samples, and for the single-family farm downwind from the cuttings and tailings surface impoundment.

Scaling these scenarios to the Los Alamos TRU waste, concentrations, and Area C considerations allows similar estimation of the doses. The drilling crew could receive a maximum external whole body dose of ~1.5 mrem to the maximally exposed member of the crew, and ~2 mrem maximum external whole body dose to the geologist. Because of the size limitations of Area C, the single-family farm was considered to be only 100 m downwind instead of 500 m. The maximum calculated dose commitment to a member of this family was 4.4×10^{-4} rem bone dose, which is about two times higher than in the WIPP case, because of the closer proximity at Area C.

Note that the doses received by the drillers and the geologist are principally external doses, caused by exposure to ^{235}U. The doses to the farm family are caused by inhalation of ^{239,240}Pu and ^{241}Am. In each of these exposures, the time after closure has little effect over the first few hundred years because of the long half-lives of the dominant radionuclides present.

Undeveloped use implies reversion to the natural state and the succession growth of native plant species. The litter-humus layer progression typically is associated with lower erosion rates. Time spans for the uncovering of the wastes could range to as high as 200 000 yr. Possible transport of TRU to the surface by native deep-rooted vegetation could result, however, in concentrations less than fallout levels. Modeling 100-yr growth of trees over a 6.5-m-deep trench with a 1.5-m cap of uncontaminated soil, into wastes averaging 0.1 nCi/g TRU indicates a surface inventory of $\sim 1 \times 10^{-2}$ pCi in an area of ~25 acres. Using physical transport modeling to simulate surface runoff flow (ARM, Ref. 7-38, and Instream Sediment Transport, Ref. 7-39), the removal and redistribution of these contaminants into the nearby canyon stream beds indicate that approximately 1.7% of the available source is removed and deposited in the lower reaches of the stream bed where normal flow usually ceases. This implies that these stream beds will not become any more contaminated from an undisturbed burial ground than they will be because of the presence of worldwide plutonium fallout levels in the soils of the water shed.

7.3.6 Estimated Radiation Exposures Because of Land Uses.

7.3.6.1 Categories of Exposure. Several generalized scenarios have been presented where varying amounts of buried TRU are released to the environment or made available for exposure of individuals during normal use of the land. In these scenarios, there are only a limited number of mechanisms for the dispersed TRU to become a potential human health hazard by ingestion. The more significant of these, taken from Ref. 7-40, are:

Category 1. Inhalation from general resuspension. General resuspension means relatively widespread air contamination because of either wind or mechanical resuspension of surface contamination, where local meteorology is an important factor in determining concentrations.

Category 2. Inhalation from local resuspension, caused by mechanical disturbance of contaminated soils producing a high local concentration of contaminated dusts in the breathing zone of the exposed individual.

Category 3. Ingestion of contaminated foods produced in the contaminated area. Plant or animal-derived foods can be contaminated either directly (for example, by metabolized TRU in the plant or the animal), or by deposition of contaminated dusts during growth or harvest.

Category 4. Ingestion of inadvertent contamination (for example, by transfer of contaminated dusts from hands or clothing to the mouth or onto prepared foods or utensils). Individuals working or residing in a contaminated area could accidentally ingest contaminants from dusts transferred into the home environment.

Each of these mechanisms for internal deposition of TRU must be associated with the previously described normal land use activities in order to carry through an estimated dose calculation. Recent work performed in deriving standards for concentrations of TRU in the environment (Refs. 7-26 and 7-41) and for proposed limits for TRU in shallow land burial contain detailed analysis of the contaminant transfer processes and critical organ dose calculations. These derivations are not repeated here, but the results are summarized in a form that will enable direct application to the conditions assumed in the analysis of each of the land use scenarios.

(Category 1). In their derivation of TRU burial limits, Healy and Rodgers (7-26) estimated a typical outdoor ambient dust loading of 100 μg/m^3, half of that concentration for indoor air, and 400 μg/m^3 for general outdoor, 8-h, 50 wk/yr working conditions. Assuming that 17 m^3 of air is inhaled during the outdoor working day (14 h working, traveling, and resting) and 6 m^3 inhaled during the rest of the day, indoors, a dose rate of 1.6 mrem/yr per pCi/g of ^{239}Pu in the resuspendable dusts was calculated. If the measured Los Alamos annual average dust loading of 35 μg/m^3 (Ref. 7-19) is substituted for the 100 μg/m³ ambient dust loading, but the working condition assumptions are unchanged, the dose rate effect is only slightly reduced (1.19 mrem/yr per pCi/g). In other words, the effects of wind or mechanical resuspension during 8-h outdoor working conditions dominate general resuspension exposures.

Accordingly, the generalized results shown in Table 7-20 can be appropriately applied to the Los Alamos Area C land use scenarios, recognizing that the results apply to outdoor workers, not to the general population.

(Category 2). During the construction phase of urbanization, where digging trenches and close contact with dusty equipment may cause exposure to very high dust loading, or during plowing for agricultural purposes, localized heavy dust loadings may cause increased exposures for short periods of time. A loading of 1 mg/m³ is estimated during the exposure appropriate for each activity (Ref. 7-40).

The 70-yr dose rates from local resuspension in a given scenario are found by multiplying the TRU concentration by the appropriate factor from Table 7-21 and the average yearly exposure time in hours.

(Category 3). Root uptake and surficial contamination by resuspended soil can result in TRU intake in foods produced locally on the burial site. The controlling factors will be the uptake coefficients of the radionuclides involved, the amount of food of various types that can be produced, the specific agricultural factors, and the amount of each type of food ingested. The quantities of various foods ingested per capita can be estimated from food surveys. The expected TRU concentration factors, expressed as the TRU concentration in the prepared food (fresh weight) per TRU concentration in the soils where the food was grown, have been estimated (7-26). The dietary concentration factors are listed in Table 7-22. Because of soil types and the size limitations of Area C, it is barely feasible that all of the dietary components for ~2 persons could be grown on the contaminated areas, even if all of the available surfaces were used.

The potential agricultural productivity of the Area C site has been modeled (on a square meter basis), using site-specific rainfall amounts, temperature, soil depth and water holding capacity, regional planting and harvesting dates, and irrigation rates and dates of application. The results are shown in Table 7-23, in terms appropriate for a dryland farm of ~18 acres and also for a 100 m² irrigated garden. The calculated dose rates from the consumption of vegetable and animal products raised on Area C land are shown in Table 7-24.

The dry land farm is a more difficult case to assess. Following the strategy of Martin and Bloom (Ref. 7-42) to estimate nutritional requirements for a beef cow (409 kg weight) and a dairy cow (650 kg weight plus 25 kg of milk/day), the annual alfalfa productivity (27 400 kg) is sufficient to meet the

TABLE 7-20

DOSE EQUIVALENT RATES TO OUTDOOR WORKERS FROM GENERAL RESUSPENSION[a]

Nuclide	ICRP Class (1-μm size)	Bone Dose Rate $\left(\frac{\text{mrem/yr}}{\text{pCi/g}}\right)$	Lung Dose Rate $\left(\frac{\text{mrem/yr}}{\text{pCi/g}}\right)$
^{238}Pu	Y	1.0	0.76
^{239,240}Pu	Y	1.6	0.76
^{241}Am	W	4.4	0.08

[a] For outdoor workers, not for the general population.

TABLE 7-21

DOSE EQUIVALENT RATES FROM LOCAL RESUSPENSION

Nuclide	ICRP Class (1-μm size)	Bone Dose Rate $\left(\frac{\text{mrem/yr}}{\text{h} \times \text{pCi/g}}\right)$	Lung Dose Rate $\left(\frac{\text{mrem/yr}}{\text{h} \times \text{pCi/g}}\right)$
^{238}Pu	Y	8.6×10^{-4}	6.5×10^{-4}
^{239,240}Pu	Y	1.4×10^{-3}	6.5×10^{-4}
^{241}Am	W	3.4×10^{-3}	6.8×10^{-5}

TABLE 7-22

SITE-PRODUCED DIETARY COMPONENTS AND DIETARY CONCENTRATION FACTORS

Diet Component	Per Capita Annual Intake (kg/yr)		Concentration Factor	
			^{238,239}Pu	^{241}Am
Fresh fruit[a]	29		7.7×10^{-4}	7.7×10^{-3}
Fresh vegetables	48		6.5×10^{-4}	6.5×10^{-3}
Root vegetables	10		5.3×10^{-4}	5.3×10^{-3}
Potatoes	38		2.0×10^{-4}	2.0×10^{-3}
Dry beans	3		7.4×10^{-4}	7.4×10^{-3}
Canned vegetables	22		1.4×10^{-4}	1.4×10^{-3}
Total[b]	150	Average	5.0×10^{-4}	5.0×10^{-3}
Poultry	20		5.0×10^{-4}	5.0×10^{-3}
Beef	79		3.9×10^{-4}	3.9×10^{-3}
Eggs	15		1.8×10^{-4}	1.8×10^{-3}
Total	114	Average	3.8×10^{-4}	3.8×10^{-3}

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[a] One-half of fresh fruit is from the contaminated area, one-half is from uncontaminated areas.

[b] Items that are assumed to have not been produced on site and amounts: bakery products (44), white grain products (11), flour (34), rice (3), macaroni (3), fruit juices (28), canned fruit (11), one-half fruit grown elsewhere (30), and milk (200).

TABLE 7-23

CONSUMABLE QUANTITIES PRODUCED BY FARMING OR GARDENING IN AREA C

Plant Crop	Dry Land Farming[a]		Irrigated Garden[c]	
	Biomass (g/m^2 dry)	Fresh Weight Consumable (kg)[b]	Biomass (g/m^2 dry)	Fresh Weight Consumable (kg)
Corn, sorghum	238	4.3×10^4	575	144
Warm-season vegetables	120	2.2×10^4	345	82
Cool-season vegetables	33	5.9×10^3	225	53
Alfalfa	76	2.7×10^4	---	—

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[a] Assumes nonirrigated, ~18 acres cultivated, and 450-mm/yr rainfall.

[b] Fresh weight factor of 5 greater than dry, and 50% consumable portion.

[c] Irrigated garden of 100 m^2.

TABLE 7-24

DOSE EQUIVALENT RATES FROM AGRICULTURAL USE OF WASTE DISPOSAL AREA C

Food Pathway to Humans Exposed	TRU Contamination in Soil[a] (mrem/yr per pCi/g)		
	^{238}Pu	$^{239,240}Pu$	^{241}Am
Vegetable portion of diet	0.11	0.17	8.6
Animal product portion of diet	0.06	0.10	4.9

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[a] Dose rates computed from per capita consumption of vegetables and animal-derived products diet portions, and uptake coefficients from Table 7-22. Dose rate conversions in mrem/yr per pCi/day after 70 yr (^{238}Pu = 0.54, ^{239}Pu = 0.87, and ^{241}Am = 4.2).

maintenance caloric requirements of only one beef cow (10 300 kg/yr) and one dairy cow (14 400 kg/yr). The caloric input required for milk production would have to be supplied by feed supplements. Assuming this were the case, and land that was needed for alfalfa production was available to produce corn and grain for chickens (~1.7 acre), ~2000 to 4000 kg of feed could be produced to support poultry and egg production.

Therefore, it is unlikely that agricultural use could provide more than a limited subsistence farming capability.

(Category 4). The final category of exposure is inadvertent ingestion, such as, transfer of contamination from the hands or clothing into one's mouth, onto food, or cooking and eating utensils. Another example is the habit of young children of putting toys, dirt, and similar items into their mouths. Healy (Ref. 7-40) estimates the ingestion of dirt by mouth of a child may be ~200 g (110 mg/day) for the typical period to 5 yr of age. There is a contaminant enrichment factor of 10, resulting from the selective transfer of small particle sizes and frequent indoor exposure. These factors were used in estimating the probable exposure caused by direct transfer.

7.3.6.2 Dose Estimates. Each of the above five categories of exposure has been normalized to unit activity in soil, which will permit scaling of doses to a range of soil activity concentrations. From the data on TRU inventory and pit volumes at Area C and an estimated additional dilution factor of 10, average concentration encountered in the trench volume is calculated to be about 0.1 nCi/g.

Land Use 1: Urbanization/Commercialization. The construction of a 30-unit subdivision in Area C would involve repeated worker exposures to local resuspension of dusts from excavated wastes. The duration of a typical worker exposure to high dust loading would be ~40 h, delivered over a period of several years as the subdivision is developed. If 10% of the excavated trench materials are not returned to the excavations as backfill but are eventually mixed with the top 2.5 cm of surface soil, a widespread surface contamination of 9 pCi/g could result. This TRU source would then be available for both generalized and local resuspension by such activities as soil preparation for gardening. The calculated exposures are shown in Table 7-25.

Land Use 2: Agricultural Uses. The agricultural land use scenario assumes the character of subsistence farming, with previously specified quantities of food and meat produced onsite. Trenching

TABLE 7-25

DOSE EQUIVALENT RATES FROM URBANIZATION/COMMERCIALIZATION LAND USE SCENARIOS

Exposure Mode	Exposure Time	Critical Organ Dose Rates (mrem/yr) ^{238}Pu	^{239}Pu	^{241}Am
Worker: dust from trenching/excavating	40 h	1.72	2.8	6.8
Worker: outdoor dust	70 yr	100	160	440
Gardener: 10 h/yr rototilling, 70 yr	700 h	0.07	0.13	0.31
Gardener: vegetable consumption	70 yr	1.0	1.5	77.4
Casual Ingestion	5 yr	5.4	8.6	41.6

operations for building construction will be less extensive than with urbanization, that is, only 5% as much trenching. The TRU contaminants would eventually be mixed in the 25-cm-deep plow depth layer over the entire site, to produce an average contaminant concentration of 0.05 pCi/g.

However, if previous land uses have resulted in the erosion of the pit covers to the point where plowing to depth could penetrate into the waste volumes, and mix some of the top layer of the wastes into this upper 25 cm, a concentration of ~2 pCi/g could result. Previously estimated soil erosion rates for agricultural land use suggest that 8 to 10 thousand years of such use would be required before plowing would expose the top layer of wastes. During this time, the ^{241}Am and ^{238}Pu activity levels would have decayed to negligible levels.

The farmer would be exposed to very dusty conditions involving direct contact with the wastes for only a few hours (10 h) during the site use. Additionally, the farmer might be exposed to high-dust concentrations while plowing and harvesting for ~80 h/yr, but the TRU source would be diluted surface soils. The remainder of his outdoor exposure time would involve general resuspension. If the farmer and his family lived onsite, and obtained their dietary components grown onsite as previously noted (Table 7-22), then the estimated doses are as shown in Table 7-26.

Land Use 3: Recreational/Undeveloped Land Use. The last two categories of land use have been combined for dose estimation, because they have a common surface contamination mechanism: long-term erosion of the soil surface, leading to exposure of portions of the wastes. It is estimated that ~0.6% of the total trench surface (120 m^2) could become exposed in patches at various locations over the site where heavy use, severe erosion, or other processes of soil removal are more effective, over a period of thousands of years.

About 0.05% of the total surface could become exposed in patches at various locations over the site where severe erosion or heavy use cause severe soil loss. If exposed wastes become mixed with the top 2.5 cm of soil, contamination levels of 0.2 pCi/g could result. These would be the same as some existing ^{239}Pu concentrations in Los Alamos site perimeter soils (Ref. 7-43). Because of the long time spans previously estimated to be required for exposure of the wastes by this land use, only the ^{239}Pu exposures would be significant. The estimated dose is shown in Table 7-27.

Land Use 4: Deliberate Intrusion. The deliberate intrusion scenario described by Healy and Rodgers (Ref. 7-26), involving 2600-h exposure to very dusty conditions over a 10-yr period, will be used to

TABLE 7-26

AGRICULTURAL LAND USE DOSE EQUIVALENT RATES

Exposure Mode	Exposure Time	Critical Organ Dose Rate (mrem/yr) ^{238}Pu	^{239}Pu	^{241}Am
Dusts from trenching and fencing	10 h	0.43	0.7	1.7
Dusts from general outdoor work	70 yr			
a. No erosion		0.05	0.08	0.22
b. Erosion (8000 yr)		0	3.2	0
Dusts from plowing and harvesting	80 h/yr for 70 yr			
a. No erosion		0.14	0.22	0.54
b. Erosion (8000 yr)		0	0.2	0
Food production	70 yr			
a. No erosion		0.01	0.01	0.43
b. Erosion (8000 yr)		0	0.54	0
Casual ingestion	5 yr			
a. No erosion		0.03	0.05	0.23
b. Erosion (8000 yr)		1.2	1.9	9.20

TABLE 7-27

DOSE EQUIVALENT RATE FROM RECREATIONAL LAND USE

Exposure Mode	Exposure Time (yr)	Critical Organ Dose (mrem/yr) ^{239}Pu
Dust from vigorous activity	70	0.3

calculate doses from this exposure mode. The calculated doses are shown in Table 7-28.

7.3.7 Discussion of Land Use Radiological Impacts. The foregoing discussion of radiation exposures from a variety of land use scenarios for Los Alamos shallow land burial sites clearly does not completely cover all of the complexities of such interactions by humans with these sites.

It must be emphasized, however, that these are not predictions of what will happen, but relative estimations of what could happen under certain specified conditions. Even these are not complete without further consideration of the possible consequences of identifiable ranges in some of the critical variables. Note that the ranking of radiation doses attributable to land uses, in order of decreasing severity is: Urbanization, Deliberate Intrusion, Agriculture, and Park/Undeveloped Uses.

This ranking remains unchanged if one focuses on ^{239,240}Pu, and, thereby eliminates issues deriving from whether or not intrusion might occur in hundreds of years (that is, intrusion occurs before the ^{241}Am has decayed, and before the ^{239}Pu has decayed much), or is more likely to occur after a few thousand years have passed.

Therefore, the following sensitivity analysis will be limited to consideration of doses from ^{239,240}Pu alone, without much loss of generality. There are three areas of uncertainty in the previous dose estimates that deserve particular attention: (1) the assumed average TRU activity concentration in waste pit contents, (2) the assumed dilution of pit materials with uncontaminated soils and wide dispersal onsite, and (3) the amount of contact or exposure time during various site uses.

TABLE 7-28

DOSE EQUIVALENTS FOR SCAVENGING IN AREA C

	Organ Dose Rates (mrem/yr)	
Nuclide	Lung	Bone
^{238}Pu	16.9	22.4
^{239,240}Pu	16.9	36.4
^{241}Am	1.8	88.4

7.3.7.1 Effect of Encountering Greater TRU Concentrations During Excavation. The wastes are not uniform in TRU concentrations. Certain locations or containers may contain higher amounts, perhaps into the millicurie range, even though the frequency of such higher concentrations drops as the concentration rises. The previously cited study of Los Alamos waste containers (Ref. 7-30) indicated that only ~1.7% of the boxes surveyed contained 100

TABLE 7-29

RESULTS OF SENSITIVITY ANALYSIS

Parameter Change	Land Use	^{239}Pu Dose Rate (mrem/yr)
Increase contacted TRU concentration to 250 nCi/g	Urbanization	7000
	Agricultural	1750
	Intruder	91 000
Increase average TRU level in general environment by 10 times (that is, decrease dilution factors)	Urbanization	15 to 1600
	Agricultural	2 to 32
	Park	3
Increase exposure time to contaminated dusts (10 times)	Urbanization	1.3 to 28
	Agricultural	2.2 to 7
	Intruder	364

to 5000 nCi/g, and only 2.2% were in the 10 to 100 nCi/g range. This survey was taken at a time of heavy throughput of plutonium wastes and may not be typical of room trash wastes over the full period of Area C use.

The barrels of sludge going into the pits beginning in the early 1950s probably contained ~300 nCi/g and thus represent another sort of routine, but infrequent, elevated TRU concentration waste. On this basis, it can be assumed that, although there is a small possibility that a utility trench randomly dug at Area C could result in a worker encountering waste concentrations in the millicurie per gram range, a more likely elevated concentration to be encountered is ~250 nCi/g. If the relatively few hours spent in trenching-type work involved significant contact with these elevated concentrations, the corresponding dose rates would be increased to those in Table 7-29.

7.3.7.2 Effect of Assuming an Elevated Average TRU Concentration. If a relatively few pockets of elevated concentrations of TRU were encountered, brought to the surface, and made available for general resuspension, the average concentration in the general outdoor work scenarios could be much higher. The consequences of a tenfold increase in expected average TRU concentration (from 0.1 to 1.0 nCi/g) in the wastes are shown in Table 7-29.

7.3.7.3 Effect of Increased Exposure Time to Contaminated Dusts. The estimates regarding the amount of time a worker or resident on the site would spend exposed to dusty conditions are uncertain and could be influenced by a variety of undefined site conditions. Therefore, the influence of a tenfold increase in time was evaluated for those scenarios where time is crucial. The results are shown in Table 7-29.

7.3.8 Comparisons of Results. Comparison of the results of this abbreviated sensitivity analysis clearly indicates that the potential radiological doses from a variety of long-term land uses of the burial site are much more sensitive to the possibility of contact with more highly contaminated wastes (>10 nCi/g) than to orders-of-magnitude changes in the estimated lower average concentration (0.1 nCi/g).

Thus, one could anticipate that there would be a much greater long-term benefit to be derived from waste management options that involve removal of the more highly contaminated materials from the wastes than from leave-in-place options with surface treatment.

At the same time, this analysis indicates that options that involve removal of higher concentrations of TRU but do not involve processing the remaining waste (which would tend to increase the average remaining TRU concentrations) are to be favored over removal, incineration, or compaction options. In other words, there is a potentially serious tradeoff between burial cost savings by incineration or compaction, and long-term impacts from eventual land uses.

Tenfold increases in the contact time do not have as great an effect on doses as the impact of encountering higher levels of TRU. Thus, even if the degree of realism in these long-term land use scenarios is not great in terms of the type and duration of interaction with the wastes, the basic conclusions concerning the desirability of removing the more highly contaminated wastes and maintaining a lower average concentration are unaffected.

7.3.9 Summary of Radiation Doses from Various Land Uses. Various land uses of the disposal sites were assessed, including: Urbanization/Commercialization, Agricultural, Recreational/Undeveloped, and Deliberate Intrusion.

The estimated radiation doses calculated for these various land uses range (in decreasing order) from the exposure received by the worker performing trench excavation work under the Urban/Commercialization scenario (440 mrem from ^{241}Am, 100 from ^{238}Pu, and 160 from ^{240}Pu), to the lowest doses received by a home gardener performing rototilling (0.31 mrem from ^{241}Am, 0.07 from ^{238}Pu, and 0.13 from ^{240}Pu). These doses are potentially additive. If a person spends his/her entire life on an urbanized site and is an outdoor worker, his total 70-yr dose rate commitment from ^{239}Pu alone might be the sum of the values shown in Table 7-25, or 173 mrem/yr. If he is exposed to equal activity contributions, all of those radionuclides considered in Table 7-25, his dose could be ~280 mrem/yr. Similar considerations apply to the other scenarios.

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8. COST-BENEFIT COMPARISONS

In considering the following comparisons, several important points bear repeating. Costs are not merely dollars but also imply indirect costs such as environmental, health, and safety considerations. Where dollar costs are cited, they are quoted in April 1980 dollars, without escalation, and are for the purpose of *comparison of the various alternatives, not for budgetary estimating purposes.* No attempt has been or is being made to select or to favor one alternative as preferable to the others.

In comparing the estimated cost in dollars (as presented in Sec. 6) it becomes readily apparent that the dollar costs are in direct proportion to the amount of handling or processing of the wastes. That is, the strategy with the least amount of handling, Alternative 1, bears the least direct, 100-yr cost, while Alternative 14, which involves the greatest amount of handling, processing and transportion, etc., involves the greatest dollar cost over the shortest time period, 15 yr.

Radiation risk bears much the same relationship; the more the waste is handled, the greater the risk of radiation exposure,

One possible advantage presented by either of the first two alternatives is that they do not preclude further action, such as implementation of the other alternatives, at some future time. Balancing this is the possible disadvantage that the wastes are still in their present, separated shallow land burial locations at Los Alamos, rather than in one centralized site.

An advantage to the other alternatives is that the TRU wastes would be placed in one centralized location, either in a deeper pit at Los Alamos or in a federally owned deep geological repository. In the federal repository, these wastes could be used in the research and development of such a facility, in preparation for the development of a possible national repository. The disadvantage(s) of such a federal facility are described in the WIPP FEIS, previously referenced. The disadvantage of the federal repository to Los Alamos could be taken to be the cost incurred for entombment of the waste in the repository. The disadvantage of the Los Alamos deeper pit would be that such a pit would have to be designed and built, with the commitment of funds, manpower, equipment, and additional land space.

The costs and benefits of the 14 alternatives are summarized in Table 8-1. The dollar costs of the first alternative are taken as unity, with the dollar costs of the other alternatives expressed as multiples of this. The relative radiological risk, as calculated in Appendix D, is compared with the local natural background, 96 mrem. The final two columns of this table list the principle advantages and disadvantages of each alternative.

The net result of the comparison of the 14 Alternatives suggested for the long-term management of Los Alamos stored and buried TRU wastes serves to amplify the complexity of the possibilities and to a large extent, may be based upon the criteria of the reviewer. If one believes that removal of the wastes in a more immobile form is important while fiscal costs are not, then Alternative 14 is preferred, with Alternatives 12, 10, 6, and 4 ranked next in order of preference. On the other hand, if costs are of primary consideration, Alternatives 1 or 2 might be preferred.

Other factors also need to be considered, such as the criteria to be required by a federal repository, regulatory and cost considerations because of burial in a deeper pit at Los Alamos, and social and political considerations.

In summary, considerably more study and estimating may be required before the final selection of one alternative or combination of the possible alternatives and implementation.

TABLE 8-1

COMPARISON OF THE COST BENEFITS OF THE 14 ALTERNATIVES

	Relative Cost or Potential Impact				
Alternative	Dollars[a]	Radiation Risk[a]	Environmental Considerations	Advantages	Disadvantages
1. Continue Current Practices	1.00[a]	0.1[a]	Low short-term impacts; possible high long-term impacts	1. Defers action to later date 2. Least present cost	TRU wastes stay at separated locations at Los Alamos in SLB
2. Engineered Improvements	1.08	0.1	Relatively lower than No. 1	1. Defers further action 2. Second least costly 3. Slightly less Environmental and Radiation Risk (short and long-term)	More costly than No. 1, with only slight increase in benefits
3. Buried-Continue Stored-Retrieve, disposal at Los Alamos[b]	1.06	1.0	Somewhat better than No. 1 or 2	1. Eliminates "Stored" category 2. Locates Stored TRU in one location	Retains all present burial sites
4. Buried-Continue Stored-Retrieve, RPF[c] offsite disposal[d]	1.47	1.2	Higher short-term, less over long term	Removes majority of TRU to offsite	Buried TRU still present, in diverse locations
5. Buried-Continue Stored-Retrieve, process, disposal at Los Alamos	1.69	2.0	Somewhat better than each of the above over long term. Higher short-term risks	Better confinement of TRU presently in storage	1. Requires sorting and processing 2. Buried TRU still at Los Alamos in diverse locations
6. Buried-Continue Stored-Retrieve, process, disposal offsite	1.81	1.9	Slightly less impact than No. 5	Removes majority of TRU from Los Alamos	1. Retains buried TRU at diverse Los Alamos sites and LL wastes 2. Requires processing

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[a] Based upon local natural background, 96 mrem/yr. The greatest risk (13.5) is not a great increment of background when consideration is given to the number of persons exposed and that most of the exposure is due to waste handling and processing.

[b] Disposal at Los Alamos denotes Deep-Pit burial, onsite.

[c] RPF denotes Resizing and Packaging Facility.

[d] Offsite disposal denotes deep geological burial at a remote federally owned site.

TABLE 8-1 (Continued)

	Relative Cost or Potential Impact				
Alternative	**Dollars[a]**	**Radiation Risk[a]**	**Environmental Considerations**	**Advantages**	**Disadvantages**
7. Buried-Eng. Improvement Stored-Retrieve, disposal at Los Alamos	1.13	0.9	Less impact than Nos. 1 thru 6 over long term. Possible higher short term	Improvement at only slightly higher cost	Retains buried TRU and LL wastes at diverse Los Alamos sites
8. Buried-Eng. Improvement Stored-Retrieve, RPF, disposal offsite	1.54	1.2	About same as No. 7	Removes majority of TRU to federal repository	Buried TRU and LL wastes retained in diverse Los Alamos sites
9. Buried-Eng. Improvement Stored-Retrieve, WPF, disposal at Los Alamos	1.76	2.0	Slightly more in short term, less long term	Improved confinement as the stored TRU better immobilized	Buried TRU and LL wastes retained in diverse Los Alamos sites
10. Buried-Eng. Improvement Stored-Retrieve, WPF, offsite disposal	1.88	1.9	About same as No. 9, except stored TRU removed to offsite (so long-term effects at Los Alamos lessened)	Removes stored TRU to offsite	Same as Nos. 6 thru 9
11. Buried-Exhume, RPF, Los Alamos Stored-Retrieve, RPF, Los Alamos	3.37	7.0	Slightly higher local short term Slightly less long term	1. Improved confinement 2. Centralizes Los Alamos TRU wastes at one location	1. Retains LL wastes at diverse Los Alamos sites 2. Three times the dollar cost of No. 1, and 61 times the risk
12. Buried-Exhume, RPF, offsite disposal Stored-Retrieve, RPF, offsite disposal	5.07	8.7	Higher short-term risks; much less long term	Removes all TRU wastes from Los Alamos	1. Costs are five times the cost of No. 1 2. Short-term risks are higher
13. Buried-Exhume, WPF, disposal at Los Alamos Stored-Retrieve, WPF, disposal at Los Alamos	6.16	11.5	Higher short term, lower long term	Centralizes all TRU wastes at Los Alamos	Buried LL wastes retained at Los Alamos sites diverse
14. Buried-Exhume, WPF, offsite disposal Stored-Retrieve, WPF, offsite disposal	7.13	13.5	Highest short term, lowest long term	Removes all TRU wastes from Los Alamos	Highest cost of the 14 Alternatives (dollars and radiation risk)

APPENDIX A

GLOSSARY OF TERMS AND ABBREVIATIONS USED

Term	Explanation of Term
β	Beta radiation symbol; charged particle (electron) emitted from certain radionuclides.
Ci, μCi, nCi	Curie, microcurie, and nanocurie; special unit of radioactivity. One curie is 3.7×10^{10} (nuclear transformations) per second. One microcurie equals 10^{-6} curies, while one nanocurie equals 10^{-9} curies. 10 nCi/g equals one part per million.
CMP	Corrugated Metal Pipe; sections of metal pipe that have been placed vertically in the ground at Los Alamos for the storage of some TRU cement wastes. Has an upper and a lower concrete plug.
CPP	Continue present practices.
d	Day
D&D	Decontamination and Decommissioning; decontamination denotes cleanup of a facility. Decommissioning denotes taking a facility out of operation, such as dismantling and disposal, or preparation for another but different use.
DACRIN	A computer code used for the calculation of radiation dose estimates for inhaled radionuclides.
dose	Term used in estimating the damage and thus useful in estimating the possible health effects caused by exposure of a living system or person to radiation or some other possibly harmful material.
FRP	Fiberglas-Reinforced Polyester-Coated plywood boxes; plywood boxes of various sizes, which are strengthened and protected from degradation by coating the plywood with fiber glass, for use as containers of TRU waste materials. These boxes are used to accommodate waste items not easily separated into pieces small enough to fit into standard-sized steel drums.
ft, ft^2, ft^3	Foot or feet, square feet, and cubic feet. English unit for length, area, and volume, respectively.

Term	Explanation of Term
g	Gram; unit of weight in metric system. Equals 2.20×10^{-3} pound.
γ	Gamma radiation; similar to light waves, but with higher energy or shorter wavelength. Originates from the nucleus of an atom.
gal	Gallon; English unit of volume.
h	Hour
HEPA	High-Efficiency Particulate Air Filter; filters used in the nuclear industry, with a typical efficiency of being capable of removing about 99.97% of all particles as small as 0.3 μm from air passed through the filter.
kg	Kilogram; unit of mass in metric system. One kg equals 2.2 pounds.
km	Kilometer; unit of length in metric system. One km equals 0.62137 miles.
ℓ	Liters; unit of volume in metric system. One liter equals 1.05671 (U.S.) quarts.
LASL	Los Alamos Scientific Laboratory. Name was changed to Los Alamos National Laboratory in January 1981.
lb	Pound; unit of mass in English system of weight.
LL	Low Level; used in this document to describe wastes which are contaminated with a lower transuranic concentration than TRU wastes (see TRU), or with other radionuclides, such as MFP, MAP, U, or ^{3}H.
m, m^2, m^3	Meter, square meters, cubic meters; unit of length, area, and volume, respectively, in metric system. One m equals 39 inches. One m^2 equals 10.76 square feet, and one m^3 equals 35.314 cubic feet.
MAP	Mixed Activation Products; radioactivity produced in a material by exposure to bombardment, such as in a nuclear reactor, causing nuclear transformation of some of the stable atoms into induced radioactivity.
man-rem	Unit of estimating dose from radiation exposure to a population. Equal to the average individual dose times the number of people in the population exposed.
MFP	Mixed Fission Products; denotes the mixture of various radionuclides remaining after a nuclear fission reaction have taken place at some previous time. Of the MF products, ^{90}Sr is probably the best known to the general public.

Term	Explanation of Term
NERP	National Environmental Research Park.
NRC	Nuclear Regulatory Commission.
O&M	Operation and Maintenance; terms used in estimating such items as the cost for the operating and maintenance of a facility or piece of equipment.
Population dose	Population dose is expressed in man-rem and is used in estimating possible effects to a human population exposed to known hazardous materials, such as radioactivity. Equal to the average individual dose (in rems) times the number of people exposed.
RPF	Resizing and Packaging Facility; a facility which could, for example, be mounted over the waste disposal area for weather protection and also confinement of the wastes, while the wastes are being exhumed from burial or retrieved from storage. Additional details describing the proposed facility may be found in Section 5.2.3 and Appendix B.
SPI	Slagging Pyrolysis Incinerator; An incinerator proposed for the combustion and melting of certain wastes and incorporation of the residues into a glassine matrix.
TA-	Technical Area; a term used at Los Alamos to describe specific onsite areas, such as the facilities located in TA-21.
TRU	Transuranics; certain radionuclides characterized by their emitting alpha radiation, their long half-lives, and high specific radiotoxicity. The radionuclides included are ^{233}U and its daughters, plutonium and transplutonium nuclides, except ^{238}Pu and ^{241}Pu.
TRU wastes	Waste materials contaminated with TRU radionuclides to concentration(s) greater than 10 nanocuries of TRU per gram of waste. An exception is that wastes known to be contaminated only with ^{238}Pu are not considered TRU wastes at Los Alamos until the concentration of ^{238}Pu exceeds 100 nCi/g.
Tuff	Tuff is a geological term used to describe the predominant soil and rock in the Los Alamos vicinity, a consolidated volcanic ash.
WIPP	Waste Isolation Pilot Plant; the proposed federally owned deep geological repository for research and development of radioactive waste materials.

Term	Explanation of Term
WPF	Waste Processing Facility; the proposed facility which would be used for processing exhumed and/or retrieved TRU wastes at Los Alamos. After sorting the wastes, combustible wastes would be processed through an incinerator, and materials suitable for cleaning (principally metal objects) would be decontaminated. Residues and other TRU wastes would be immobilized and packaged for terminal disposal.
yr	Year.

APPENDIX B

EXPANDED DESCRIPTION OF ALTERNATIVES

1. GENERAL

This section supplements the descriptions of the waste management alternatives given in Sec. 5. The descriptions are based upon preliminary conceptual designs. After the selection process has narrowed down these alternatives, a more detailed conceptual design can be completed.

2. CONTINUATION OF PRESENT PRACTICES

Under this alternative, the practices currently employed for surveillance and maintenance of the Los Alamos waste disposal and storage sites would be continued for 100 yr. The long-term waste management decision could be deferred until some future time when the waste disposal technology is further developed. A long-term decision can be made any time during the 100-yr period, but, for this study, it is assumed to occur at the end of this time period.

Current waste disposal practices are in accordance with established Los Alamos guidelines, which reflect DOE criteria for shallow land burial. The Los Alamos guidelines prescribe procedures for construction of the disposal pits, waste burial, water drainage, maintenance, revegetation, and environmental monitoring. The guidelines were formally promulgated in April 1974 and revised in December 1980. Continuing studies have not revealed any hazards attributable to disposal practices.

Waste site maintenance activities include upkeep of roads, fences, signs, monuments, and surveillance equipment; erosion control; slumping pit surface maintenance; and control of intrusion by plants and animals. Surveillance activities include air sampling, moisture analysis, meteorological measurements, dose rate measurements, plant uptake analysis, soil sampling, and animal ingestion analysis.

The TRU waste is no longer disposed of but is being and has been stored since 1971. The waste is packaged and stored in such a manner that it can be retrieved in contamination-free packages for up to 20 yr after its placement in storage. Continuation of current practices for some of this waste for up to 100 yr would require a greater degree of surveillance and maintenance than would the buried waste. As the waste packages deteriorate, surface subsidence is expected to occur because of the void volumes within and around the waste packages and the overall low density of the waste. Early detection and repair of this subsidence would be required.

Surveillance and maintenance costs would probably be the same for each option involving these activities regardless of whether it is LL or TRU waste and buried or stored. The total waste area requiring upkeep would be approximately the same whether or not the TRU fraction is removed.

3. ENGINEERED IMPROVEMENTS

Engineering improvements enhance the long-term integrity of the buried and stored waste sites. Implementation of this alternative does not foreclose the option of eventually exhuming or retrieving the waste, but it would be more costly. For this study, it is assumed that surveillance and maintenance activities, as described for "continuation of present practices," would be required for 100 yr after the completion of the engineered improvement construction.

The locations of the stored TRU waste and the buried waste containing, or possibly containing, quantities of TRU waste are described in Sec. 3.2.1. The total surface area of these pits, trenches, pads, and absorption beds is about 79 400 m^2 (855 000 ft^2). The techniques employed to enhance the disposal of the wastes are basically the same for the stored and buried waste except that a thicker overburden of compacted tuff would be placed over the stored waste because the greater void volume in the waste could eventually lead to surface subsidence. Thus, a deeper overburden would allow for a greater degree of slumping without exposing the waste to the atmosphere.

The engineered improvement process for the buried waste involves removing the current semicompacted tuff overburden to within about 0.3 m (1 ft) of the waste. This would not be necessary in some instances where the waste pits have been covered with 3 to 6 m (10 to 20 ft) of tuff. Following the removal of the overburden, the waste would be covered with a minimum of 1.5 m (5 ft) of compacted tuff. Road construction equipment would be used to compact the tuff. The thickness of the compacted tuff overburden would vary because grading would be required to provide adequate drainage (see Fig. B-1). A 0.3-m (1-ft)-thick layer of 20- to 30-m (8- to 12-in.) river rock riprap will be placed over the tuff to minimize erosion and reduce the possibility of intrusion. Local experience at the sites of Indian ruins has shown that the riprap would prevent soil erosion and actually accumulate blowing particles into the riprap, causing a surface buildup.

For the stored TRU waste, the existing semicompacted tuff overburden would not be removed because this would increase the probability of the heavy equipment crushing the waste containers and causing a cave-in. Instead, the tuff would be applied above the existing overburden to achieve a total thickness of 4.6 m (15 ft) of tuff over the waste. Again, river rock (riprap) would be placed over the tuff to minimize erosion. Erosion may be a greater problem for the TRU waste stored above ground on asphalt pads because of the greater height above the ground. The height of the stacked waste plus the 4.6 m (15 ft) of overburden would result in a mound about 9 m (30 ft) above the normal ground level; thus, it would be exposed to the wind to a greater degree, and a steeper slope (2:1) would be required to limit the distance of the tuff runout from the sides of the pads.

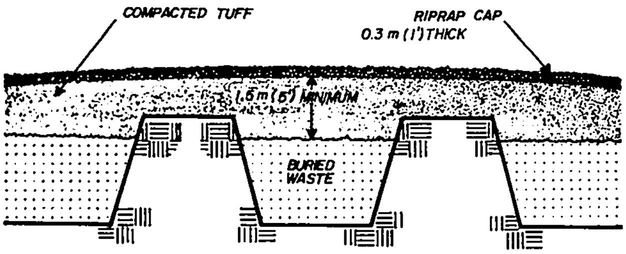

Fig. B-1.
Cross section through waste burial pits showing concept for engineered improvements.

4. EXHUMATION

The term exhumation as used herein refers to the overall operation of excavating potential TRU wastes that were disposed of (as opposed to stored) in pits, liquid absorption beds, and shafts. The exhumation process includes sorting out the TRU-waste fraction, reducing the size of oversized TRU-waste items as necessary to allow packaging, and returning the LL waste to the pits. The total volume of the pits and shafts at the Laboratory are estimated to be approximately 330 000 m^3 (11 300 000 ft^3). However, not all of this waste may contain TRU wastes. Types of waste disposal and estimated waste volumes are as follows: pits—310 000 m^3 (10 900 000 ft^3); shafts—4 400 m^3 (155 000 ft^3); and absorption beds—7 000 m^3 (245 000 ft^3). The TRU in the absorption beds may be less than 10 nCi/g, or may be concentrated in smaller, separate pockets. About 53% of the buried waste is located at Area G with about 32% at Area C, and about 15% at TA-21 (Areas A, B, T, and V).

In preparing this document, the identified waste exhumation facility is basically the same as that proposed for the exhumation of the buried waste at INEL (Ref. B-1). Also, the exhumation operations are similar to the INEL operations with some exceptions: The Los Alamos waste disposal sites are located on terrain that is not as level as at INEL, which may present some problems for moving structures of this size. Some of the waste disposal shafts are up to 20 m (65 ft) deep and are filled with a single concrete plug 2.4 m (8 ft) in diameter; and the Los Alamos disposal sites are located at several separate areas creating problems in moving the exhumation structure from site to site. Also, waste exhumed for processing would have to be transported over public roads to a centralized WPF.

As a result of these conditions, three complete exhumation facilities would be required: one each for Areas C and G and one for the combined Areas A, B, T, and V at TA-21. The time required to complete the waste exhumation operations (see Fig. B-2) are 8-1/2 yr at TA-21, 12-1/2 yr at Area C, and 14-1/2 yr at Area G. If Areas A and B were omitted, it is possible that a separate facility in TA-21 might not be required. However, this could complicate other items; for example, transportation.

The exhumation facility, as conceived (see Fig. B-3), is a double-walled structure to provide containment of the waste during exhumation operations. Air pressure below ambient would be maintained between the outer and inner walls with a still lower pressure maintained within the building. Thus, air leakage would be into, rather than out of the structure. Air would travel from clean areas into potentially contaminated areas and then exhausted from the building through a roughing filter and two HEPA filters before being released in the atmosphere.

A seal mechanism would seal the building to the ground during exhumation operations. The building would be equipped with retractable wheels to support its weight during relocation operations. The wheels are similar to those used in industry to facilitate moving large, heavy objects. Movable, channel-shaped steel tracks would be provided to permit the building to be moved on a year-round basis. A production transfer airlock, a vehicle airlock, a personnel airlock, two emergency exits, and a backfill port would be provided through the building walls. Electrical power, heating, ventilating, and other auxiliary support systems would be provided from portable trailer-mounted facilities.

The initial step of the exhumation operation would be to level and stabilize an area on one end of a disposal site to provide a working surface for erecting the exhumation building. The soil cover over the waste area would be leveled sufficiently and stabilized to allow movement of the building. (Stabilization is required for the building seal mechanism to effectively seal the building to the

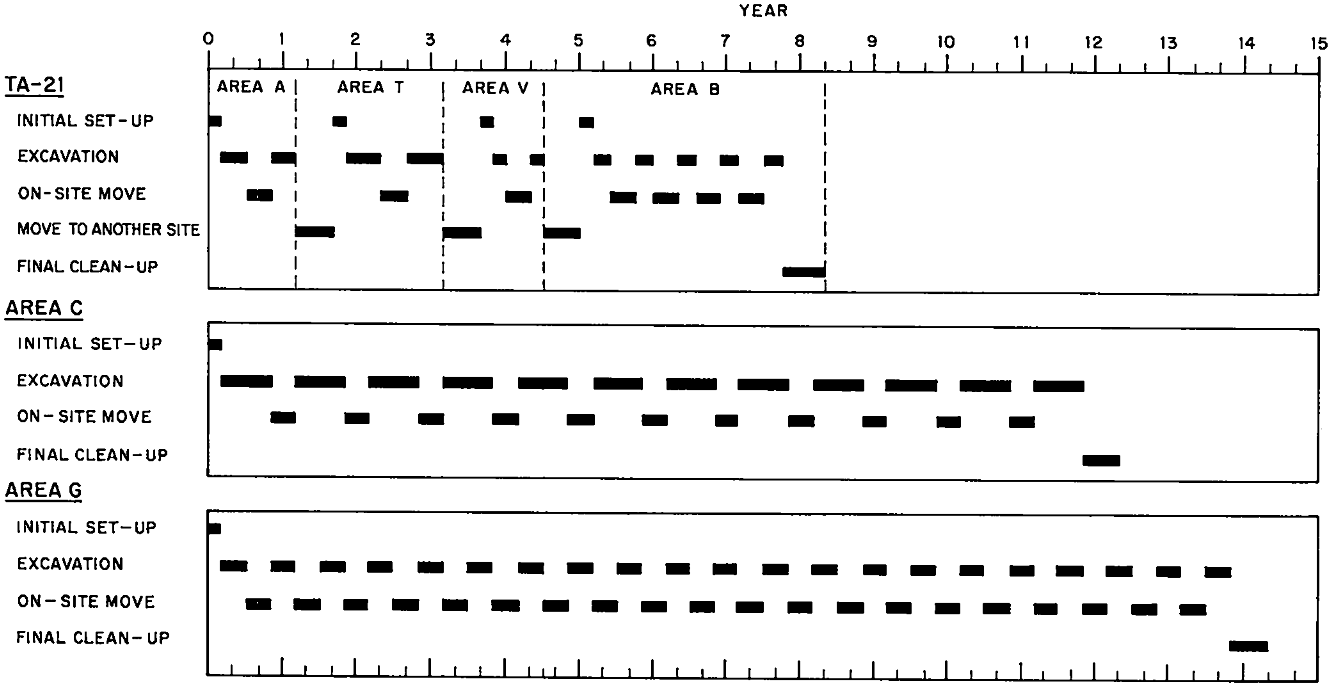

Fig. B-2.
Buried waste excavation schedule.

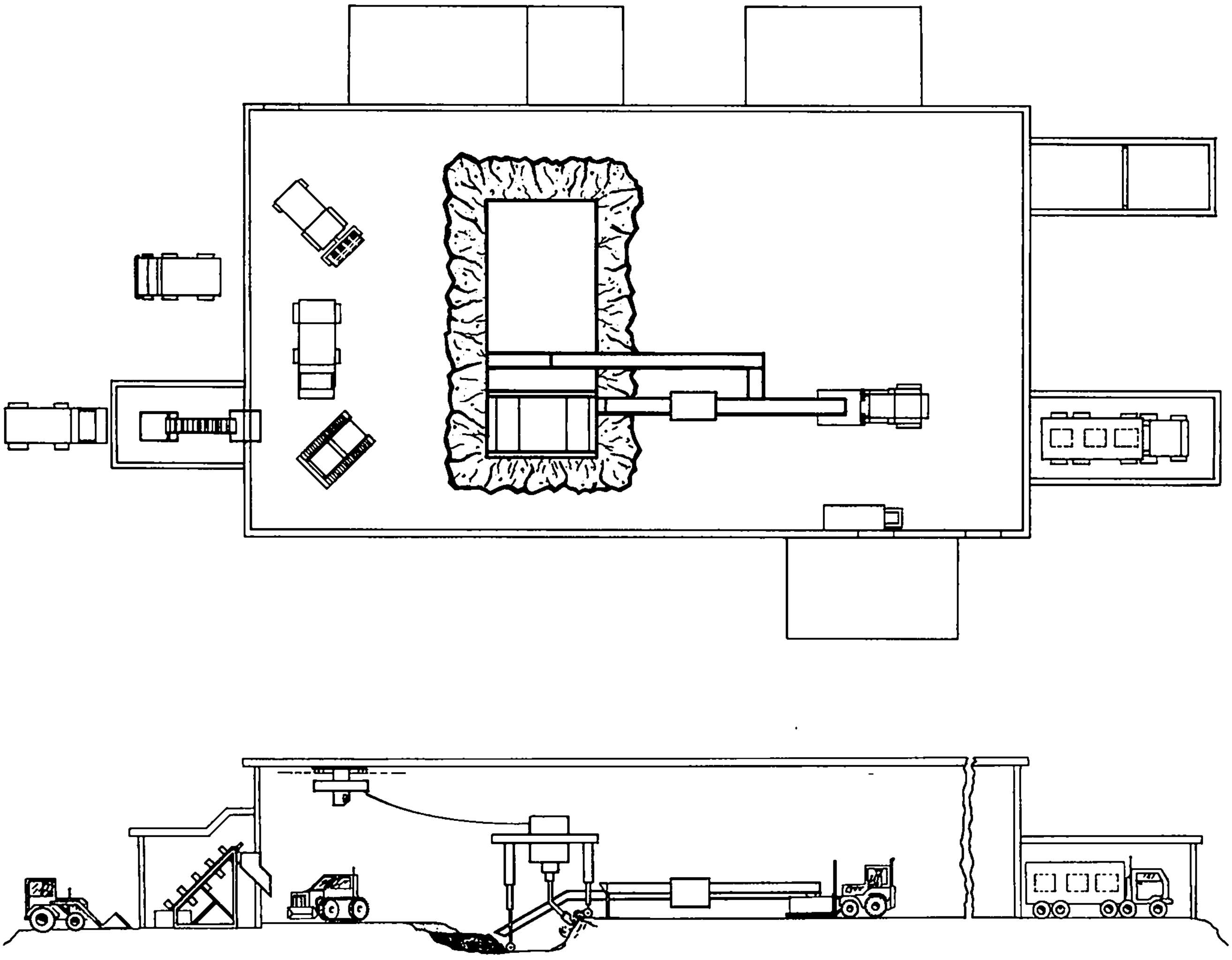

Fig. B-3.
Buried waste exhumation facility.

ground during exhumation operations.) After the equipment has been checked out, the exhumation operations would commence.

All operations within the exhumation building would be performed by personnel directly controlling the exhumation equipment from environmentally protected cabs located on the equipment. Removable shields would be mounted on the equipment cabs in case they are needed. Standard radiation protection procedures would be employed for personnel who must enter the exhumation facility to perform special tasks.

Specific exhumation procedures would vary with the size of the pits and the type and condition of the waste. For exhumation from the pits and absorption beds, a hole would be excavated at one end of the waste location to facilitate excavation and removal of the waste and contaminated soil from the pit or bed. For removal of the cemented waste in shafts, a similar procedure would be used to remove the soil from around the cemented columns. After exposing about 1 m (3 ft) of columns, special equipment would be used to break up the concrete. (The concrete is expected to be of low quality.) After removal of the broken-up concrete, the process would be repeated at a greater depth. Care would have to be taken by proper shoring or sloping of side walls to avoid cave-ins.

After exhumation, large waste items would be set aside for a special assay to determine the TRU content. If found to contain 10 or more nCi/g of TRU, they would be resized to fit in the 1.2 by 1.2 by 2.1-m

(4 by 4 by 7-ft) transfer containers. Large LL waste items would be transported to a high-capacity waste assay system. Waste determined to contain 10 or more nCi/g of TRU would be diverted to a packaging station for loading into the transfer containers. The LL waste would continue on to a portion of the pit already excavated. (The only exception is that the LL waste from Area B would be relocated.) Each container would normally be filled to approximately 80% of its volume unless limited by weight. When full, each container would be moved by a transport vehicle to the production transfer airlock where the containers will be monitored for gamma radioactivity. Containers with surface readings higher than 200 mrem/h will be shielded. If the waste is to be transferred to the WPF for further treatment or to the Los Alamos deeper-pit disposal site, the containers would be loaded into a special enclosed onsite transfer vehicle. TRU waste going directly to an offsite disposal site would be placed in an overpack that meets appropriate state and federal standards.

5. WASTE PROCESSING FACILITIES (WPF)

The WPFs proposed in this study would process and package TRU waste to meet disposal standards. The facilities are sized for processing retrieved and exhumed TRU waste (Fig. B-4) and for stored waste only (Fig. B-5). A third facility (Fig. B-6) is described herein for resizing and packaging (RPF)

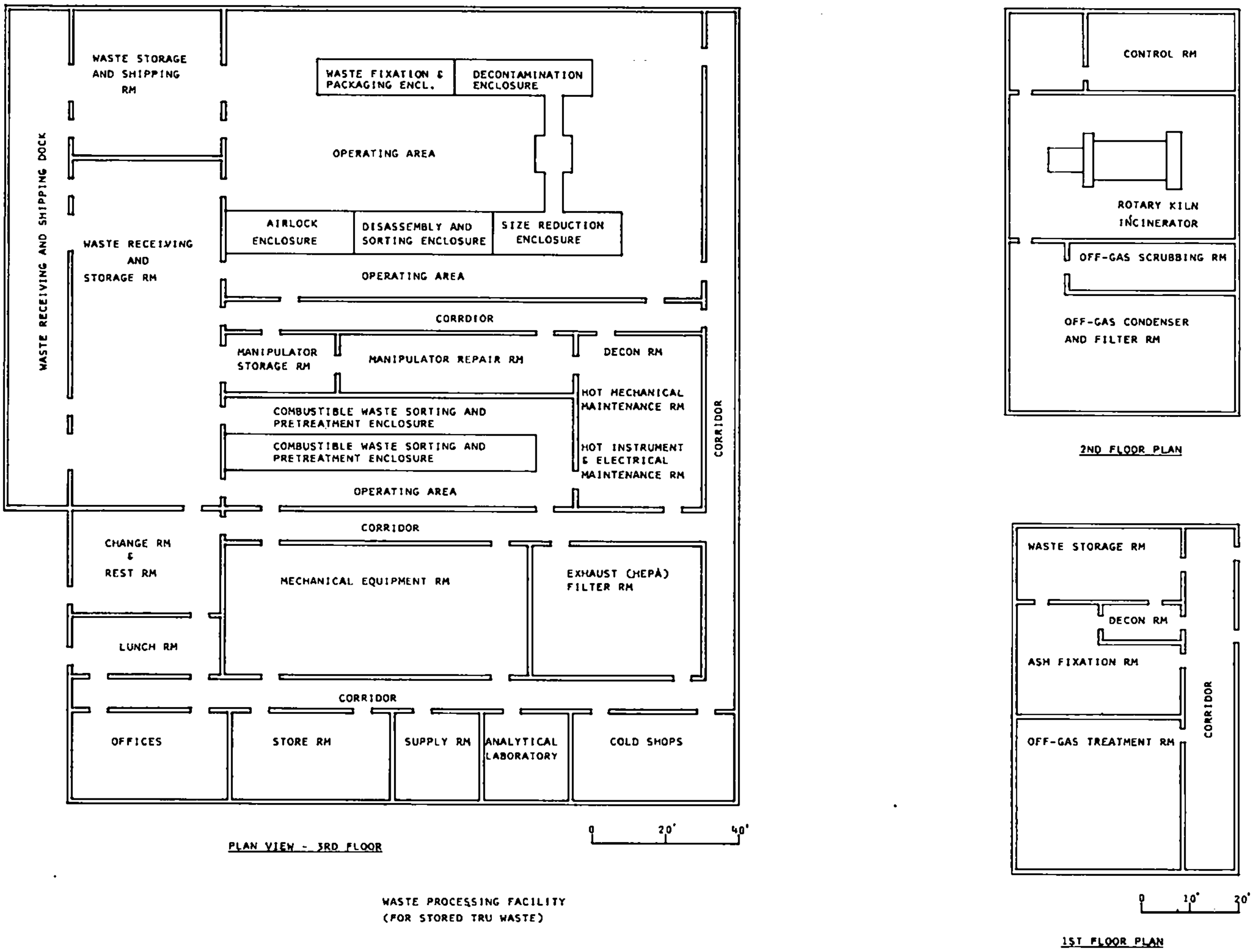

Fig. B-4.
Waste processing facility for buried and stored waste.

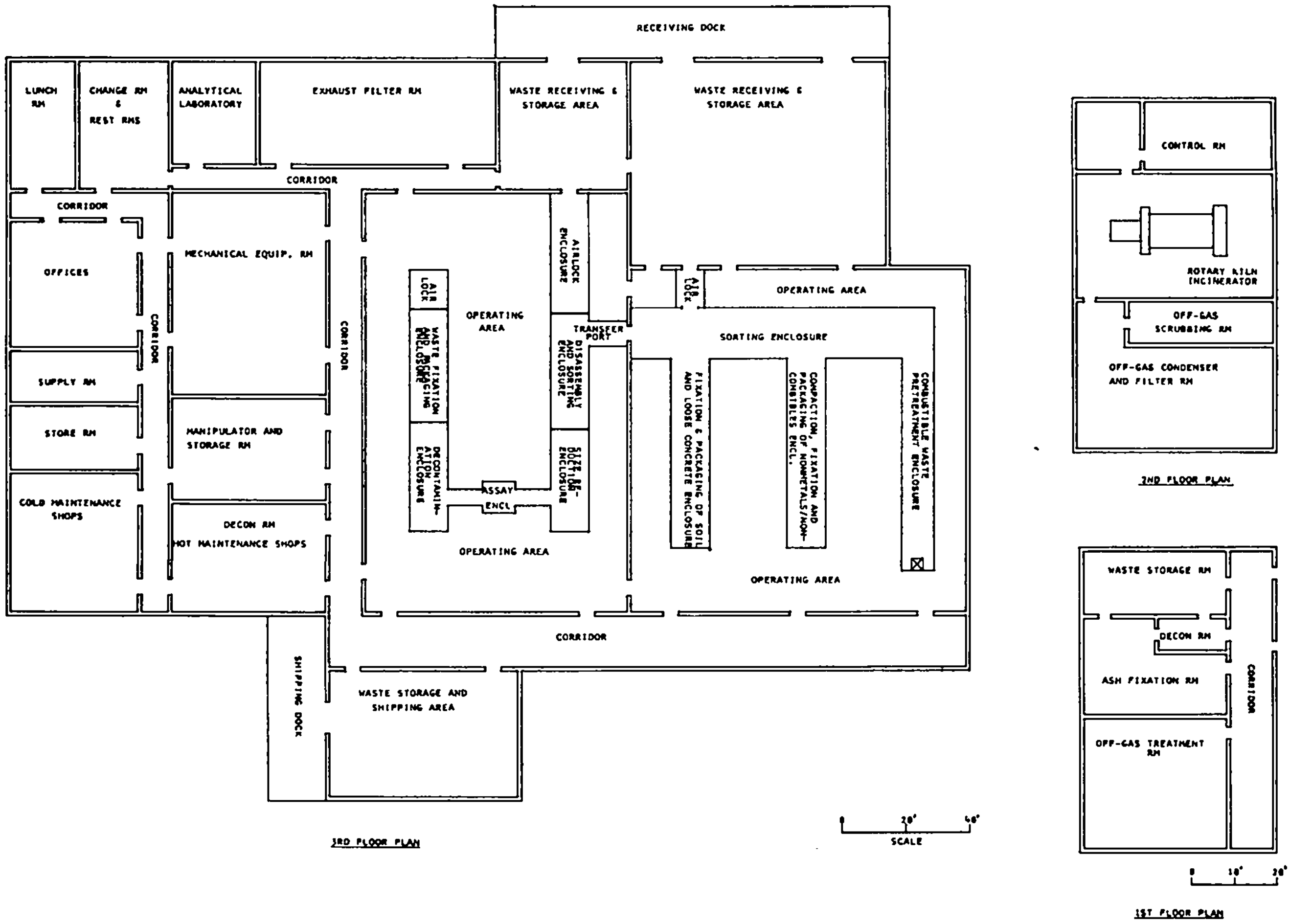

Fig. B-5.
Waste processing facility for stored waste.

waste now stored in boxes that would not be acceptable at the offsite federal waste disposal facility because they are oversize.

The WPF would be designed in accordance with applicable federal regulations and standards to protect the public and the operating personnel. Areas of the building containing more than 500 g of TRU elements would be designed and constructed so that its decommissioning would be easier at the end of its useful life. The facility would be designed for a 20-yr lifetime, and process equipment would be designed to be readily replaceable or have a design lifetime of 20 yr. Both of the two WPF's proposed are three-story structures to take advantage of gravity in waste transfers.

5.1 WPF for Stored and Buried Waste

A WPF with extensive sorting and waste fixation capability would be required for exhumed/stored waste because of the wide variety of exhumed materials and large amounts of loose soil and broken concrete. Material flow through the WPF is shown in Fig. B-7. Fixation and encapsulation presently proposed would be accomplished by mixing the waste with concrete. Encapsulation in concrete could also be applied to other exhumed noncombustibles if required. The incinerator proposed is the rotary kiln type because of its tolerance for noncombustibles, thus simplifying the pretreatment steps such as sorting. The processing area would be 3765

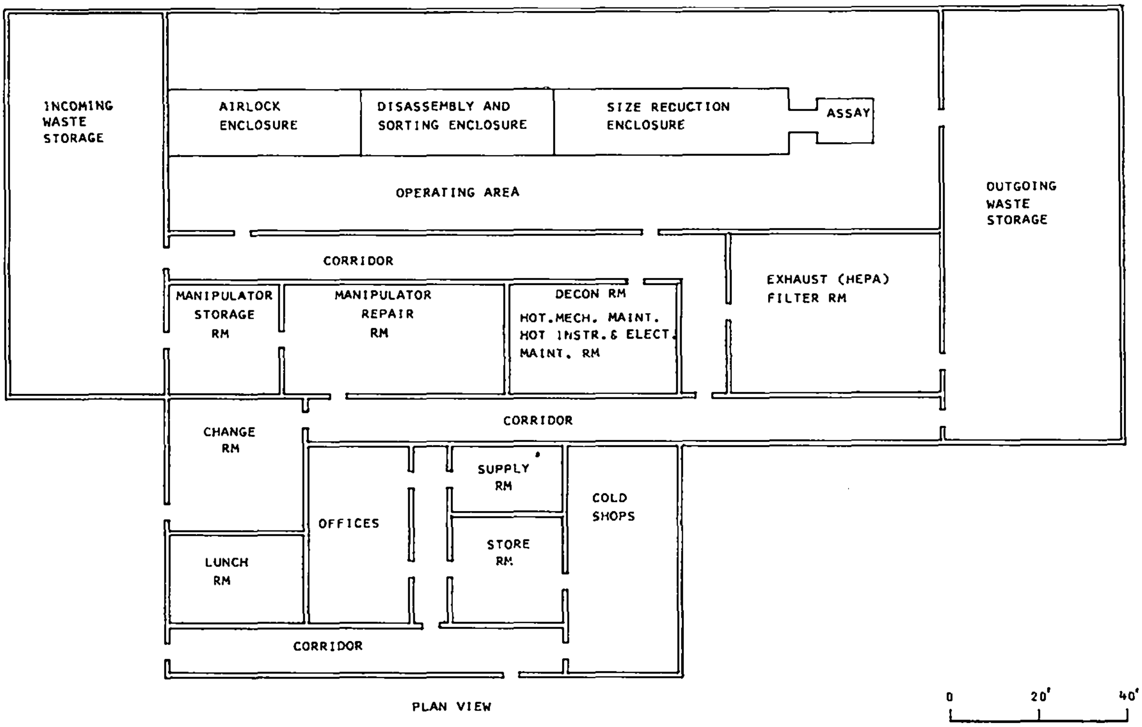

Fig. B-6.
Resizing and packaging facility for stored waste (Alternatives 4, 8, and 12).

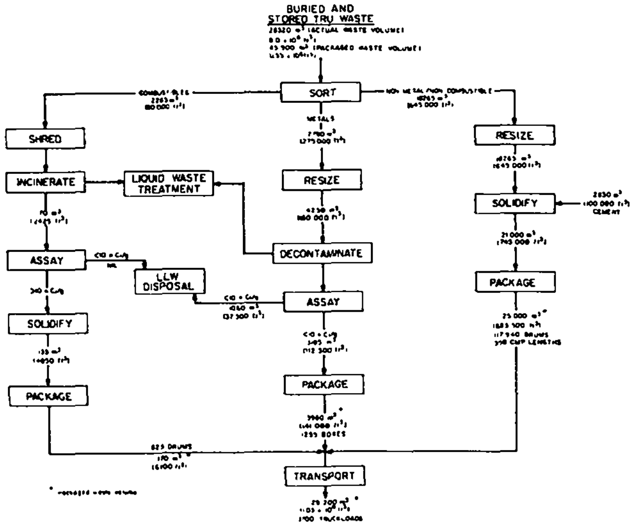

Fig. B-7.
Flow of stored and buried waste through WPF.

m² (40 550 ft²) with an additional 1630 m² (17 570 ft²) for support areas.

Operations at the WPF for exhumed and stored waste would include the following steps.

1. Sort waste into combustibles, metals, and nonmetals/noncombustibles. The waste preparation operation must be capable of sorting 28 320 m³ (1.0 × 10⁶ ft³) of waste in a 15-yr period based on a 3-shift/day and 5-day/week operation.

2. Incinerate the combustibles in a rotary kiln incinerator. The incinerator proposed in this study would require a capacity of at least 7 kg/h (15 lb/h) to handle the expected 2265 m³ (80 000 ft³) of combustible TRU waste during the 15-yr period of operation. The off-gas cleanup system would be similar to that used for the Los Alamos Controlled-Air Incinerator, thus taking advantage of development work already accomplished.

3. Decontaminate metal waste and separate into TRU and LL wastes. The decontamination facilities would operate 1 shift/day and 5 days/week to process 4250 m³ (150 000 ft³) of metal waste over the 15-yr period.

4. Compact materials that may not be suitable for incineration or decontamination, such as used drums and HEPA filters.

5. Immobilize dispersible materials such as broken pieces of concrete, soil, and incinerator ash. The immobilization process must be capable of handling 18 400 m^3 (650 000 ft^3) in a 15-yr period based on a 3-shift/day and 5-day/week. The feed would consist primarily of ash from the incinerator, soil from exhumation, and broken concrete containing TRU waste.

6. Reduce the size of noncombustibles if advantageous for packaging or decontamination.

7. Package all waste forms for shipment to terminal disposal.

5.2 WPF for Stored Waste Only

The WPF for processing stored waste only would require 3120 m^2 (33 580 ft^2) processing area and 1125 m^2 (12 100 ft^2) for support areas. Sorting the waste would be simpler and the volume processed would be less. Figure B-8 depicts the flow through the smaller WPF. Operations would be similar to those at the large WPF with the following differences.

The waste preparation step should be capable of handling boxes as large as 9 by 3 by 2.4 m (30 by 10 by 8 ft) and resizing the contents if necessary. Total throughput for this facility would be 9630 m^3 in a 5-yr period.

The decontamination operation should be capable of processing 2550 m^3 (90 000 ft^3) of metal waste in a 5-yr period assuming 2-shift/day and 5-day/week operations.

The rotary kiln incinerator for 1130 m^3 (40 000 ft^3) of combustibles should have a capacity of at least 7 kg/h (15 lb/h) to process the waste in 5 yr assuming a 50% on-time.

Immobilization (fixation) would be required for about 28 m^3 (1000 ft^3) of incinerator ash, plus a lesser but unknown amount of ash residues from the processing of plutonium now in storage.

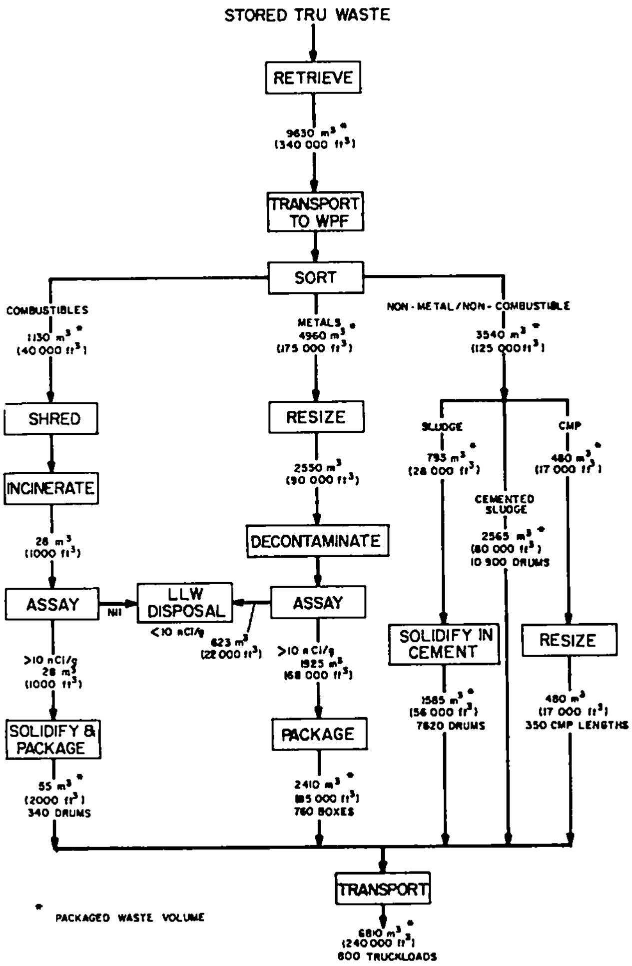

Fig. B-8.
Flow of stored waste through WPF.

5.3 Waste Resizing and Packaging Facility (RPF)

The RPF for retrieved stored waste uncrates waste now packaged in boxes as large as 9 by 3 by 2.4 m (30 by 10 by 8 ft), reducing the size so that it can be packaged in containers acceptable at an offsite terminal repository. This facility would be required for Alternatives 4, 8, and 12, which involve the retrieval of stored waste for shipment to an offsite terminal repository without processing, that is, without decontamination or incineration. The RPF would be designed in accordance with DOE Manual, Appendix 6301, Part I. A total of 1700 m³ (60 000 ft³) of packaged waste would be processed through the RPF in a 2-yr period (Fig. B-9). The RPF would contain about 1700 m² of surface area as a single-story building.

6. TRANSPORTATION

6.1 Off-Site Transportation

Waste to be sent to an offsite geological repository, assumed to be in southeastern New Mexico, would be shipped by truck because there is no rail line to Los Alamos. Accident-resistant DOT Type-B shipping containers would be required for structural and heat protection of the TRU waste in accident conditions as defined in Appendix B, 10 CFR 71, Hypothetical Accident Conditions. Shipping containers such as the Supertiger, the TRUPACK being developed by Sandia Laboratories (Ref. B-2) or some other similar licensed Type-B container are assumed to be available at the time needed and will have capacity for thirty-six 210-ℓ (55-gal) drums or four 1.2- by 1.2- by 2.1-m (4- by 4- by 7-ft) boxes. As future waste shipping containers are developed, it may be determined that other size boxes are preferable; but for study purposes, any such changes are not expected to greatly affect the costs.

To calculate the costs and risks for waste transportation, a specific route was assumed to the disposal site (Fig. B-10). Because waste shipments would not be initiated for several years, highway changes may make other routes preferable to the one assumed. The largest cities along the route include Santa Fe, Roswell, and Carlsbad, New Mexico. A one-way trip of about 540 km (335 mi) would require about 8 h.

6.2 On-Site Transportation

On-site transportation would involve shipments of unprocessed waste to the WPF or directly to onsite disposal if processing were not required. The three locations that would be candidates for exhumation are all several miles apart and the townsite separates one from the other two. If existing roads were used,

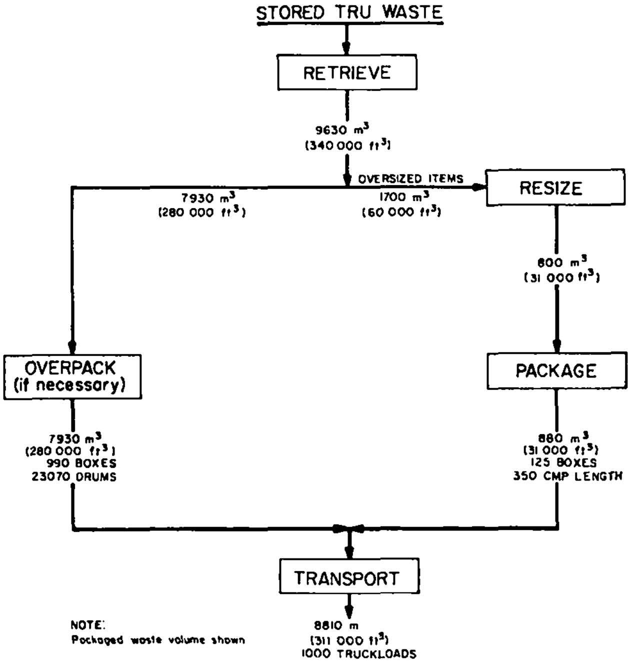

Fig. B-9.
Flow of stored TRU waste through RPF.

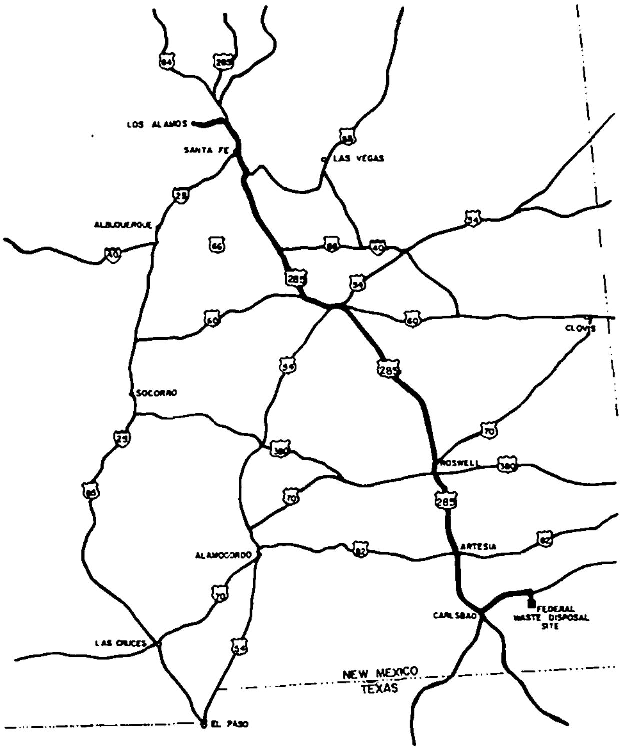

Fig. B-10.
Proposed route to federal waste disposal site.

waste shipments from at least one location would be through the townsite. Although TRU waste has been transported through the town for many years, the volumes that would arise from exhumation would probably require that the time of the shipments be selected to avoid heavy traffic hours. The packages from either the exhumation site or the WPF could be transported on a roller-system flatbed truck with appropriate rigging for securing the load.

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2. J. M. Freedman, S. H. Sutherland, and R. G. Eakes, "Contact-Handled Transuranic Waste Transportation," Proc. Am. Nucl. Soc. Trans., 1979 Winter Meeting, San Francisco, California, November 11-15, 1979, Vol. 33, pp. 450-451.

APPENDIX C

ENGINEERED IMPROVEMENTS

GENERAL

The natural disaster scenarios postulated in this Appendix for the Los Alamos vicinity assess the improved confinement possible through Engineered Improvements. These scenarios are also addressed in Sec. 7.1.4 of this study, in relation to the possible radiological health implications.

The engineered improvements enhance the long-term stability of the disposal sites and reduce the probability of releasing to the environment. Potential mechanisms for activity release include erosion, radionuclide migration, intrusion by man or animal, tornadoes, earthquakes, meteorites, aircraft strikes, and volcanos. Because of the geological characteristics at the Los Alamos waste disposal sites, there appears to be little serious threat of the activity being released laterally or downward through the tuff surrounding the sides and bottoms of the disposal pits. Thus the improvements considered involve the placement of engineered barriers atop the waste sites. Various materials considered for barrier construction included concrete, asphalt, clay, and tuff. Tuff was selected because calculations show it to be as effective as the other materials. Tuff is readily available locally in the large volumes required, whereas other materials must be trucked into Los Alamos from outside the immediate area.

Each of the release mechanisms, except volcanos and intrusion by man, were examined to determine the depth of compacted tuff that would be required to protect the waste. It was concluded that it is not feasible to protect against a volcanic eruption from below the waste. An eruption at a distance could possibly enhance the waste containment by providing additional cover. Absolute prevention of intrusion by man is virtually impossible. Therefore, these two criteria were not considered to be limiting factors.

Erosion

The vertical and horizontal erosion rates of the Los Alamos mesa tops have been estimated to be 2.2 cm (0.87 in.)/1000 yr and 10 cm (4 in.)/1000 yr, respectively (Ref. C-1). At these erosion rates and without any engineered improvements, the surface of the buried waste would be exposed in about 50 000 yr, while the lateral erosion would expose the waste nearest the canyon rim during the following 100 000 yr. Implementation of the proposed engineered improvements would greatly reduce the rate of vertical erosion; in fact, the riprap cover may not only inhibit erosion, but affect an accumulation of cover.

Radionuclide Migration

Tests conducted at Los Alamos have shown that there is little or no migration of radionuclides from subsurface water movement at the burial sites (Ref. C-2). Thus if care is taken to provide proper drainage of surface water from the waste disposal sites when the engineered improvements are implemented so there is no source for subsurface water, then radionuclide migration should not be an area of serious concern. Another mechanism for radionuclide migration is plant uptake. The bulk of a plant's root system is concentrated in the upper 1 m (3.3 ft) of soil. Only a very small percentage of the tree root biomass is found at depths greater than 1.5 m (5 ft) with the bulk of the root hairs responsible for water and nutrient uptake found in the upper 15 cm (6 in.) (Ref. C-1). Thus with a minimum of 1.5 m (5 ft) of compacted tuff cover, plant uptake should not present a problem. Should it be a problem, it would be detected during the 100 yr of surveillance, and corrective action could be taken.

Animal Intrusion

The probability of animal intrusion, like intrusion by man, is difficult to quantify or predict over the long term. Most of the rodents now inhabiting the area are capable of burrowing through 2.1 m (7 ft) of uncompacted tuff without much difficulty. It is also true that the proposed riprap could trap soil, thus attracting vegetation and, in turn, rodents.

A series of experiments are being conducted by the Laboratory Life Science Group to study the habits of rodents in locations representative of solid waste burial areas. These experiments will provide data that would answer some of the questions regarding animal intrusion. However, it is difficult, if not impossible, to predict what types of animals might evolve during thousands of years.

Tornados

The probability of a tornado occurring at Area G is less than 1.5×10^{-6}/yr (Ref. C-1). The greatest damage resulting from tornados occurs to aboveground structures because tornados have little excavating capability. The greatest hazard to the buried waste would be cover penetration by flying missiles (pipe, planks, etc.). Even if these should penetrate the waste overburden, the crater would not be large enough to expose the waste. Less than 0.3 m (1 ft) of overburden would be required to provide protection for a maximum pressure drop of 5.2 kPa (0.75 psi) (Ref. C-3).

Earthquakes

Past studies (Refs. C-1 and C-4) estimate that ~130 earthquakes of an average magnitude of 6.7 (Richter) may have occurred along fault lines west of Los Alamos in the past 1.1×10^6 yr. An earthquake of magnitude 6.7 could be predicted for about once every 8200 yr, producing a displacement of ~1 m (3-1/4 ft). This yields an occurrence probability of $\sim 1.3 \times 10^{-4}$/yr. Wastes currently located in burial pits are covered by a minimum thickness of 1 m (3 ft) of crushed tuff (usually closer to 1.5 m (5 ft)). Thus, if a burial site was located on an active fault zone, the probability that the waste would be exposed to the atmosphere by ground displacement caused by an earthquake is $\sim 1.3 \times 10^{-4}$/yr or about once every 8 200 yr. There are no known faults intersecting any burial sites, therefore, expected earth displacement would be predictably less than for the fault zone. Also, with a minimum total cover of 2.1 m (7 ft) over the waste as proposed for engineering improvements, sufficient vertical displacement to expose the waste would not be expected. The worst damage would be ground shifting and cracking, leaving openings from the surface to the waste. Eroding material would eventually fill these crevices if corrective maintenance were not provided.

Meteorites

Wheeler, Smith, and Gallegos report the probability of a meteorite with a mass of at least 0.6 kg (1.3 lb) striking the operation area of Area G is $\sim 10^{-7}$ impacts/yr (Ref. C-1). A meteorite of this size could create a crater 3 m (9.8 ft) in diameter and penetrate through ~1 m (3.3 ft) of the semicompacted burial ground cover. The consequences of such an impact are expected to be minor. For the proposed alternative, the waste would be protected by at least 0.3 m (1 ft) of the original cover material, 1.5 m (5 ft) of compacted tuff plus 0.3 m (1 ft) of riprap for a total cover of 2.1 m (7 ft). Thus the probability of a meteorite of sufficient size striking the disposal sites and penetrating more than this depth is $<10^{-7}$ impacts per yr, or sufficiently small to be considered not credible.

Aircraft Crash. The probability of an aircraft crashing into a nuclear power plant has been evaluated as shown in Table C-1, which was adapted from Ref. C-5.

A number of factors affect these probabilities, such as the size of the airport, the volume and size of traffic, the relationship of the plant to air corridors, and the direction of the plant from the airport. The relationship between probabilities (P), distance (D) of plant from airport, and the area (A) or size of the plant can be defined by the equation

$$\frac{P_1 D_1^2}{A_1} = \frac{P_2 D_2^2}{A_2} .$$

Using this equation, the probabilities for an aircraft crashing into the waste sites at TA-21 (Areas A, B, T, and V) and Areas C and G are shown in Table C-2.

The engineered improvement alternative would provide adequate protection against a small aircraft striking the disposal site. Thus even though the probability is $>1 \times 10^{-7}$, the consequences would be expected to be negligible. No credit has been taken for the fact that the Los Alamos Airstrip is a closed facility (that is, no aircraft are permitted to use the facility without prior approval). Nor has credit been taken for the fact that Los Alamos is a restricted air space, which means no general aircraft may fly over the Laboratory area at <12 000 ft above mean sea level, which corresponds to ~6 000 ft above the local terrain.

For large aircraft, the probabilities of an aircraft striking sites C and G are slightly $>1 \times 10^{-7}$, and for the TA-21 sites the probability is ~50 times higher. Taking into consideration that there is a low volume of traffic at the Los Alamos Airport, only one runway is available, TA-21 is not in the landing pattern, the airport is closed during bad weather conditions, and the use of large aircraft is limited, the probability of a crash at the TA-21 disposal sites approaches a non-credible accident.

TABLE C-1

PROBABILITY OF AIRCRAFT STRIKING NUCLEAR POWER PLANT (Ref. 6)

Aircraft Size kg (lb)	Location of Plant	
	Beyond 8 km (5 mi) of Airport	Within 8 km (5 mi) of Airport
Small <5440 (12 500)	1.4×10^{-8}	3.3×10^{-6}
Large >5440 (12 500)	4.6×10^{-7}	1.1×10^{-6}

TABLE C-2

PROBABILITY OF AIRCRAFT STRIKING WASTE DISPOSAL SITE

Aircraft Size	Waste Site		
	TA-21	Area C	Area G
Small	1.6×10^{-4}	5.6×10^{-6}	6.9×10^{-6}
Large	5.3×10^{-6}	1.8×10^{-7}	2.3×10^{-7}

REFERENCES

1. M. L. Wheeler, W. J. Smith, and A. F. Gallegos, "A Preliminary Evaluation of the Potential for Plutonium Release from Burial Grounds at Los Alamos Scientific Laboratory," Los Alamos Scientific Laboratory report LA-6694-MS (February 1977).

2. "Nuclear Waste Management Technology Development Program," Los Alamos Scientific Laboratory progress report LA-7501-PR (unpublished data).

3. Environmental Surveillance (Group H-8), "Environmental Monitoring in the Vicinity of the Los Alamos Scientific Laboratory—Calendar Year 1972," Los Alamos Scientific Laboratory report LA-5184 (1973).

4. Environmental Surveillance (Group H-8), "Transuranic Solid Waste Management Programs—July-December 1974," Los Alamos Scientific Laboratory progress report LA-6100-PR (October 1975).

5. I. B. Wall, "Probabilistic Assessment of Aircraft Risk for Nuclear Power Plants," Nuclear Safety 15, 276-284 (May-June 1974).

APPENDIX D

DETAILS OF RADIATION DOSE ESTIMATES

This appendix tabulates the details of the integrated man-rem impact reported in the main body of the document. The calculations for the doses listed here are based on the assumptions listed in Sec. 4.4, and the methodology described in Secs. 7.1.1-7.1.7. Occupational doses from normal operations and accidents, and population doses from accidents were calculated for each option. Occupational doses for normal operations were estimated as a function of the waste forms and volume handled, the radiation potential, and the operational tasks required. The resulting external (gamma) doses are reported in man-rem in Tables D-1 through D-11.

TABLE D-1

OCCUPATIONAL EXTERNAL DOSES FOR NORMAL OPERATIONS

Option B3. Exhume Buried Waste (TA-21, Area A)

Waste Description and Notes	Total Volume and Waste Form	Task	Volume Handled (m^3)	Per Cent of Total (man-days)	Task (man-days)	Per Cent of Total Dose	Occupational Dose (man-rem)
Area A pits are filled with combustibles and noncombustibles mixed with soil backfill. It is estimated exhumation would require two shifts per day, 250 days per year. Each shift requires a basic crew of 17 workers. In each of the six areas, the exhumation workers are estimated to receive small doses in varying amounts depending on task assignment. The average dose for workers in the area multiplied by the man hours required to exhume the area gives the total dose. Percentages of the total dose are assigned to the tasks in relation to the potential that each task presents for exposure. The dose for each area will vary and for Area A is estimated to be 0.6 mrem/man/day. To complete the Area A exhumation, 1.8 years (440 work days) would be required, or a total of 15 000 man days.	14 000 m^3 (500 000 ft^3) Miscellaneous debris mixed with soil	Exhume	14 000	36	5 400	35	3.1
		Separate oversize items	380	5	740	13	1.1
		Size reduce for transfer container	350	4	590	10	0.9
		Assay	14 000	10	1 500	15	1.2
		Return non-TRU to low level burial	13 000	25	3 700	5	0.4
		Load TRU into transfer containers	a	10	1 500	20	1.7
		Decontaminate and move exhumation building and equipment		10	1 500	2	0.5
			TOTAL	100	15 000	100	8.9

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[a] The TRU nuclide inventory and TRU waste volume in the Area A pits are not known, but are thought to be very low, probably only a few hundred cubic meters. However, in the absence of a better number, the assumption that 5% of the wastes are TRU was made to complete the calculations. The assumed 700 m^3 of TRU waste in the Area A pits is many times too high.

TABLE D-2

OCCUPATIONAL EXTERNAL DOSES FOR NORMAL OPERATIONS

Option B3. Exhume Buried Waste (TA-21, Area B)

Waste Description and Notes	Total Volume and Waste Form	Task	Volume Handled (m^3)	Per Cent of Total (man-days)	Task (man-days)	Per Cent of Total Dose	Occupational Dose (man-rem)
Area B has several pits that were used for waste burial and are not well defined. Combustibles and noncombustibles are mixed with soil backfill. It is estimated the exhumation will require two 17-worker shifts per day. For Area B, the dose is estimated to be 0.6 mrem/man/day. To complete the exhumation, 3.0 years (750 work days) are required, or a total of 26 000 man days.	21 000 m^3 (750 000 ft^3) Debris mixed with soil	Exhume	21 000	34	8 700	35	5.4
		Separate oversize items	570	4	1 000	13	2.0
		Size reduce to fit transfer container	570	4	1 000	10	1.5
		Assay	21 000	9	2 300	15	2.2
		Package low-level fraction and transfer to another disposal site at Los Alamos	21 000	30	7 700	15	2.2
		Load TRU into transfer containers	430	9	2 300	10	1.5
		Decontaminate and move exhumation	---	10	2 600	2	0.5
			TOTAL	100	26 000	100	15.0

TABLE D-3

OCCUPATIONAL EXTERNAL DOSES FOR NORMAL OPERATIONS

Option B3. Exhume Buried Waste (TA-21, Area T)

Waste Description and Notes	Total Volume and Waste Form	Task	Volume Handled (m^3)	Per Cent of Total (man-days)	Task (man-days)	Per Cent of Total Dose	Occupational Dose (man-rem)
Area T contains absorption beds and shafts. There are four absorption beds and they consist of stone, gravel, and sand placed in trenches. There are 62 unlined shafts filled with TRU-contaminated waste that was fixed in a cement paste. It is estimated the exhumation would require two 17-worker shifts per day. For the exhumation of the beds, it is estimated the dose would be 1.04 mrem/man/day, and for the shafts, it would be 1.6 mrem/man/day. To complete the exhumation, 2 years (500 work days) would be required, or a total of 17 000 man days; 6 800 days are attributed to the absorption beds and 10 000 to the shafts.	2 700 m^3 (96 000 ft^3) of absorption bed stone, gravel, sand, and soil	**For Beds**					
		Exhume	2 700	20	3 400	17	4.0
		Assay	2 700	5	850	6	1.5
		Return LL to burial	2 500	10	1 700	3	0.6
		Load TRU into transfer containers	170	5	850	4	1.0
			SUB TOTAL	40	6 800	30	7.1
	3 800 m^3 (135 000 ft^3) of cement monolith forms 1.8 m to 2.4 m diameter by 20 m deep	**For Shafts**					
		Exhume	3 800	25	4 300	30	7.0
		Size reduce cement monoliths	3 800	5	850	16	3.6
		Assay	3 800	5	850	13	3.1
		Return LL to burial	370	2	340	1	0.3
		Load TRU into transfer containers	3 500	13	2 200	8	1.8
		Decontaminate and move exhumation building and equipment	---	10	1 700	2	0.5
			SUB TOTAL	60	10 000	70	16.0
			GRAND TOTAL	100	17 000	100	23.0

TABLE D-4

OCCUPATIONAL EXTERNAL DOSES FOR NORMAL OPERATIONS

Option 3B. Exhume Buried Waste (TA-21, Area V)

Waste Description and Notes	Total Volume and Waste Form	Task	Volume Handled (m^3)	Per Cent of Total (man-days)	Task (man-days)	Per Cent of Total Dose	Occupational Dose (man-rem)
Area V has three absorption beds consisting of stone, gravel, and sand in trenches. It is estimated exhumation would require two 17-worker shifts per day. For Area V, the dose is estimated to be 0.6 mrem/man/day. To complete the exhumation, 1.25 years (310 work days) could be required, or a total of 11 000 man days.	4 300 m^3 (150 000 ft^3) of absorption bed stone, gravel, sand, and soil	Exhume	4 300	38	4 000	47	3.0
		Assay	4 300	10	1 000	11	0.7
		Return LL to burial	4 000	37	3 900	25	1.6
		Load TRU into transfer containers	[a]	5	530	9	0.6
		Decontaminate and move exhumation building and equipment	---	10	1 000	8	0.5
			TOTAL	100	11 000	100	6.4

---

[a] If the 5% TRU is estimated, this calculates to about 210 m^3, which is about 41 grams of ^{239}Pu. This is much higher than inventory calculations estimate. In reality, the actual amount of Pu present should be much lower, probably about 0.1 Ci, in about 6 m^3 of waste volume.

TABLE D-5

OCCUPATIONAL EXTERNAL DOSES FOR NORMAL OPERATIONS

Option B3. Exhume Buried Waste (TA-50, Area C)

Waste Description and Notes	Total Volume and Waste Form	Task	Volume Handled (m^3)	Per Cent of Total (man-days)	Task (man-days)	Per Cent of Total Dose	Occupational Dose (man-rem)
Area C contains 6 pits and 107 shafts with buried waste that is potentially TRU-contaminated. The waste is both combustible and noncombustible. The waste buried in the pits was originally packaged in metal drums or in plastic bags, and/or placed within cardboard boxes. The condition of these containers is considered to be deteriorated so that packages could easily be broken on exhumation. There are 97 unlined and 10 steel- and concrete-lined shafts filled with combustible and noncombustible wastes. The waste in the shafts is high in β and α activity and could require remote handling. It is estimated that the exhumation would require two 17-worker shifts per day. For the exhumation of the pits, it is estimated the dose would be 1.04 mrem/man/day, and for the remote handled shaft waste 4.0 mrem/man/day. To complete the exhumation, 12 years at 250 work days per year would be required; 10.8 years are attributed to the pit waste and 1.2 years to the shaft waste.	**Pit Waste:**	**Pits:**					
	100 000 m^3 (3 700 000 ft^3)	Exhume	100 000	33	34 000	24	33
	19% metals	Separate oversize items	2 800	2	2 000	9.0	12
	8% nonmetals—noncombustibles	Size reduce to fit transfer container	2 800	4	4 000	6.9	9.4
	21% combustibles	Assay	100 000	7	7 100	10	14
	52% soil	Return LL to burial	99 000	29	30 000	3.5	4.7
		Load TRU into transfer containers.	4 900	5	5 100	14	19
		Decontaminate and move exhumation building and equipment.	---	10	10 000	2.1	3.0
			SUB TOTAL	90	92 000	70	95
	Shaft Waste:	**Shafts:**					
	140 m^3 (4 800 ft^3) unlined combustible and noncombustible debris. High activity. 5 m^3 (180 ft^3) Steel- and concrete-lined combustible and noncombustible debris. High activity. Both types of shafts vary in diameter from 0.3 to 1 m and in depth from 3 m to 6.1 m.	Special shaft remote handling exhumation operations.	141	10	10 000	30	41
			GRAND TOTAL	100	100 000	100	140

TABLE D-6

OCCUPATIONAL EXTERNAL DOSES FOR NORMAL OPERATIONS

Option B3. Exhume Buried Waste (TA-54, Area G)

Waste Description and Notes	Total Volume and Waste Form	Task	Volume Handled (m^3)	Per Cent of Total (man-days)	Task (man-days)	Per Cent of Total Dose	Occupational Dose (man-rem)
Area G contains 7 pits and 66 shafts with buried waste that is TRU-contaminated. The waste is combustible and noncombustible. The waste buried in the pits was originally packaged in metal drums or in plastic bags placed within cardboard boxes. The condition of many of these containers is considered to be deteriorated so that packages could easily be broken on exhumation. The waste in the shafts is high in β and α and activity and could require remote handling.	**Pit Waste:**	**Pit Waste:**					
	170 000 m^3 (6 000 000 ft^3)	Exhume	170 000	29	55 000	20	57
	19% metals	Separate oversize items	4 600	3	5 700	7.6	21
	8% nonmetals noncombustibles	Size reduce to fit transfer containers	4 600	5	9 400	5.8	16
	21% combustibles	Assay	170 000	7	13 000	8.7	24
	52% soil	Return LL to burial	160 000	26	49 000	2.9	8
It is estimated the exhumation would require two 26-worker shifts per day. For the exhumation of the pits, it is estimated the dose would be 1.04 mrem/man/day and for the remote-handled shaft waste 4.0 mrem/man/day. To complete the exhumation, 14.5 years at 250 work days per year would be required; 12.3 years are attributed to the pit waste and 2.2 years to the shaft waste.		Load TRU into transfer containers	8 000	5	9 400	12	35
		Decontaminate and move exhumation building and equipment	---	10	19 000	1.8	5
			SUB TOTAL	85	160 000	60	170
	Shaft Waste: 430 m^3 (15 000 ft^3) 60 of the shafts are 0.6 m to 1.8 m in diameter and are not lined. Six are 0.3 m in diameter and are concrete lined. The shafts vary in depths from 7.6 m to 18.3 m and contain combustible and noncombustible debris.	**Shafts:** Special shaft remote handling exhumation operations	430	15	28 000	40.5	130
			GRAND TOTAL	100	190 000	100	280

TABLE D-7

OCCUPATIONAL EXTERNAL EXPOSURES FOR NORMAL OPERATIONS

Option B4. Process Exhumed Waste in the Waste Processing Facility (WPF)

Waste Description and Notes	Waste Form	Task	Units Handled	Per Cent of Total Effort	Task (man-days)	Task Dose (mrem/man/day)	Occupational Dose (man-rem)
The 19 000 m^3 (660 000 ft^3) of TRU waste exhumed is trucked to a WPF for processing. The waste consists of concrete, metal, combustible, and noncombustible materials. The WPF is estimated to operate 3 shifts per day, 250 days per year for 15 years. Each day requires a total of 3 supervisors, 3 process engineers, 9 maintenance workers, 3 radiation surveyors, 1 health physicist, 1 chemist and 36 operators for a total of 56 persons who would work in the potentially radioactive areas. This is a total of 210 000 man days. The dose for the workers varies from 1.04 to 1.6 mrem/man/day. The decommissioning of the WPF is not considered in the above but is estimated to require a crew of 17 men 2 years working one shift per day. The dose for these workers is estimated as 1.6 mrem/man/day.	Of the total 8% are combustibles, 27.5% metals and 64.5% nonmetal noncombustibles	Truck to WPF.	2 800 truck-loads	6	13 000	1.04	13
		Sort	19 000 m^3	16	34 000	1.6	54
		Size reduce metals	5 100 m^3	5	11 000	1.6	17
		Decontaminate metals	5 100 m^3	5	11 000	1.6	17
		Shred combustibles	1 500 m^3	3	6 300	1.6	10
		Incinerate	1 500 m^3 combustibles	3	6 300	1.6	10
		Size reduce nonmetal noncombustibles	12 000 m^3	14	29 000	1.6	47
		Cement fixation of nonmetal noncombustible waste	14 000 m^3	14	29 000	1.6	47
		Cement fixation of incineration ash	90 m^3	1	2 100	1.6	3.4
		Assay	19 000 m^3	16	34 000	1.6	54
		Return low level to burial	700 m^3	2	4 200	1.04	4.4
		Package final waste forms	830 boxes and 78 000 drums or 2 400 trucks	15	32 000	1.6	50
			SUB TOTAL	100	210 000	18	330
	WPF structure and equipment	Decommission WPF		---	8 500	1.6	14
			GRAND TOTAL	100	220 000	20	340

TABLE D-8

OCCUPATIONAL EXPOSURES FOR NORMAL OPERATIONS

Option B7. Package Exhumed Waste Without Treatment

Waste Description and Notes	Total Volume Packaged	Waste Form	Task	Units Handled	Per Cent of Total Effort	Task (man-days)	Occupational Dose (man-rem)
The 330 000 m^3 volume of waste exhumed from Areas A, B, T, V, C, and G is miscellaneous debris consisting of combustibles, metals, and nonmetal—non-combustibles (principally cement-fixed waste and dewatered sludges). The related tasks of sorting, assaying, and returning contaminated soil and non-TRU wastes to burial have been accounted for in the exhumation option, Option B3. The TRU fraction would be resized and packaged for transport to final destination at the exhumation site. This task requires an overall effort of 6 000 man-days throughout the 15 years of the exhumation operation. The dose for these workers is estimated as 1.04 mrem/man/day.	Actual waste volume is 19 000 m^3 (660 000 ft^3)	Combustible, metal, and non-metal non-combustible	Unload transfer containers	19 000	50	3 000	3.1
			Package in final boxes	11 000	50	3 000	3.1
				TOTAL	100	6 000	6.2

TABLE D-9

OCCUPATIONAL EXTERNAL EXPOSURES FOR NORMAL OPERATIONS

Options B4, B5, B8, and B9. Buried Waste Final Package Transport Occupational Dose

Waste Description and Notes	Task	Units Handled	Task (man-days)	Task Dose (mrem/man/day)	Dose (man-rem)
Option B5--Transfer processed waste from WPF to an assumed onsite deep pit. The operation would require 6 workers in shifts working intermittently for an equivalent of 6 yr (over a 15-yr period) or 9000 man-days.	Load truck	830 boxes 78 000 drums	3 500	1.04	3.6
	Transport	2 900 truckloads	2 000	1.04	2.0
	Unload truck	830 boxes 78 000 drums	3 500	1.04	3.6
		TOTAL	9 000	3.2	9.2
Option B6--Ship processed waste from WPF to Federal Repository 540 km (340 miles). The operation would require 9 workers in shifts working intermittently for an equivalent of 6 yr or 14 000 man-days.	Load truck	830 boxes 78 000 drums	6 800	1.04	6.8
	Transport	2 900 truckloads	6 800	1.04	6.8
		TOTAL	14 000	2.1	14
Option B8--Transfer packaged unprocessed waste from exhumation area to an assumed onsite deep pit. The operation would require 5 workers in shifts working intermittently for an equivalent of 6 yr (over a 15-yr period, or 7 500 man-days.	Load truck	11 000 boxes	2 800	1.04	2.9
	Transport	2 700 trucks	1 900	1.04	2.0
	Unload truck	11 000 boxes	2 800	1.04	2.9
		TOTAL	7 500	3.2	7.8
Option B9--Ship packaged unprocessed waste from WPF to Federal Repository 540 km (340 miles). The operation would require 8 workers in shifts working intermittently for an equivalent of 6 yr of 12 000 man-days.	Load truck	11 000 boxes	6 000	1.04	6.2
	Transport	2 700 trucks	6 000	1.04	6.2
		TOTAL	12 000	2.1	12
		GRAND TOTAL	110 000	11	43

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[*] Based on the WIPP EIS, it is estimated there would be a population dose of 130 man-rem attributable to those shipments during normal operations.

TABLE D-10

SUMMARY OF OCCUPATIONAL[a] DOSES FOR BURIED WASTE NORMAL OPERATIONS

Option	Description	Total Man-days	Occupational Man-rem/Option
B1	Continue-Current Practice		11[b]
B2	Engineered Improvements		8.8[b]
B3	Exhume Buried Waste	3.6×10^5	470
B4	Process Exhumed Waste	2.2×10^5	340
B5	On-Site Deep Pit Burial After Processing	9×10^3	9.2
B6	Off-Site Deep Geologic Burial After Processing	1.4×10^4	13
B7	Package Without Treatment	6×10^3	6.2
B8	On-Site Deep Pit Burial for Packaged Untreated Waste	7.5×10^3	7.8
B9	Off-Site Deep Geologic Burial for Packaged Untreated Waste	1.2×10^4	12

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[a] Occupational doses are from external radiation.

[b] Includes stored waste contributions and a 100-yr surveillance period.

TABLE D-11

OCCUPATIONAL EXTERNAL DOSES FOR STORED WASTE NORMAL OPERATIONS

Option	Waste Type and Task	Crew Size	Task Time (d)	Total Units	Units/ Task	Dose (mrem/Task)	Total (man-day)	Task Total Dose (man-rem)	Option Total (man-rem)
S1—Leave in place	Maintenance and surveillance	5	2.2×10^4	---	NA	---	1.1×10^5	11.0	11.0
S2—Eng. improve	Maintenance and surveillance	5	2.2×10^4	---	NA	---	1.1×10^5	8.8	8.8
S3—Retrieve	Remove overburden from pad	7	2	6	1	10	8.4×10^1	0.1	
	Retrieve and load drums	10	1	23 000	72	40	3.2×10^3	13.0	
	Retrieve and load FRP	13	1	990	16	40	8.0×10^2	2.5	
	Retrieve and load oversize FRP	13	1	190	8	40	3.0×10^2	0.9	
	Cut, cap, load CMP	11	3	180	2	200	2.9×10^3	18.0	
	Retrieve and load casks	12	1	480	10	20	5.8×10^2	0.4	
	Lift and load shafts into shield	9	1	100	2	200	4.5×10^2	10.0	45
S4—WPF	Unload drums	5	1	23 000	72	20	1.6×10^3	6.4	
	Process sludge drums	18	1	3 800	36	20	1.9×10^3	2.1	
	Process drum metal	18	1	6 800	18	20	6.8×10^3	7.5	
	Process drum combust	18	1	1 600	18	20	1.6×10^3	1.8	
	Process and load cement sludge drum	5	1	11 000	72	10	7.6×10^2	1.5	
	Load processed drums	5	1	19 000	72	10	1.3×10^3	2.6	
	Unload FRP	7	1		16	20	4.3×10^2	1.2	
	Unload oversize FRP	7	1	190	8	10	1.6×10^2	0.2	
	Process oversize FRP metal	18	1	190	8	60	4.2×10^2	1.4	
	Process FRP metal	18	1	870	16	60	9.7×10^2	3.2	
	Process FRP and oversize FRP combust	18	1	220	5	20	8.1×10^2	0.9	
	Package and load CMP	11	1	180	7	50	2.8×10^2	2.2	
	Load processed boxes	7	1	600	16	20	2.6×10^2	0.8	
	Load ash drums	5	1	310	72	20	2.1×10^1	0.09	
	Unload casks	7	1	480	10	20	3.4×10^2	1.0	
	Process casks	18	1	480	10	20	8.6×10^2	1.0	
	Unload, process and load shafts	18	1	100	2	200	9.0×10^2	10.0	44

TABLE D-11 (Continued)

Option	Waste Type and Task	Crew Size	Task Time (d)	Total Units	Units/ Task	Dose (mrem/Task)	Total (man-day)	Task Total Dose (man-rem)	Option Total (man-rem)
S5—WPF to deep pit	Transport, unload, stack drums	6	1	19 000	72	30	1.6×10^3	7.9	
	Transport, unload, stack boxes	8	1	810	16	30	4.2×10^2	1.5	
	Transport, unload, stack CMP	11	1	180	4	50	4.8×10^2	2.2	
	Transport, unload, stack shafts	9	1	100	4	100	2.3×10^2	30	42
S6—WPF to offsite	Transport drums	2	2	19 000	36	0.6	2.1×10^3	0.3	
	Transport boxes	2	2	810	4	1.6	8.1×10^2	0.3	
	Transport CMP	2	2	180	2	3.2	3.5×10^2	0.3	
	Transport shafts	2	2	100	1	6.4	4.0×10^2	0.6	1.5
S7—Size reduction	Unload oversize FRP	8	1	190	8	40	2.4×10^1	1.0	
	Remove contents	8	1	190	2	40	9.5×10^1	3.8	
	Size reduction	8	1	190	1	40	1.9×10^2	7.6	
	Load waste into containers	8	1	190	8	40	2.4×10^1	1.0	
	Load containers on truck	8	1	570	16	20	3.5×10^1	0.7	14
S8—Deep pit	Transport, unload, stack drums	6	1	23 000	72	20	1.9×10^3	6.4	
	Transport, unload, stack FRP	8	1	1 100	16	20	5.6×10^2	1.4	
	Transport, unload, stack CMP	11	1	180	4	50	4.8×10^2	2.2	
	Transport, unload stack casks	8	1	480	10	20	3.8×10^2	1.0	
	Transport, unload, stack shafts	9	1	100	4	100	2.3×10^2	3.0	14
S9—Offsite	Transport drums	2	2	23 000	36	0.6	2.6×10^3	0.4	
	Transport FRP	2	2	1 100	4	1.6	2.8×10^2	0.5	
	Transport CMP	2	2	180	2	3.2	3.5×10^2	0.3	
	Transport casks	2	2	480	5	1.6	3.8×10^2	0.2	
	Transport shafts	2	2	100	1	6.4	4.0×10^2	0.6	2.0

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