APPENDIX C:

TRANSPORTATION RISK ANALYSIS

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This appendix provides the detailed methodology, input parameters and assumptions, and results for the transportation risk analysis performed in support of this Mixed Oxide Fuel Fabrication Facility Environmental Impact Statement (MOX EIS). The analysis evaluates transportation of depleted uranium hexafluoride (UF_6) from the Portsmouth Gaseous Diffusion Plant in Portsmouth, Ohio, to the Global Nuclear Fuel-Americas, LLC Fuel Fabrication Facility in Wilmington, North Carolina; transportation of the uranium dioxide (UO_2) conversion product from Wilmington to the proposed MOX facility; transportation of plutonium metal from U.S. Department of Energy (DOE) storage sites; and transportation of the fresh MOX fuel from the proposed MOX facility to a surrogate nuclear power plant site.

C.1 Methodology

C.1.1 Overview

The transportation risk assessment considers human health risks from routine transport (normal, incident-free conditions) of hazardous materials and from potential accidents. In both cases, risks associated with the nature of the cargo itself, or “cargo-related” impacts, and those related to the transportation vehicle (regardless of type of cargo), or “vehicle-related” impacts, are considered.

C.1.1.1 Routine Transportation Risk

The radiological risk associated with routine transportation is cargo-related and results from the potential exposure of people to low levels of external radiation near a loaded shipment. It is assumed that there are no cargo-related risks posed by incident-free transport of hazardous chemicals. No direct chemical exposure to radioactive material will occur during routine transport because, as discussed in Section C.2.2, these materials will be in packages that are designed and maintained to ensure that they will contain and shield their contents during normal transport. Any leakage or unintended release would be considered under accident risks.

Vehicle-related risks during routine transportation are caused by potential exposure to increased vehicular emissions. These emissions include diesel exhaust, tire and brake particulate emissions, and fugitive dust raised from the roadbed by passing vehicles.

C.1.1.2 Accident Transportation Risk

The cargo-related radiological risk from transportation-related accidents lies in the potential release and dispersal of radioactive material into the environment during an accident and the subsequent exposure of people through multiple exposure pathways, such as exposure to contaminated soil, inhalation, or the ingestion of contaminated food. Cargo-related hazardous chemical accident impacts to human health during transportation come from immediate inhalation exposure resulting from container failure and chemical release during an accident.

Vehicle-related accident risks refer to the potential for transportation-related accidents that result in fatalities caused by physical trauma unrelated to the cargo.

C.1.2 Routine Risk Assessment Methodology

The RADTRAN 4 computer code (Neuhauser and Kanipe 1992) was used in the routine and accident cargo-related risk assessments to estimate the radiological impacts to collective populations. RADTRAN 4 was developed by Sandia National Laboratories to calculate population risks associated with the transportation of radioactive materials by truck, rail, air, ship, or barge. The code has been used extensively for transportation risk assessments since it was originally issued in the late 1970s as RADTRAN (RADTRAN 1) and has been reviewed and updated periodically. RADTRAN 1 was originally developed to facilitate the calculations presented in NUREG-0170 (NRC 1977b).

C.1.2.1 Collective Population Risk

The radiological risk associated with routine transportation results from the potential exposure of people to low-level external radiation in the vicinity of loaded shipments. Even under routine transportation, some radiological exposure could occur. Because the radiological consequences (dose) would occur as a direct result of normal operations, the probability of routine consequences is taken to be 1 in the RADTRAN 4 code. Therefore, the dose risk is equivalent to the estimated dose.

For routine transportation, the RADTRAN 4 computer code considers major groups of potentially exposed persons. The RADTRAN 4 calculations of risk for routine highway and rail transportation include exposures of the following population groups:

- *Persons along the Route (Off-Link Population)*. Collective doses were calculated for all persons living or working within 0.8 km (0.5 mi) of each side of a transportation route. The total number of persons within the 1.6-km (1-mi) corridor was calculated separately for each route considered in the assessment.

- *Persons Sharing the Route (On-Link Population)*. Collective doses were calculated for persons in all vehicles sharing the transportation route. This group includes persons traveling in the same or opposite directions as the shipment, as well as persons in vehicles passing the shipment.

- *Persons at Stops*. Collective doses were calculated for people who might be exposed while a shipment was stopped en route. For truck transportation, these stops include those for refueling, food, and rest.

- *Crew Members*. Collective doses were calculated for truck transportation crew members involved in the actual shipment of material. Workers involved in loading or unloading were not considered. The doses calculated for the first three population groups were added together to yield the collective dose to the public; the dose calculated for the fourth group represents the collective dose to workers.

The RADTRAN 4 calculations for routine dose generically compute the dose rate as a function of distance from a point source (Neuhauser and Kanipe 1995). Associated with the calculation of routine doses for each exposed population group are parameters such as the radiation field strength, the source-receptor distance, the duration of exposure, vehicular speed, stopping time, traffic density, and route characteristics (such as population density). The RADTRAN manual contains derivations of the equations used and descriptions of these parameters (Neuhauser and Kanipe 1995).

C.1.2.2 Maximally Exposed Individual Risk

In addition to the assessment of the routine collective population risk, the risk to a maximally exposed individual (MEI) was estimated. In RADTRAN 4, the MEI is assumed to be located 30 m (100 ft) from the transport route as the radioactive shipment passes by at a speed of 24 km/h (15 mph).

C.1.2.3 Vehicle-Related Risk

Vehicle-related health risks resulting from routine transportation are associated with the generation of air pollutants by transport vehicles during shipment and would be independent of the radioactive or chemical nature of the shipment. The health endpoint assessed under routine transportation conditions was the excess latent mortality from inhalation of vehicular emissions. These emissions consist of particulate matter in the form of diesel engine exhaust, tire and brake particulates, and fugitive dust raised from the roadway by the transport vehicle. Risk factors for pollutant inhalation in terms of latent mortality have been used in this analysis. Vehicle-related risks from routine transportation were calculated for each shipment by multiplying the total distance traveled by the appropriate risk factor.

C.1.3 Accident Assessment Methodology

As stated above, the radiological transportation accident risk assessment also uses the RADTRAN 4 code for estimating collective population risks. The hazardous chemical transportation accident risk assessment relies on the HGSYSTEM model (Post 1994a,b; Hanna et al. 1994). The model is a widely applied code recognized by the U.S. Environmental Agency (EPA) for use in chemical accident consequence predictions. The FIREPLUME model (Brown et al. 1997) was used to supplement the HGSYSTEM model in the analysis of fire scenarios involving depleted uranium releases. The HGSYSTEM and FIREPLUME models were used previously in assessing the hazardous chemical transportation impacts from transportation of depleted uranium materials (Biwer et al. 1997).

The risk analysis for potential accidents differs fundamentally from the risk analysis for routine transportation because occurrences of accidents are statistical in nature. The accident risk assessment is treated probabilistically in RADTRAN 4 for radiological risk and in the HGSYSTEM approach used to estimate the hazardous chemical component of risk. Accident risk is defined as the product of the accident consequence (dose or exposure) and the probability of the accident's occurring. In this respect, RADTRAN 4 and the HGSYSTEM approach both estimate the collective accident risk to populations by considering a spectrum of transportation-related accidents. The spectrum of accidents was designed to encompass a range of possible accidents, including low-probability accidents that have high consequences, and high-probability accidents that have low consequences (such as "fender benders"). For radiological risk, the results for collective accident risk can be directly compared with the results for routine collective risk because the latter results implicitly incorporate a probability of occurrence of 1 if the shipment takes place. Such is not the case for chemical materials, because routine transport would pose no exposure risk.

C.1.3.1 Radiological Accident Risk Assessment

The RADTRAN 4 calculation of collective accident risk uses models that quantify the range of potential accident severities and the responses of transported packages to accidents. The spectrum of accident severity is divided into several categories, each of which is assigned a conditional probability of occurrence — that is, the probability that if an accident does occur, it will be of a particular severity. Release fractions, defined as the fraction of the material in a package that could be released in an accident, are assigned to each accident severity category on the basis of the physical and chemical form of the material. The model takes into account the mode of transportation and the type of packaging through selection of the appropriate accident probabilities and release fractions, respectively. The accident rates, the definition of accident severity categories, and the release fractions used in this analysis are discussed further in Sections C.2 and C.3.

For accidents involving the release of radioactive material, RADTRAN 4 assumes that the material is dispersed in the environment according to standard Gaussian diffusion models. For the risk assessment, default data for atmospheric dispersion were used, representing an instantaneous ground-level release and a small-diameter source cloud (Neuhauser and Kanipe

1995). The calculation of the collective population dose following the release and dispersal of radioactive material includes the following exposure pathways:

- External exposure to the passing radioactive cloud,
- External exposure to contaminated ground,
- Internal exposure from inhalation of airborne contaminants, and
- Internal exposure from the ingestion of contaminated food.

For the ingestion pathway, state-average food transfer factors, which relate the amount of radioactive material ingested to the amount deposited on the ground, were calculated in accordance with the methods described by U.S. Nuclear Regulatory Commission (NRC) Regulatory Guide 1.109 (NRC 1977a) and were used as input to the RADTRAN code. Doses of radiation from the ingestion or inhalation of radionuclides were calculated by applying standard dose conversion factors (DOE 1988a,b).

C.1.3.2 Chemical Accident Risk Assessment

The risks from exposure to hazardous chemicals during transportation-related accidents can be either acute (resulting in immediate injury or fatality) or latent (resulting in cancer that would present itself after a latency period of several years). The acute health endpoint, potential irreversible adverse effects, was evaluated for the assessment of cargo-related population impacts from transportation accidents. Accidental releases during transport of the uranium compounds (UF_6 and UO_2) were evaluated quantitatively.

The acute effects evaluated were assumed to exhibit a threshold nonlinear relationship with exposure; that is, some low level of exposure can be tolerated without inducing a health effect. To estimate risks, chemical-specific concentrations were developed for potential irreversible adverse effects. All individuals exposed at these levels or higher following an accident were included in the transportation risk estimates. In addition to acute health effects, the cargo-related risk of excess cases of latent cancer from accidental chemical exposures could be evaluated. However, none of the chemicals that might be released in any of the accidents would be carcinogenic. As a result, no predictions for excess latent cancers from accidental chemical releases are presented in this report.

The primary exposure route of concern with respect to accidental release of hazardous chemicals would be inhalation. Although direct exposure to hazardous chemicals via other pathways, such as ingestion or absorption through the skin (dermal absorption), would also be possible, these routes would be expected to result in much lower exposure than the inhalation pathway doses for the uranium compounds. The likelihood of acute effects would be much less for the ingestion and dermal pathways than for inhalation.

The HGSYSTEM model (Version 3.0) (Hanna et al. 1994) has a built-in source-term algorithm that is used to compute the rate, quantity, and type of atmospheric release of a hazardous air pollutant, including pool evaporation from a spill of a volatile organic liquid. The model can be used to evaluate frequently encountered accidental releases from ruptured tanks, drums, and pipes. The model incorporates a chemical data library of physical and chemical properties (such as vapor pressure, boiling point, and molecular weight) for 30 compounds. Physical properties of the chemical released, along with container content input, such as the container geometry and rupture characteristics (e.g., hole size), are used by HGSYSTEM to compute chemical release rate and duration. The risk assessment for hazardous chemicals assumed that particulate releases would be of short duration as liquid and solid (as respirable fraction) aerosols.

The approach for hazardous chemicals incorporates the same accident severity categories and release fractions used by RADTRAN 4 for radiological accidents. The risks associated with the consequences estimated with the HGSYSTEM code were computed separately with a risk quantification spreadsheet program.

C.1.3.3 Vehicle-Related Accident Risk Assessment

The vehicle-related accident risk refers to the potential for transportation accidents that could result directly in fatalities not related to the nature of the cargo in the shipment. This risk represents fatalities from physical trauma. State-average rates for transportation fatalities are used in the assessment. Vehicle-related accident risks are calculated by multiplying the total distance traveled by the rates for transportation fatalities. In all cases, the vehicle-related accident risks are calculated on the basis of distances for round-trip shipment since the presence or absence of cargo would not be a factor in accident frequency.

C.2 Input Parameters and Assumptions

The principal input parameters and assumptions used in the transportation risk assessment are discussed in this section. Where appropriate, applicable government regulations are referenced. Transportation of hazardous chemical and radioactive materials is governed by U.S. Department of Transportation (DOT), NRC, and EPA regulations, and by the Hazardous Materials Transportation Act. These regulations may be found in the *Code of Federal Regulations* (CFR) at 49 CFR Parts 171-178, 49 CFR Parts 383-397, 10 CFR Part 71, and 40 CFR Parts 262 and 265, respectively. State organizations are also involved in regulating such transport within their borders. All transportation-related activities must be in accordance with applicable regulations of these agencies. However, the DOT and NRC have primary regulatory responsibility for shipment of radioactive materials. Those regulations most pertinent to this risk assessment can be found in 49 CFR 173 (*Shippers—General Requirements for Shipments and Packagings*), 49 CFR 397 (*Transportation of Hazardous Materials; Driving and Parking Rules*), and 10 CFR 71 (*Packaging and Transportation of Radioactive Material*).

C.2.1 Route Characteristics

The transportation route selected for a shipment determines the total potentially exposed population and the expected frequency of transportation-related accidents. For truck transportation, the route characteristics most important to the risk assessment include the total shipping distance between each origin-and-destination pair of sites and the population density along the route.

C.2.1.1 Route Selection

The DOT routing regulations concerning radioactive materials on public highways are prescribed in 49 CFR 397.101(*Requirements for Motor Carriers and Drivers*). The objectives of the regulations are to reduce the impacts of transporting radioactive materials, to establish consistent and uniform requirements for route selection, and to identify the role of state and local governments in routing radioactive materials. The regulations attempt to reduce potential hazards by prescribing that populous areas be avoided and that travel times be minimized. In addition, the regulations require that the carrier of radioactive materials ensure that the vehicle is operated on routes that minimize radiological risks, and that accident rates, transit times, population density and activity, time of day, and day of week are considered in determining risk. However, the final determination of the route is left to the discretion of the carrier, such as for shipments of depleted UF_6 and UO_2, unless the shipment contains a "highway route controlled quantity" (HRCQ) of radioactive material as defined in 49 CFR 173.403 (*Definitions*), such as the plutonium metal or the MOX fuel.

A vehicle transporting an HRCQ of radioactive materials is required to use the interstate highway system except when moving from origin to interstate or from interstate to destination, when making necessary repair or rest stops, or when emergency conditions make continued use of the interstate unsafe or impossible. Carriers are required to use interstate circumferential or bypass routes, if available, to avoid populous areas. Any state or Native American tribe may designate other "preferred highways" to replace or supplement the interstate system. Under its authority to regulate interstate transportation safety, the DOT can prohibit state and local bans and restrictions as "undue restraint of interstate commerce." State or local bans can be preempted if inconsistent with the HRCQ regulations. Shipments of TRU waste will follow designated Waste Isolation Pilot Plant (WIPP) routes to the WIPP repository.

For this analysis, representative shipment routes were identified using the WebTRAGIS (Version 1.10) routing model (Johnson and Michelhaugh 2000) for the truck shipments. The routes were selected to be reasonable and consistent with routing regulations and general practice, but they are considered only representative because the actual routes used would be chosen in the future and are often determined by the shipper. At the time of shipment, route selection would reflect current road conditions, including road repairs and traffic congestion.

The HIGHWAY data network in WebTRAGIS is a computerized road atlas that includes a complete description of the interstate highway system and of all U.S. highways. In addition, most principal state highways and many local and community highways are identified. The code is periodically updated to reflect current road conditions and has been compared with reported mileages and observations of commercial trucking firms.

Routes are calculated within the model by minimizing the total impedance between origin and destination. The impedance is basically defined as a function of distance and driving time along a particular segment of highway. The population densities along a route are derived from 2000 census data from the U.S. Bureau of the Census.

The WebTRAGIS database version used was Highway Data Network 2.1. Summary route information on the truck routes used in the analysis is provided in Table C.1.

C.2.1.2 Population Density

Three population density zones — rural, suburban, and urban — were used for the population risk assessment. The fractions of travel and average population density in each zone were determined with the WebTRAGIS routing model. Rural, suburban, and urban areas are characterized according to the following breakdown: rural population densities range from 0 to 54 persons/km^2 (0 to 139 persons/mi^2); suburban densities range from 55 to 1,284 persons/km^2 (140 to 3,326 persons/mi^2); and urban covers all population densities greater than 1,284 persons/km^2 (3,326 persons/mi^2). Use of these three population density zones is based on an aggregation of the 11 population density zones provided in the WebTRAGIS model output. For calculation purposes, information about population density was generated at the state level and used as RADTRAN input for all routes. Route average population densities and other route characteristics are given in Table C.1.

C.2.1.3 Accident and Fatality Rates

For calculating accident risks, vehicle accident involvement and fatality rates are taken from data provided in Saricks and Tompkins (1999). For each transport mode, accident rates are generically defined as the number of accident involvements (or fatalities) in a given year per unit of travel by that mode in the same year. Therefore, the rate is a fractional value — the accident-involvement count is the numerator, and vehicular activity (total traveled distance) is the denominator. Accident rates are derived from multiple-year averages that automatically account for such factors as heavy traffic and adverse weather conditions. For assessment purposes, the total number of expected accidents or fatalities is calculated by multiplying the total shipping distance for a specific case by the appropriate accident or fatality rate.

For truck transportation, the rates presented in Saricks and Tompkins (1999) are specifically for heavy combination trucks involved in interstate commerce. Heavy combination trucks are rigs composed of a separable tractor unit containing the engine and one to three freight trailers connected to each other and the tractor. Heavy combination trucks are typically used for shipping radioactive wastes. Truck accident rates are computed for each state on the basis of

Table C.1. Summary route data

Route		Total distance [km (mi)]	Fraction of travel			Average population density [persons/km^2 (persons/mi^2)]		
Origin	**Destination**		**Rural**	**Suburban**	**Urban**	**Rural**	**Suburban**	**Urban**
Portsmouth, OH	Wilmington, NC	936 (581)	55.5	40.7	3.9	18.5 (47.8)	366.7 (949.8)	2,155 (5,582)
Wilmington, NC	PDCF	443 (275)	60.1	37.5	2.4	15.7 (40.7)	353.1 (914.6)	2,140 (5,543)
Pantex	PDCF	2,179 (1,354)	67.8	28.5	3.7	13.4 (34.6)	332.4 (861.0)	2,271 (5,882)
Hanford Site	PDCF	4,434 (2,755)	76.7	20.9	2.3	11.3 (29.2)	320.5 (830.1)	2,244 (5,811)
Proposed MOX facility	WIPP	2,442 (1,518)	70.7	26.7	2.6	13.2 (34.2)	315.6 (817.4)	2,173 (5,627)
Proposed MOX facility	Surrogate Nuclear Power Plant	2,147 (1,334)	57.1	37.4	5.5	18.5 (47.8)	342.1 (886.1)	2,366 (6,128)

statistics compiled by the DOT Office of Motor Carriers for 1994 to 1996. Saricks and Tompkins (1999) present accident involvement and fatality counts, estimated kilometers of travel by state, and the corresponding average accident involvement and fatality rates for the 3 years investigated. Fatalities (including of crew members) are deaths that are attributable to the accident and that occurred within 30 days of the accident.

The truck accident assessment presented in this EIS uses accident (fatality) rates for travel on interstate highways. The total accident risk for a case depends on the total distance traveled in various states and does not rely on national average accident statistics. However, for comparative purposes, the national average truck accident rate on interstate highways presented in Saricks and Tompkins (1999) is 3.15×10^{-7} accidents/truck-km (5.07×10^{-7} accidents/mi).

Note that the accident rates used in this assessment were computed using all interstate shipments, regardless of the cargo. Saricks and Kvitek (1994) point out that shippers and carriers of radioactive material generally have a higher-than-average awareness of transportation risk and prepare cargoes and drivers for such shipments accordingly. This preparation should have the twofold effect of reducing component and equipment failure and mitigating the contribution of human error to accident causation. However, these mitigating effects were not considered in the accident assessment.

C.2.2 Packaging

Shipment packaging for radioactive materials must be designed, constructed, and maintained to ensure that it will contain and shield the contents during normal transportation. For more highly radioactive material, the packaging must contain and shield the contents in severe accidents. The type of packaging used is determined by the radioactive hazard associated with the packaged material. The basic types of packaging required by the applicable regulations are designated as Type A, Type B, or industrial packaging (generally for low-specific-activity [LSA] material).

C.2.2.1 Depleted UF_6 and UO_2 Packaging

Depleted UF_6 and UO_2 shipments would use Type A and industrial packaging, respectively. These types of packaging must withstand the conditions of normal transportation without the loss or dispersal of the radioactive contents. "Normal" transportation refers to all transportation conditions except those resulting from accidents or sabotage. Approval of Type A packaging is obtained by demonstrating that the packaging can withstand specified testing conditions intended to simulate normal transportation. Type A packaging usually does not require special handling, packaging, or transportation equipment. The depleted UF_6 would be shipped in Model 30B cylinders (USEC 1999) with overpacks, and the depleted UO_2 would be shipped in 55-gal drums.

C.2.2.2 Plutonium Metal, MOX Fuel, and TRU Waste

The plutonium metal, MOX fuel, and TRU waste would be shipped in Type B packaging. In addition to meeting all the Type A standards, Type B packaging must also provide a high degree of assurance that the package integrity will be maintained even during severe accidents, with essentially no loss of the radioactive contents or serious impairment of the shielding capability. Type B packaging is required for shipping large quantities of radioactive material and must satisfy stringent testing criteria (as specified in 10 CFR 71). The testing criteria were developed to simulate conditions of severe hypothetical accidents, including impact, puncture, fire, and immersion in water. The most widely recognized Type B packagings are the massive casks used to transport highly radioactive spent nuclear fuel from nuclear power stations. Large-capacity cranes and mechanical lifting equipment are usually necessary for handling Type B packagings. Many Type B packagings are transported on trailers specifically designed for that purpose.

Plutonium metal as pits is expected to be shipped in DOE-approved FL containers, while piece parts might be shipped in DOE-approved USA/9975 containers (DOE 1999b). TRU waste would be transported to the WIPP in Type B containers referred to as the Transuranic Package Transporter-II (TRUPACT-II).

The MOX fresh fuel package is a Type B cylindrical container designed to carry three MOX fuel assemblies. MOX fuel does not require specific shielding material, and the containment shell provides a single containment boundary in accordance with 10 CFR 71.63(b)(1). The current design (DCS 2001b) specifies 4.46 m (175 in.) as the overall package length without the impact limiters. The impact limiters themselves are of a conventional polyurethane filled design and have an outer diameter of 1.5 m (60 in.). The outer diameter of the package containment shell is 0.74 m (29 in.). The package is designed to accommodate 3,200 kg (7,100 lb) of payload, including internal supports and the fuel assemblies. The package gross weight is 6,580 kg (14,500 lb).

C.2.3 Shipment Configurations and Number of Shipments

The anticipated shipment information for the proposed action is summarized in Table C.2. Table C.3 lists the radionuclide inventory for each shipment type. Depleted UF_6 shipments would consist of five overpacked 30B cylinders per truck, as depicted in Figure C.1. Each cylinder would contain about 2,277 kg (5,020 lb) of depleted UF_6. Depleted UO_2 shipments would consist of 24 55-gal drums in a commercial covered tractor trailer. Each drum would contain approximately 667 kg (1,470 lb) of depleted UO_2. For this analysis, sufficient quantities of UF_6 and UO_2 were assumed to be shipped so that a total of 34 MT(37.5 tons) of plutonium could be fabricated into MOX fuel assemblies for irradiation as reactor fuel (DCS 2002a). Thus, a total of 110 shipments of depleted UF_6 and 60 shipments of depleted UO_2 would be required.

As discussed in Section 4.4.1.1, it was assumed that 26.7 MT (29.4 tons) of plutonium would require transportation to the PDCF from Pantex and Hanford. On the basis of the information

Table C.2. Shipment information

Origin	Destination	Material	Package type	Amount per package [kg (lb)]	Packages per shipment	Number of shipments
Portsmouth, OH	Wilmington, NC	UF_6	30B cylinder	2,277 (5,020)	5	110
Wilmington, NC	MOX facility	UO_2	30-gal drum	667 (1,470)	24	60
Pantex	PDCF	Pu metal	Type B	62.3 (137)[a]	NA[b]	343
Hanford	PDCF	Pu metal	Type B	62.3 (137)[a]	NA	87
MOX facility	Surrogate nuclear power plant	MOX fuel	Type B	3 assemblies	1	598
WSB	WIPP	TRU waste	TRUPACT-II	2,590 (5,700)[a]	3	299–2,314

[a] Estimated amount per shipment.

[b] Not available, dependent on actual container used.

Table C.3. Single-shipment radionuclide inventories (Ci)[a]

					TRU Waste[c,d]	
Isotopes	UF_6	UO_2	Pu metal	MOX fuel[b]	Volume Reduction	No Volume Reduction
U-234	0.474	0.868	NA[e]	NA	0.0231	0.00299
U-235	0.0445	0.0752	NA	0.00706	0.000530	6.87×10^{-5}
U-238	2.57	4.74	NA	0.438	5.43×10^{-6}	7.04×10^{-7}
Th-234	2.57	4.74	NA	NA	NA	NA
Pa-234m	2.57	4.74	NA	NA	NA	NA
Pu-236	NA	NA	NA	2.22	NA	NA
Pu-238	NA	NA	836	429	0.0822	0.0107
Pu-239	NA	NA	7,070	4,860	0.567	0.0735
Pu-240	NA	NA	1,730	1,080	0.110	0.0142
Pu-241	NA	NA	129,000	43,000	9.88	1.28
Pu-242	NA	NA	0.494	0.0956	3.76×10^{-5}	4.87×10^{-6}
Am-241	NA	NA	3,820	NA	3,650	474

[a] To convert from Ci to Bq, multiply by 3.7×10^{10}.

[b] Source: DCS (2001b).

[c] Source: DCS (2002b).

[d] Source: DCS (2004).

[e] NA = not applicable.

Figure C.1. Trailer carrying five UF_6 cylinders in overpacks (Photo courtesy of United States Enrichment Corporation [USEC 1999]).

presented in Didlake (1998), approximately 62.3 kg (137 lb) of plutonium would be in each shipment. The plutonium would be packaged in a suitable Type B container and shipped via the Safeguards Transporter (SGT) discussed later in this section.

Approximately 1,748 MOX fuel assemblies would be shipped to commercial reactor sites. Transport of the MOX fuel would be by SGT, one MOX fuel package per shipment. Figure C.2 shows a representative shipment configuration. With three assemblies per shipping cask, 598 shipments would be expected between the years 2007 and 2021 (DCS 2002a).

The SGT is a specially designed component of a tractor-trailer vehicle and is used by the Office of Secure Transportation of the DOE Albuquerque National Nuclear Security Administration (NNSA) Service Center for the transport of special nuclear materials, such as plutonium. Since 1975, more than 151 million km (94 million mi) of travel transporting DOE-owned cargo has been accumulated without an accident involving a fatality or a release of radioactive material. Although details of vehicle enhancements and some operational aspects are classified, key characteristics are as follows (DOE 1999b):

- Enhanced structural characteristics and a highly reliable tie-down system to protect the cargo from impact;

- Heightened thermal resistance to protect the cargo in case of fire;

- Established operational and emergency plans and procedures governing the shipment of nuclear materials;

- Couriers who are armed federal officers and who have received vigorous specialized training;

- An armored tractor component that provides courier protection against attack and contains advanced communications equipment;

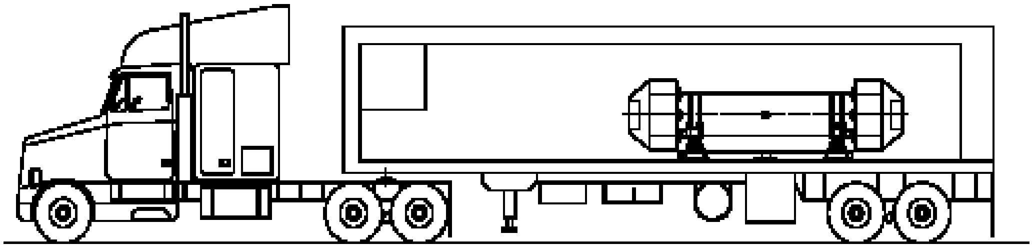

Figure C.2. MOX fresh fuel package loaded in SGT.

- Specially designed escort vehicles containing advanced communications and additional couriers;
- 24-hour-a-day, real-time communications to monitor the location and status of all SGT shipments; and
- Significantly more stringent maintenance standards than those for commercial transport equipment.

TRU waste was assumed to be fixed in cement, placed in standard waste boxes (SWBs), and shipped in TRUPACT-II containers from the WSB to the WIPP for disposal (DCS 2002b; 2004). Each TRUPACT-II contained 2 SWBs, and each truck shipment consisted of 3 TRUPACT-II containers. The number of TRU waste shipments could range from about 23 to 178 shipments per year (DCS 2004). The upper end of the range assumes that no volume reduction of the waste occurs, but the annual throughput in either case contains the same amount of americium. Thus, the total number of shipments over the 13-year operational life of the WSB would range from 299 to 2,314.

C.2.4 Accident Characteristics

Assessment of transportation accident risk takes into account the fraction of material in a package that would be released or spilled to the environment during an accident, commonly referred to as the release fraction. The release fraction is a function of the severity of the accident and the material packaging. For instance, a low-impact accident, such as a "fender-bender," would not be expected to cause any release of material. Conversely, a very severe accident would be expected to release nearly all of the material in a shipment into the environment. The method used to characterize accident severities and the corresponding release fractions for estimating both radioactive and chemical risks are described below.

C.2.4.1 Accident Severity Categories

A method to characterize the potential severity of transportation-related accidents has been described in the NRC NUREG-0170 report, *Final Environmental Statement on the*

Transportation of Radioactive Material by Air and Other Modes (NRC 1977b). The NRC method divides the spectrum of transportation accident severities into eight categories. Other studies have divided the same accident spectrum into six categories (Wilmot 1981), 20 categories (Fischer et al. 1987), or more (Sprung et al. 2000); however, these latter studies focused primarily on accidents involving shipments of spent nuclear fuel (SNF). In this analysis, the NUREG-0170 scheme was used for all shipments.

The NUREG-0170 scheme for accident classification is shown in Figure C.3 for truck transportation. Severity is described as a function of the magnitudes of the mechanical forces (impact) and thermal forces (fire) to which a package may be subjected during an accident. Because all accidents can be described in these terms, severity is independent of the specific accident sequence. In other words, any sequence of events that results in an accident in which a package is subjected to forces within a certain range of values is assigned to the accident severity category associated with that range. The scheme for accident severity is designed to take into account all credible transportation-related accidents, including those accidents with low probability but high consequences and those with high probability but low consequences.

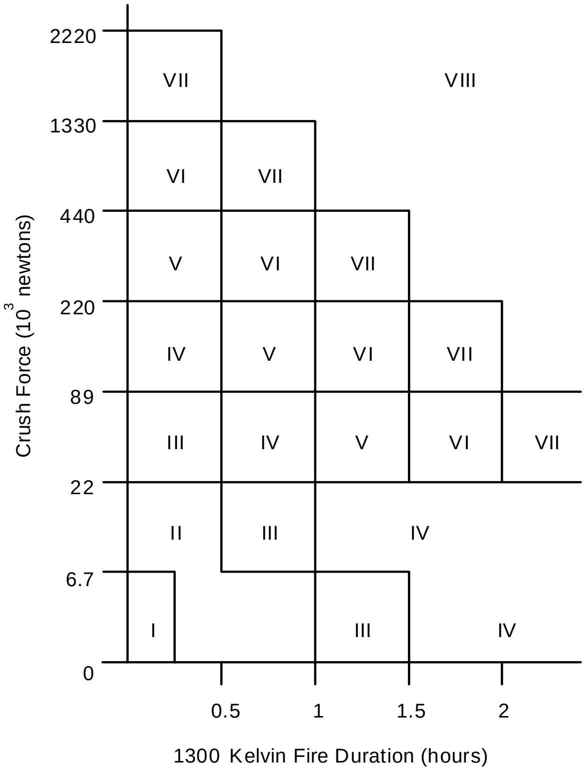

Figure C.3. Scheme for NUREG-0170 classification by accident severity category for truck accidents (*Source*: NRC 1977b).

Each severity category represents a set of accident scenarios defined by a combination of mechanical and thermal forces. A conditional probability of occurrence — that is, the probability that if an accident occurs, it is of a particular severity — is assigned to each category. The fractional occurrences for accidents by accident severity category and population density zone are shown in Table C.4 and are used for estimating both radioactive and chemical risks.

Category I accidents are the least severe but the most frequent; Category VIII accidents are very severe but very infrequent. To determine the expected frequency of an accident of a given severity, the conditional probability in the category is multiplied by the baseline accident rate. Each population density zone has a distinct distribution of accident severities related to differences in average vehicular velocity, traffic density, location (rural, suburban, or urban), and other factors.

C.2.4.2 Package Release Fractions

In NUREG-0170, radiological and chemical consequences are calculated by assigning package release fractions to each accident severity category. The release fraction is defined as the fraction of the material in a package that could be released from the package as the result of an accident of a given severity. Release fractions take into account all mechanisms necessary to create release of material from a damaged package to the environment. Release fractions vary according to the type of package and the physical form of the material.

Representative release fractions for accidents involving depleted UF_6 and UO_2 shipments were taken from NUREG-0170 (NRC 1977b). The recommendations in NUREG-0170 are based on best engineering judgments and have been shown to provide conservative estimates of

Table C.4. Fractional occurrences for truck accidents by severity category and population density zone

		Fractional occurrence by population density zone		
Severity category	**Fractional occurrence**	**Rural**	**Suburban**	**Urban**
Truck				
I	0.55	0.1	0.1	0.8
II	0.36	0.1	0.1	0.8
III	0.07	0.3	0.4	0.3
IV	0.016	0.3	0.4	0.3
V	0.0028	0.5	0.3	0.2
VI	0.0011	0.7	0.2	0.1
VII	8.5×10^{-5}	0.8	0.1	0.1
VIII	1.5×10^{-5}	0.9	0.05	0.05

Source: NRC (1977b).

material releases following accidents. The release fractions used are those reported in NUREG-0170 for both low-specific-activity (LSA) drums and NRC Type A packages. Release fractions for accidents of each severity category are given in Table C.5. As shown in that table, the amount of material released from the package ranges from zero for minor accidents to 100% for the most severe accidents. As shown in Table C.5, representative release fractions for accidents involving fresh MOX fuel were assumed to be the same as those developed for SNF in the NRC's study (Fischer et al. 1987), commonly referred to as the Modal Study, on the behavior of SNF in Type B containers under accident conditions. These values were derived on the basis of best engineering judgments. These values are expected to be conservative when applied to fresh MOX fuel because the fuel has not yet become embrittled through use.

Also important for the purposes of risk assessment are the fraction of the released material that can be entrained in an aerosol (part of an airborne contaminant plume) and the fraction of the aerosolized material that is also respirable (of a size that can be inhaled into the lungs). These fractions depend on the physical form of the material. Most solid materials are difficult to release in particulate form and are, therefore, relatively nondispersible. Conversely, liquid or gaseous materials are relatively easy to release if the container is breached in an accident.

Table C.5. Estimated release fractions for Type A and Type B packages under various accident severity categories

Severity category	Release fraction[a]			
	NUREG-0170			
	Type A[b]	Type B[c]	Type B[d]	TRUPACT-II[e]
I	0	0	0	0
II	0.01	0	6×10^{-8}	0
III	0.1	0.01	2×10^{-7}	8×10^{-9}
IV	1	0.1	2×10^{-6}	2×10^{-7}
V	1	1	2×10^{-6}	8×10^{-5}
VI	1	1	2×10^{-5}	2×10^{-4}
VII	1	1	2×10^{-5}	2×10^{-4}
VIII	1	1	2×10^{-5}	2×10^{-4}

[a] Values are for total material release fraction (the fraction of material in a package released to the environment during an accident).

[b] *Source:* NRC (1977b), used for depleted UF_6 and UO_2 shipments.

[c] *Source:* NRC (1977b), used for Pu metal shipments.

[d] *Source:* Fischer et al. (1987), used for fresh MOX fuel shipments.

[e] *Source:* DOE (1997). Aerosolized and respirable fractions are both assumed to equal 1.0.

The aerosolized fraction for the UF_6 was taken to be 0.01 except in the case of higher severity accidents (Categories VI through VIII) involving fire, for which it was taken to be 0.33 (Policastro et al. 1997). The respirable fraction was taken to be 1 for all accidents. For UO_2, which was assumed to behave as a loose powder, the aerosolized fraction was set to 0.1, with a respirable fraction of 0.05 (Biwer et al. 1997). The aerosolized fraction and the respirable fraction were taken to be 1×10^{-6} and 0.05, respectively, for the Pu metal expected to behave as immobile material (Neuhauser and Kanipe 1992). For the MOX fuel, the aerosolized fraction was taken to be 1, and the respirable fraction taken to be 0.05 in accordance with spent fuel particulates as derived from NUREG-0170 in Neuhauser and Kanipe (1992). Release fractions used for the TRU waste shipments are given separately in Table C.5.

C.2.4.3 Atmospheric Conditions during Accidents

Hazardous material released to the atmosphere is transported by the wind. The amount of dispersion, or dilution, of the contaminant material in the air depends on the meteorologic conditions at the time of the accident. Because predicting the specific location of an off-site transportation-related accident and the exact meteorologic conditions at the time of the accident is impossible, generic atmospheric conditions were selected for the accident risk assessment. Neutral weather conditions were assumed. These conditions were represented by Pasquill atmospheric stability Class D with a wind speed of 4 m/s (9 mph). Because neutral meteorological conditions are the most frequently occurring atmospheric stability condition in the United States, these conditions are most likely to be present in the event of an accident involving a hazardous material shipment. Observations at National Weather Service surface meteorological stations at more than 300 U.S. locations indicate that on a yearly average, neutral conditions (represented by Pasquill Classes C and D) occur about half (50%) the time; stable conditions (Pasquill Classes E and F) occur about one-third (33%) of the time; and unstable conditions (Pasquill Classes A and B) occur about one-sixth (17%) of the time (Doty et al. 1976). The neutral category predominates in all seasons, but it is most prevalent (nearly 60% of the observations) during winter.

C.2.5 Radiological Risk Assessment Input Parameters and Assumptions

The dose (and, correspondingly, the risk) to populations during routine transportation of radioactive materials is directly proportional to the assumed external dose rate from the shipment. The actual dose rate from the shipment is a complex function of the composition and configuration of shielding and containment materials used in the packaging, the geometry of the loaded shipment, and the characteristics of the radioactive material itself.

Shipments of depleted UF_6 and UO_2 have been studied previously (Biwer et al. 1997) for the Depleted UF_6 Programmatic EIS (PEIS) (DOE 1999a). Representative shipment dose rates were developed using the MicroShield™ shielding code (Negin and Worku 1992). The input to MicroShield™ consisted of the activity of a material, the geometry and composition of the shipping package, and the amount of material in the package. Where multiple packages per shipment were assumed, a dose rate for the shipment was derived from the summation of the individual package dose rates, taking into consideration the configuration of the packages on the transport vehicle and the relative distances to a receptor.

Table C.6 lists the external dose rates developed for the Depleted UF_6 PEIS and used in this transportation analysis. The dose rates are presented in terms of the transport index (TI), which is the dose rate at 1 m (3 ft) from the lateral sides of the transport vehicle. The regulatory limit established in 49 CFR Part 173.441 (*Radiation Level Limitations*) and 10 CFR Part 71.47 (*External Radiation Standards for All Packages*) to protect the public is 0.1 mSv/h (10 mrem/h) at 2 m (6 ft) from the outer lateral sides of the transport vehicle. The estimated dose rate at a distance of 1 m (3 ft) from a truck shipment of depleted UO_2 identical to that considered for this analysis was 0.0076 mSv/h (0.76 mrem/h). Depleted UF_6 in larger, 14-ton cylinders in overcontainers was estimated to have external dose rates of 0.0023 mSv/h (0.23 mrem/h) and 0.0024 mSv/h (0.24 mrem/h) for truck (1 cylinder/tractor-trailer) and rail (4 cylinders/railcar) shipments, respectively. For this analysis, depleted UF_6 shipments, each involving five 30B cylinders, were assumed to have an external dose rate of 0.0024 mSv/h (0.24 mrem/h), which is more consistent with the line source geometry of the railcar shipments in the Depleted UF_6 PEIS (DOE 1999a). These estimated dose rates for the depleted uranium shipments are less than 5% of the allowed maximum value. A value of 0.040 mSv/h (4.0 mrem/h) was used for the WSB TRU waste shipments. This value represents the highest estimated dose rate for TRUPACT-II truck shipments estimated for any TRU waste generator site considered in the *Waste Isolation Pilot Plant Disposal Phase Final Supplemental Environmental Impact Statement* (DOE 1997). For MOX fuel shipments, preliminary analysis has estimated a conservative value of 0.0484 mSv/h (4.84 mrem/h) for the external dose rate at 1 m (DCS 2001a). The regulatory maximum of 0.10 mSv/h (10 mrem/h) at 2 m was assumed for the plutonium metal. This dose rate corresponds approximately to 0.14 mSv/h (14 mrem/h) at 1 m.

In addition to the specific parameters discussed previously, values for a number of general parameters must be specified within the RADTRAN code to calculate radiological risks. These general parameters define basic characteristics of the shipment and traffic and are specific to the mode of transportation. The user's manual for the RADTRAN code (Neuhauser and Kanipe 1992) contains derivations and descriptions of these parameters. The general RADTRAN input parameters used in the radiological transportation risk assessment are summarized in Table C.7.

C.2.6 Hazardous Chemical Risk Assessment Input Parameters and Assumptions

To estimate the consequences of chemical accidents, two potential health effects end points were evaluated: (1) adverse effects and (2) irreversible adverse effects. Potential adverse effects range from mild and transient effects — such as respiratory irritation, redness of the eyes, and skin rash — to more serious and potentially irreversible effects. Potential irreversible adverse effects are defined as effects that generally occur at higher concentrations and are permanent in nature — including death, impaired organ function (such as damaged central nervous system or lungs), and other effects that may impair everyday functions.

Table C.6. External dose rates and package sizes used in RADTRAN

Shipment	Dose rate at 1 m [mSv/h (mrem/h)]	Package size (m)
UF_6	0.0024 (0.24)	12[a]
UO_2	0.0076 (0.76)	6.0[a]
Pu metal	0.14 (14)	9
TRU waste	0.040 (4.0)	7.4
MOX fuel	0.0484 (4.84)	3.66[b]

[a] *Source:* Biwer et al. (1997).

[b] Active length of fuel assembly (DCS 2001a).

Table C.7. General RADTRAN input parameters[a]

Parameter	Truck[b]
Number of crew members	2
Distance from source to crew (m)	3.1
Average vehicular speed (km/h)[c]	
Rural	88.49
Suburban	40.25
Urban	24.16
Stop time (h/km)	0.011
Number of people exposed while stopped	50
Distance for exposure while stopped (m)	20
Number of people per vehicle sharing route	2
Population densities (persons/km^2)[d]	Route specific
One-way traffic count (vehicles/h)	
Rural	470
Suburban	780
Urban	2,800

[a] Accident conditional probabilities are listed by severity category in Table C.4; accident release fractions are given in Table C.5.

[b] *Source:* Biwer et al. (1997).

[c] Fraction of rural and suburban travel on freeways was set to 1 in RADTRAN. Thus, the rural speed was used for both urban and suburban zones.

[d] Route-specific population densities are listed in Table C.1.

For uranium compounds, an intake of 10 mg or more was assumed to cause potential adverse effects (McGuire 1991), and an intake of 30 mg or more was assumed to cause potential irreversible adverse effects. These intake levels are based on NRC guidance (NRC 1994). For hydrogen fluoride (HF), which is a by-product of UF_6 reacting with moisture in the air following an accidental release, potential adverse effects levels were assumed to occur at levels that correspond to Emergency Response Planning Guideline No. 1 (ERPG-1) or equivalent levels, and potential irreversible adverse effects levels were assumed to occur at levels that correspond to ERPG-2 or equivalent levels. The ERPG values have been generated by teams of toxicologists who review all published (as well as some unpublished) data for a given chemical (AIHA 1996). In addition to potential irreversible adverse effects, the number of fatalities from accidental chemical exposures was estimated to facilitate comparisons with radiological impacts. For exposures to uranium and HF, it was estimated that the number of fatalities occurring would be about 1% of the number of irreversible adverse effects (EPA 1993a; Policastro et al. 1997).

Application of the FIREPLUME code involves the choice of a number of parameters that affect the results. Input values were selected to represent reasonable conditions at a generic location without being too conservative. More details about the models and input parameters are presented in Post et al. (1994a,b) and Brown et al. (1997).

C.2.7 Routine Nonradiological Vehicle Emission Risks

Vehicle-related risks during incident-free transportation include incremental risks caused by potential exposure to airborne particulate matter from fugitive dust and vehicular exhaust emissions. The health end point assessed under routine transport conditions is the excess (additional) latent mortality caused by inhalation of vehicular emissions. These emissions are primarily in the form of diesel exhaust and fugitive dust (resuspended particulates from the roadway). Strong epidemiological evidence exists suggesting that increases in ambient air concentrations of PM_{10} (particulate matter with a mean aerodynamic diameter less than or equal to 10 μm) lead to increases in mortality (EPA 1996a,b). Currently, it is assumed that no threshold exists and that the dose-response functions for most health effects associated with PM_{10} exposure, including premature mortality, are linear over the concentration ranges investigated (EPA 1996a). Over both the short and long terms, fatalities (mortality) may result from life-shortening respiratory or cardiovascular diseases (EPA 1996a; Ostro and Chestnut 1998). The long-term fatalities also are assumed to include those from cancer.

The increased ambient air particulate concentrations caused by the transport vehicle, due to fugitive dust and diesel exhaust emissions, were related to such premature latent fatalities in the form of risk factors by Biwer and Butler (1999) for transportation risk assessments. Thus, in this assessment, a value of 8.36×10^{-10} latent fatalities/km for truck transport was used. This value is for heavy combination trucks (truck class VIIIB). The risk factor is for areas with an assumed population density of 1 person/km^2. One-way shipment risks are obtained by multiplying the appropriate risk factor by the average population density along the route and the route distance. The risks reported for routine vehicle risks in this analysis are for round-trip travel of the transport vehicle.

The vehicle risks reported here are estimates based on the best available data. However, as is true for the radiological risks, there is a large, not readily quantifiable, degree of uncertainty in the vehicle emission risk factors. For example, large uncertainties exist as to the extent of increased mortality with an incremental rise in particulate air concentrations and as to whether there are threshold air concentrations that are applicable. Also, estimates of the particulate air concentrations caused by transport vehicles are dependent on location, road conditions, vehicle conditions, and weather.

As discussed by Biwer and Butler (1999), there are large uncertainties in the human health risk factors used to develop the emission risks. In addition, because of the conservatism of the assumptions made to reconcile results with those presented in an EPA study (EPA 1993b), latent fatality risks estimated with the above risk factor may be considered to be near an upper bound. Use of this risk factor for truck class VIIIB will give estimated fatalities comparable to those from accident fatalities in some cases. In addition, the question as to what exactly constitutes a fatality as a direct consequence of increased PM_{10} levels from vehicle emissions is still an open question, but long-term fatalities have been associated with increased levels of PM_{10} (Biwer and Butler 1999).

C.3 Transportation Impacts

Single shipment transportation impacts are presented in Table C.8. Total collective population transportation impacts are presented in Section 4.4.1.3.

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Table C.8. Single-shipment collective population transportation risks

	Depleted UF_6	Depleted UO_2	Pu metal		MOX	TRU Waste
Impact category	From Portsmouth, OH to Wilmington, NC	From Wilmington, NC to MOX facility	From Pantex to PDCF	From Hanford to PDCF	From MOX facility to surrogate commercial reactor	From WSB to WIPP
Population impacts						
Cargo-related[a]						
Radiological impacts						
Dose risk[b] (person-rem)						
Routine crew	0.0055	0.0075	0.14	0.27	0.16	0.16
Routine public						
Off-link	4×10^{-4}	2.2×10^{-4}	0.026	0.035	0.0064	0.0063
On-link	9.8×10^{-4}	5.8×10^{-4}	0.072	0.12	0.016	0.020
Stops	0.0041	0.0029	0.33	0.67	0.057	0.10
Total	0.0054	0.0037	0.43	0.82	0.079	0.13
Accident[c]	0.0023	8.2×10^{-4}	8.8×10^{-5}	3.8×10^{-4}	0.027	0.0027–0.021
Latent cancer fatalities[d]						
Crew fatalities	3×10^{-6}	5×10^{-6}	9×10^{-5}	2×10^{-4}	9×10^{-5}	9×10^{-5}
Public fatalities	5×10^{-6}	3×10^{-6}	3×10^{-4}	5×10^{-4}	6×10^{-5}	8×10^{-5}– 9×10^{-5}
Chemical impacts						
Irreversible adverse effects[e]	1.2×10^{-9}	0	NA[f]	NA	NA	NA
Vehicle-related[g]						
Emission fatalities	4×10^{-4}	1×10^{-4}	7×10^{-4}	9×10^{-4}	0.001	6×10^{-4}
Accident fatalities	2.7×10^{-5}	2×10^{-5}	5.4×10^{-5}	1.1×10^{-4}	4.8×10^{-5}	5.8×10^{-5}

[a] Cargo-related impacts are impacts attributable to the radioactive or chemical nature of the waste material.

[b] To convert from person-rem to person-Sv, multiply by 0.01.

[c] Dose risk is a societal risk and is the product of accident probability and accident consequence.

[d] Latent cancer fatalities are calculated by multiplying dose by the FGR 13 health risk conversion factor of 0.06 fatal cancer per person-Sv (6×10^{-4} fatal cancer per person-rem) (Eckerman et al. 1999).

[e] Potential for irreversible adverse effects from chemical exposures. Exposure to HF or uranium compounds is estimated to result in fatality of approximately 1% or less of those persons experiencing irreversible adverse effects (Policastro et al. 1997).

[f] NA = not applicable.

[g] Vehicle-related impacts are impacts independent of the cargo in the shipment.

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APPENDIX D:

SOCIOECONOMICS

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SOCIOECONOMICS

This appendix (1) discusses the methods and briefly describes the data sources that were used to perform the socioeconomic analyses for this environmental impact statement (EIS) (Section D.1) and (2) presents fiscal data collected from each of the counties, cities, and school districts in the region of influence (as defined below) (Section D.2).

D.1 Impact Assessment Methods

The socioeconomic analysis for a Mixed Oxide Fuel Fabrication Facility (the proposed MOX facility), including its supporting facilities, the Pit Disassembly and Conversion Facility (PDCF) and the Waste Solidification Building (WSB), at the Savannah River Site (SRS) assessed impacts at two geographic scales. A regional economic area (REA) was used to assess impacts on employment and income for the various alternatives. An REA is a broad market area defined by the economic linkages among the regional industrial and service sectors and the communities within a region. In this case, the REA consists of 15 counties in South Carolina and Georgia (see Table D.1). A region of influence (ROI) that consists of the four counties in which the majority (90%) of the SRS employees live was used to assess impacts on population, housing, community services, and traffic (see Table D.1).

D.1.1 Impacts on Regional Employment and Income

The assessment of projected impacts of the proposed facilities on regional employment and income was based on the use of regional economic multipliers. These multipliers capture the indirect (off-site) effects of on-site activities associated with construction and operation.

To estimate employment impacts of the proposed MOX facility, the PDCF, and the WSB at the SRS, direct and indirect employment impacts associated with construction and operation were taken from data provided in the Surplus Plutonium Disposition (SPD) EIS (DOE 1999, Appendix F, Section 9.2). The indirect (off-site) employment impacts were estimated from these data by using the relationship between direct and indirect employment of the facilities in the REA at the SRS as estimated in the SPD EIS. By using direct (on-site) facility employment data taken from the project Environmental Report (ER)(DCS 2002) as the basis for calculation, the indirect employment impacts were estimated for the peak year of construction and for the first year of operations.

The impact of facility construction and operation on regional incomes was estimated by using facility employment impact estimates together with average regional income multipliers for the REA taken from Intelligent Multi-Resource Planning (IMPLAN) regional economic data (MIG, Inc., 2001). IMPLAN input-output economic accounts show the flow of commodities to

Table D.1. Jurisdictions included in the regional economic area and ROI at the SRS

Regional Economic Area

Georgia	**South Carolina**
Counties	Counties
Burke	Aiken
Columbia	Allendale
Glascock	Bamberg
Jefferson	Barnwell
Jenkins	Edgefield
Lincoln	
McDuffie	
Richmond	
Warren	
Wikes	

Region of Influence

Georgia	**South Carolina**
Counties	Counties
Columbia	Aiken
Richmond	Barnwell
Cities	Cities
Augusta	Aiken
Blythe	Jackson
Grovetown	New Ellenton
Harlem	North Augusta
Hephzibah	Wagener
School Districts	School Districts
Columbia County	Aiken County
Richmond County	Barnwell #19
	Barnwell #29
	Barnwell #45

industries from producers and institutional consumers. The accounts also show consumption activities by workers, owners of capital, and imports from outside the region. The IMPLAN model contains 528 sectors representing industries in agriculture, mining, construction, manufacturing, wholesale and retail trade, utilities, finance, insurance and real estate, and consumer and business services. The model also includes information for each sector on employee compensation; proprietary and property income; personal consumption expenditures; federal, state, and local expenditures; inventory and capital formation; imports; and exports.

Impacts on employment are described in terms of the total number of jobs created in the region in the peak year of construction and in the first year of operation. The relative impact of the increase in employment in the REA was calculated by comparing total facility construction employment over the period in which construction would occur with baseline REA employment forecasts over the same period. Impacts are expressed in terms of the percentage point difference in the average annual employment growth rate with and without facility construction. The forecasts were based on data from the U.S. Department of Commerce (U.S. Bureau of the Census 1992, 2002b).

D.1.2 Impacts on Population

An important consideration in assessing potential impacts of the proposed facilities was the number of workers, families, and children who might move into the ROI (in-migrate), either temporarily or permanently, with construction and operation of the proposed facilities. The capacity of regional labor markets to provide sufficient workers in the appropriate occupations required for facility construction and operation is closely related to the occupational profile of the REA and to occupational unemployment rates. To estimate the in-migration that would occur to satisfy direct labor requirements, the analysis developed estimates of available labor in each direct labor category on the basis of REA unemployment rates applied to each occupational category. In-migration associated with indirect labor requirements was derived from estimates of available labor in the REA economy as a whole able to satisfy the demand for labor by industry sectors in which facility spending would initially occur. The national average household size was used to calculate the number of additional family members who would accompany direct and indirect in-migrating workers.

Impacts on population are described in terms of the total number of in-migrants arriving in the region in the peak year of construction and in the first year of operation. The relative impact of the increase in population in the REA was calculated by comparing total facility construction in-migration over the period in which construction would occur with baseline REA population forecasts over the same period. Impacts are expressed in terms of the percentage point difference in the average annual population growth rate with and without project construction. The forecasts were based on data from the U.S. Census Bureau (U.S. Bureau of the Census 2002a).

D.1.3 Impacts on Local Housing Markets

The in-migration of workers that would occur during construction and operation would have the potential to substantially affect the housing market in the ROI. The analysis considered these impacts by estimating the increase in demand for rental housing units in the peak year of construction and for owner occupied housing in the first year of operation that would result from the in-migration of both direct and indirect workers into the ROI. The impacts on housing are described in terms of the number of rental units required in the peak year of construction and the number of owner occupied units required in the first year of operations. The relative impact on the existing housing in the ROI was estimated by comparing the calculated facility-related housing demand with the forecasted number of vacant rental housing units in the peak year of construction and the forecasted number of vacant owner occupied units in the first year of operations. The forecasts were based on data from the U.S. Census Bureau (U.S. Bureau of the Census 1994, 2002a).

D.1.4 Impacts on Community Services

In-migration associated with construction and operation of the facilities could increase demand for educational services and for other public services (e.g., police and fire protection, health services) in the ROI. Estimates of the total number of in-migrating workers and their families for facility construction and operation were used as a basis for calculating the potential increase in public service demands in the core ROI counties in which the majority of new workers would be expected to locate. Impacts of the facilities on county, city, and school district revenues and expenditures were also calculated on the basis of baseline data provided in the jurisdictions' annual comprehensive financial reports. Impacts were forecasted for the peak year of construction and in the first year of operations on the basis of per capita revenues and expenditures for each jurisdiction. The population forecasts were based on data from the U.S. Census Bureau (U.S. Bureau of the Census 2002a).

Impacts of facility-induced in-migration on community service employment were also calculated for the core ROI counties. The estimated numbers of in-migrating workers and families were used to calculate the numbers of new sworn police officers, firefighters, and general government employees required to maintain the existing levels of service for each community service. Calculations were based on the existing number of employees per 1,000 population for each community service. The analysis of the impact on educational employment estimated the number of teachers in each school district required to maintain existing teacher-student ratios across all student age groups. Impacts on health care employment were estimated by calculating the number of physicians in each county required to maintain the existing level of service. The estimated impacts are given in terms of the number of additional physicians and the number of additional staffed hospital beds required to maintain the existing levels of service (expressed in terms of number of doctors and number of staffed hospital beds per 1,000 population). Information on existing employment and levels of service was collected from the individual jurisdictions providing each service.

D.1.5 Impacts on Traffic

Impacts on traffic in the ROI are described in terms of the effects of the increase in traffic from the facilities on the "levels of service" of major road segments used to commute to and from the site by existing site employees. The analysis allocated trips made by construction workers to individual road segments on the basis of the residential distribution of existing site workers. The impact on the existing annual average number of daily trips was then calculated, and the impact on the level of service provided by each individual segment was estimated. Traffic information used in the analysis was collected from state and county transportation departments.

D.1.6 Impacts of Accidents

The impacts of accidents associated with a MOX facility on agriculture, water, and fisheries resources, and subsequently on the economies of communities surrounding SRS, were not estimated in the EIS because it is not expected that the impacts from an accident would be significant. In the case of the most serious accident, potential damage to crops under the plume in the event of an airborne release and the subsequent damage to water resources from the associated runoff would be small because the amount of radioactive material deposited per unit area would be relatively small. Dilution of runoff would occur fairly rapidly in the affected rivers and streams and would not cause any significant risk to the economies of the communities downstream of the location of the proposed facility. Any interdiction of crops as a result of the deposition of radioactive material would be a limited, one-time event, and if it were to occur at all, only would affect a small number of farm communities. Emergency response activities associated with a release from the facility would be handled by local emergency response and health authorities already prepared for accidents at SRS, with no resulting additional burden on local community financial resources.

D.2 Region of Influence Fiscal Data

Financial data for local governmental bodies and school districts in the ROI for the facilities are presented in Tables D.2 and D.3.

Table D.2. ROI local government financial data ($ millions)

Category	Columbia County, Georgia		
	Columbia County	**Town of Grovetown**	**Town of Harlem**
Revenues			
Taxes	23.4	0.7	0.9
Licenses and permits	0.3	0.0	0.0
Intergovernmental	1.6	1.0	0.0
Charges for services	1.1	0.4	0.2
Fines and forfeits	1.6	0.2	0.1
Miscellaneous	0.9	0.1	0.0
Total	28.9	2.5	1.3
Expenditures			
General government	8.1	0.7	0.2
Public safety	11.8	0.7	0.4
Highways and streets	3.3	0.3	0.2
Health, welfare and sanitation	0.9	0.4	0.1
Culture and recreation	2.5	0.0	0.0
Debt service	0.0	0.0	0.0
Intergovernmental	0.0	0.0	0.0
Other	0.9	0.0	0.0
Total	27.5	2.1	1.0
Revenues less expenditures	+1.4	+0.3	+0.3

Table D.2. Continued

	Richmond County, Georgia		
Category	**City of Augusta/ Richmond County**	**City of Blythe**	**City of Hephzibah**
Revenues			
Taxes	55.9	0.1	0.8
Licenses and permits	2.3	0.0	0.0
Intergovernmental	3.0	0.0	0.0
Charges for services	12.8	0.0	0.0
Fines and forfeits	9.0	0.0	0.0
Miscellaneous	3.0	0.1	0.1
Total	86.0	0.2	0.9
Expenditures			
General government	26.3	0.1	0.1
Public safety	34.2	0.1	0.4
Highways and streets	6.1	0.0	0.0
Health, welfare and sanitation	5.2	0.0	0.0
Culture and recreation	9.3	0.0	0.0
Debt service	2.0	0.0	0.0
Intergovernmental	2.4	0.0	0.0
Other			
Total	85.5	0.2	0.5
Revenues less expenditures	+0.5	0.0	+0.4

Table D.2. Continued

Category	Aiken County, South Carolina		
	Aiken County	City of Aiken	Town of Jackson
Revenues			
Taxes	16.0	6.4	0.2
Licenses and permits	0.6	4.6	0.1
Intergovernmental	7.7	1.5	0.0
Charges for services	2.0	3.7	0.2
Fines and forfeits	3.2	0.6	0.2
Miscellaneous	1.0	11.0	0.0
Total	30.5	27.8	0.7
Expenditures			
General government	12.1	1.6	0.5
Public safety	10.6	5.4	0.1
Highways and streets	3.7	1.9	0.0
Health, welfare and sanitation	1.7	2.4	0.1
Culture and recreation	2.4	2.3	0.0
Debt service	0.0	0.3	0.0
Intergovernmental	0.0	0.0	0.0
Other	0.0	11.8	0.3
Total	30.5	25.7	0.9
Revenues less expenditures	0.0	+2.1	-0.2

Table D.2. Continued

Category	Aiken County, South Carolina Town of New Ellenton	 City of North Augusta	 Town of Wagener
Revenues			
Taxes	0.3	3.7	0.1
Licenses and permits	0.1	2.0	0.1
Intergovernmental	0.1	0.6	0.0
Charges for services	0.2	0.8	0.1
Fines and forfeits	0.1	0.5	0.0
Miscellaneous	0.0	0.3	0.1
Total	0.8	7.9	0.4
Expenditures			
General government	0.2	1.5	0.2
Public safety	0.4	3.4	0.1
Highways and streets	0.1	0.8	0.0
Health, welfare and sanitation	0.1	0.0	0.1
Culture and recreation	0.1	1.7	0.0
Debt service	0.0	0.0	0.0
Intergovernmental	0.0	0.0	0.0
Other	0.0	0.3	0.0
Total	0.9	7.7	0.4
Revenues less expenditures	-0.1	+0.2	0.0

Table D.2. Continued

Category	Barnwell County	City of Barnwell	Town of Blackville	Town of Williston
	Barnwell County, South Carolina			
Revenues				
Taxes	3.0	1.2	0.4	1.1
Licenses and permits	0.0	0.4	0.1	0.0
Intergovernmental	1.6	0.2	0.1	0.2
Charges for services	0.0	0.2	0.2	0.0
Fines and forfeits	0.0	0.1	0.2	0.0
Miscellaneous	4.3	0.0	0.0	0.0
Total	8.9	2.1	1.0	1.3
Expenditures				
General government	2.5	0.4	0.1	0.2
Public safety	2.0	0.9	0.5	0.6
Highways and streets	0.6	0.2	0.0	0.2
Health, welfare and sanitation	1.1	0.2	0.1	0.2
Culture and recreation	0.2	0.0	0.1	0.0
Debt service	0.2	0.0	0.0	0.0
Intergovernmental	0.0	0.0	0.0	0.0
Other	2.0	0.0	0.1	0.1
Total	8.6	1.7	0.9	1.3
Revenues less expenditures	+0.3	+0.4	+0.1	0.0

Sources: Columbia County, annual financial report, June 30, 2000; City of Grovetown Financial Report, December 31, 2000; City of Harlem Annual Financial Report, December 31, 2000; City of Augusta/Richmond County, Annual Financial Statements, December 31, 1999; City of Blythe, Annual Financial Report, December 31, 2000; City of Hephzibah, Financial Statements and Independent Auditors Report, June 30, 2000; Aiken County, Annual Financial Report, June 30, 2000; City of Aiken, Annual Report, June 30, 2000; Town of Jackson, Financial Statements, June 30, 2000; Town of New Ellenton, Financial Statements, June 30, 1999; City of North Augusta, Annual Financial Statements, December 31, 2000; Town of Wagener, Financial Statements, June 30, 1999; Barnwell County, Audited Financial Statements, June 30, 2000; City of Barnwell, Financial Statements, September 30, 2000; Town of Blackville, Audited General Purpose Financial Statements, June 30, 2000; Town of Williston, Financial Statements, June 30, 2000.

Table D.3. ROI school district financial data ($ millions)

Category	Georgia		South Carolina	
	Columbia County	Richmond County	Aiken County	Barnwell County[a,b]
Revenues				
Local sources	32.8	81.2	31.5	8.9
State sources	64.4	134.6	66.5	20.0
Federal sources	0.1	16.1	0.1	0.1
Other	2.2	0.0	0.0	0.0
Total	99.5	231.9	98.1	29.0
Expenditures				
Administration and instruction	65.5	161.1	65.0	17.7
Services	27.9	48.0	34.6	8.3
Debt service	0.0	0.0	0.0	1.0
Other	0.0	0.0	0.0	1.2
Total	93.4	209.1	99.8	28.2
Revenues less expenditures	+6.1	+22.8	-1.6	+0.8

[a] Includes Williston School District #19, #29, and #45.

[b] Revenue data estimated based on South Carolina Department of Education, 2001 School and District Report Cards, and Williston School District #29, Financial Statements, June 30, 2000.

Sources: Columbia County Board of Education, General Purpose Financial Statements, June 30, 2000; Georgia Department of Education, Local, State and Federal Revenue Report Fiscal Year 2001, available at http://dbl.doe.k12go.us:8001/ows-bin/owo/fin_pack_revenue.display.proc; Consolidated School District of Aiken County Financial Statements, June 30, 2000; South Carolina Department of Education, 2001 School and District Report Cards, available at http://www.unyscschools.com/reportcard/2001/; DCS 2002; Williston School District #29, Financial Statements, June 30, 2000.

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APPENDIX E:

HUMAN HEALTH RISK

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HUMAN HEALTH RISK

This appendix provides detailed information concerning the input data and assumptions used in the chemical and radiological human health risk assessments performed for this Mixed Oxide (MOX) Fuel Fabrication Facility Environmental Impact Statement. For chemicals, only accidents are addressed in this appendix; the evaluation of health impacts from chemical exposures during normal operations is discussed in Sections 3.10, 4.2.2, and 4.3.1.

E.1 Chemical

Impacts from the accidental release of chemical materials were assessed for Savannah River Site (SRS) workers outside the restricted area of the facility (“SRS employees”) and members of the public. Impacts to facility workers would be sensitive to the specific circumstances of each accident and are not estimated in this assessment.

About 30 MOX process chemicals were identified for use in the proposed MOX facility and support facilities. A chemical was eliminated from the analysis if it had a very low volatility (i.e., vapor pressure <1 Pa (7.5 x 10^{-3} mmHg), had a low toxicity (i.e., a temporary emergency exposure limit 1 [TEEL 1] $\geq$15 mg/m^3, was stored in small quantities (maximum container quantity <38 L [10 gal]), or was stored and used as a solid. Impacts of a chemical release with these characteristics would be expected to be minimal. Chemicals eliminated from evaporative spill analysis because of very low vapor pressures at ambient temperatures were (1) manganese nitrate, (2) oxalic acid, (3) silver nitrate, (4) uranyl nitrate, (5) sodium hydroxide, (6) aluminum nitrate, and (7) phosphoric acid. Chemicals eliminated because of low toxicity were (1) aluminum sulfate, (2) isopropanol, (3) sodium carbonate, (4) sodium sulfite, and (5) zirconium nitrate. Chemicals eliminated because they are solids were azodicarbonamide, sodium nitrite, and zinc stearate. All other material inventories were analyzed in detail. A spill of sulfuric acid at the PDCF was also eliminated from further analysis based on the assumption that it would contain a concentration of less than 30% sulfur trioxide (i.e., not fuming) and would therefore not pose a toxic inhalation hazard.

The quantity of material released to the atmosphere was determined on the basis of the available physical properties of the spilled chemical (e.g., vapor pressure, mass transfer coefficient), meteorological conditions (e.g., wind speed), and the chemical storage conditions (e.g., temperature, pressure) (see Table E.1). This quantity defined the source term, which was determined either by estimating chemical evaporation rates or pressurized release rates and the associated release durations. The evaporative source term was used as input to the National Oceanic and Atmospheric Administration (NOAA) Areal Locations of Hazardous Atmospheres (ALOHA) dispersion model (Reynolds 1992). Impacts from pressurized releases were simulated with the HGSYSTEM model.

Table E.1. Chemical inventory, spill quantity, concentrations, and mole fraction (MF) calculations[a]

				Density		Concentrations			
Facility and Chemical name	**Formula**	**MW_{solute} (g/mole)**	**MW_{sol} (g/mole)**	**Pure Compound (kg/m^3)**	**Solution (kg/L)**	**M_{pure} [100%] (moles/L)**	**M (moles/L)**	**(%)**	**N (moles/ L x #_H atoms)**
MOX (BAP and BRP)									
Dodecane	$C_{12}H_{26}$	170.34	170.3	750	0.75	4.4	4.4	100	44.28
Nitrogen tetroxide	N_2O_4	92.01	92	1,450	1.45	15.76	15.76	***100***	15.76
Hydrazine	H_6N_2O	32.05	50.1	1,030	1.01	32.14	11.25	***35***	67.5
Hydrazine-NaOH mixture	N_2H_4-NaOH	32.05	72.0	1,030	1.03	32.14	0.03	0.10	***0.16***
Hydrazine/hydroxylamine nitrate mixture	$H_4N_2O_4 - N_2H_4$	32.05	128.1	1,030	1.54	32.14	***0.15***	0.47	0.6
Hydroxylamine nitrate (HAN)	$H_4N_2O_4$	96.05	114.1	1,540	1.29	16.03	***1.90***	11.8	7.6
Hydrogen peroxide	H_2O_2	34.02	52	1,440	1.27	42.33	14.82	***35***	29.6
Tributyl phosphate (TBP)	$C_{12}H_{27}O_4P$	266.36	266.4	980	0.98	3.68	3.68	***100***	99.3
Nitric acid (13.6 M)	HNO_3	63.01	81	1,380	1.28	21.90	13.6	62.1	***13.6***
Nitric acid (2.1 M)	HNO_3	63.01	81	1,380	1.20	21.90	2.1	9.6	***2.1***
WSB									
Nitric acid (10.1 M)	HNO_3	63.01	81	1,276	1.18	15.74	10.1	**64**	10.1
PDCF[b]									
Chlorine (gas)	Cl_2	70.91	70.9	1,491	1.49	21.03	21.03	***100***	21.03

Table E.1. Continued

	Inventory		Spill volume		Spill moles				Spill mass		
Facility and Chemical name	**Process tank fill quantity (kg)**	**(ga)l**	**Solution (gal)**	**(L)**	**n_{solute} (moles)**	**$n_{solvent}$ (water) (moles)**	**$n_{solution}$ (moles)**	**MF**	**m_{solute} (kg)**	**$m_{solvent}$ (x or H_2O) (kg)**	**$m_{sol.}$ (kg)**
MOX (BAP and BRP)											
Dodecane	511	180	180	681	2,998.5	0	2,998.5	1	510.8	0.00	510.8
Nitrogen tetroxide	1,317	240	240	908	14,315.2	0	14,315.2	1	1,317	0.00	1,317
Hydrazine	491	126	126	478	5,371.4	3,491	8,862.8	0.6061	268.9	62.90	331.8
Hydrazine-NaOH mixture	1,497	384	384	1,455	46.6	46,725	46,771.3	0.0010	4.4	841.75	846.1
Hydrazine/hydroxylamine nitrate mixture	2,445	627	627	2,376	356.4	76,012	76,368.8	0.0047	45.7	1,369.36	1,415.0
Hydroxylamine nitrate (HAN)	1,166	200	200	758	1,440.2	1,270	2,709.7	0.5315	138.3	22.87	161.2
Hydrogen peroxide	300	55	55	208	3,088.6	2,008	5,096.2	0.6061	105.1	36.17	141.2
Tributyl phosphate (TBP)	467	126	126	478	1,757.0	0	1,757.0	1	468.0	0.00	468.0
Nitric acid (13.6 M)	841	161	161	610	8,298.6	3,145	11,443.8	0.7252	522.9	56.66	579.6
Nitric acid (2.1 M)	6,901	1,321	1,321	5,007	10,514	9,506	20,020	0.5252	662.5	171.24	833.8
WSB											
Nitric acid (10.1 M)	1,690	350	350	1,327	13,365	4,811	18,176	0.7353	842.1	86.67	928.8
PDCF[b]											
Chlorine (gas)	430	240	240	911	19,158	0	19,158	1	430	0.00	430

[a] In general, chemicals used, concentrations, and process tank fill quantities for the proposed MOX facility were obtained from DCS (2004b, Table 8-2a and DCS 2003a, 2004a); values for the PDCF were obtained from DOE (1999, Appendix E). Concentrations obtained from these sources are in bold italics; others are calculated values.

[b] Sulfuric acid was also listed for this facility with an annual usage of 470 kg. The concentration was not given, so quantitative spill modeling was not performed. If dilute, the solution would have low volatility and would present minimal hazards from accidental spills. However, if it was a concentration of 30% or more sulfur trioxide, sulfuric acid is highly water reactive and could present inhalation risks to facility workers or SRS employees if spilled.

Abbreviations: MOX: proposed MOX Fuel Fabrication Facility; BAP: Aqueous Polishing Area; BRP: Reagent Processing Building; WSB: Waste Solidification Building; PDCF: Pit Disassembly and Conversion Facility.

For modeling potential impacts to the general public at the SRS site boundary (approximately 8.2 km [5.1 mi] from the proposed MOX facility), the estimated source term was used as input to the ALOHA dispersion model. For modeling potential impacts to SRS workers (assumed to be located a minimum of 100 m [330 ft] from the proposed MOX facility), the ARCON96 model (Ramsdell and Simonen 1997) was used because this model accounts for near-field concentrations affected by low wind speeds, plume meander, and building wake effects. This model is also used to be consistent with U.S. Nuclear Regulatory Commission (NRC) guidance regarding control room habitability during a hazardous chemical release (NRC Regulatory Guide 1.78 (NRC 2001). ARCON96 was used for modeling impacts for all receptors (SRS workers and general public) for uranium dioxide powder releases, similar to the modeling done for accidental releases of other radionuclides.

Two of the MOX process chemicals, nitrogen tetroxide and chlorine, are stored as pressurized liquids. Impacts from accidental releases of these two compounds were estimated with the HGSYSTEM model (Post 1994a,b).

Evaporative releases can be considered as either the “puddle” or “direct” source release mode in ALOHA. To use the puddle option, physical properties of the spilled chemical must be known. These properties, such as vapor pressure and molecular weight, are required in estimating evaporation rates. Physical properties are included for approximately 800 pure chemicals in ALOHA’s chemical library. Because only two of the 13 MOX chemicals are included in the library and because the effect of dilute solution adjustments to vapor pressure are not allowed in ALOHA, the direct source release option was used to assess impacts for 11 evaporative spill scenarios. A simple evaporation algorithm, similar to ALOHA and other source evaporation codes, such as ADAM (Raj and Morris 1987; Kawamura and MacKay 1987), was incorporated into a spreadsheet along with the necessary physical properties for each of the eight chemicals. A brief description of the spreadsheet algorithm and its limitations and assumptions are given below:

$$Q_{evap} = \frac{A_p * k_m * MW_m * P_{sat}}{R * T_p}, \tag{E-1}$$

where

A_p = pool area (m^2),

k_m = mass transfer coefficient (m/s),

MW_m = molecular weight of chemical (g/mole),

P_{sat} = saturation vapor pressure of chemical (Pa),

R = Universal Gas Constant (= 8314.472), and

T_p = pool temperature (K).

The evaporation rate from spilled chemical pools is conservatively assumed to be constant, along with the pool temperature and saturation vapor pressure, for the entire release duration. The saturation vapor pressure is set equal to the partial pressure over the pool. The saturation vapor pressure or the partial pressures of the vapors emanating from the pool are a function of the pool temperature through use of chemical-specific Antoine or Harlacher coefficients for inorganic compounds, and through the use of the Clausius-Clapeyron equation for organic compounds (e.g., tributyl phosphate [TBP]). In addition to the assumption that the saturation vapor pressure is equal to the vapor pressure of the chemical at ambient release conditions, the pool temperature is assumed equal to the ambient temperature for the entire release duration. Two ambient cases were assessed, one representing the 95th percentile temperature during the day and the other the 95th percentile during the night (see discussion of the full set of assumed weather conditions below). In cases where temperature-specific data (e.g., Antione coefficients and equations) were not available, temperature-dependent P_{vap} adjustments from a reference level (e.g., STP) were made using the ratio of vapor pressures (reference level to compound value at specified temperature) for compounds with similar physical properties for which these pressures were known at two representative temperature levels.

Two of the chemical compounds in the inventory are binary mixtures. The vapor pressure of mixtures was estimated using the following equation (CCPS 1996):

$$P_{mixvap} = \frac{\sum_{i=1}^{n} MF_i * P_{vapi} * MW_i * e^{-kP_{vap}t}}{\sum_{i=1}^{n} MF_i * MW_i} \tag{E-2}$$

where

MF_i = mole fraction of component i,

P_{vapi} = vapor pressure of component i,

k = $k_m A_p / n_T RT$,

n_T = total number of moles of mixture,

MW_i = molecular weight of component i, and

t = 1.

Raoult’s Law was used to make additional adjustments to spill vapor pressures to account for dilute solutions(such a solution lowers the vapor pressure of the solvent below that of the solute in proportion to the mole fraction of the solute). Table E.1 gives the computed mole fractions used in the analysis, along with the assumed spill volumes and the given chemical inventories and concentrations.

The mass transfer coefficient (k_m), used in most evaporative release models, is computed by one of two main methods used in source emission models, as shown in Equations E-3 and E-4 below. Both values were calculated for each chemical in the analysis and the expression giving the largest mass transfer rate between the liquid and the vapor was used in estimating the chemical-specific evaporative rate:

$$k_m = \frac{N_{Sh} D_{ma}}{d_p} \tag{E-3}$$

$$k_{m_2} = 0.0048\, u_{10}^{7/9}\, d_p^{-1/9} N_{Sc}^{-2/3} \tag{E-4}$$

where

D_{ma} = molecular diffusivity;

d_p = pool depth;

u_{10} = wind speed at 10-m level;

υ_m = kinematic viscosity of the chemical;

N_{Re} = Reynolds number,

= $u_{10} d_p / \upsilon_m$;

N_{Sc} = Schmidt number,

= υ_m / D_{ma};

and

N_{Sh} = Sherwood number,

$$= 0.664 N_{Sc}^{1/3} N_{Re}^{1/2} \quad for \quad N_{Re} < 320{,}000$$

$$= 0.037 N_{Sc}^{1/3} [N_{Re}^{0.8} - 15{,}200] \; for \; N_{Re} \geq 320{,}000 \,.$$

Chemical-specific molecular diffusivities (i.e., of chemical in air) and kinematic viscosities were used in all cases where data were available. In the absence of data (about one-third of the cases), the molecular diffusivity of water or the kinematic viscosity of air were used as substitutes. This estimate was made to be conservative (i.e., use of Graham's Law to estimate molecular diffusivity would produce a value smaller than that of water).

Pressurized releases (i.e., nitrogen tetroxide and chlorine) were modeled with HGSYSTEM's SPILL, AEROPLUME, and HEGADAS modules. To estimate the effects of building aerodynamic influence, the WAKE module was also run, assuming winds perpendicular to the largest building width. The source term was generated from the SPILL module, which simulates the transient liquid release from a pressurized vessel. AEROPLUME is a multicomponent, two-phase thermodynamic aerosol jet model that simulates steady-state release rates from a rupture or a leaking pressurized vessel and the near-field vapor cloud development of the flashed vapor and aerosol components in expelled jet release. Upon formation of the flow field from the release point and establishment of a heavy aerosol laden cloud, the release is linked to the HEGADAS module to simulate dense vapor cloud dispersion and entrainment of ambient air as the cloud moves and disperses downwind. For the building-influenced case, the WAKE module uses the source term from the SPILL module and simulates the aerodynamics in the wake of structures and neutrally buoyant vapor cloud dispersion beyond the wake. In the near-field, WAKE also simulates the concentration field of a release that may get trapped with the cavity recirculation region close to the building. It can also account for air entrainment and escape of vapors initially captured in the cavity region in back of the building, and the transport and dispersion of contaminants in the far wake and beyond.

Site-specific data used are from a 60-m meteorological tower in the H-Area, relatively close to the proposed MOX location. Hourly wind speed and direction and related fluctuating parameters at the 60-m level were available for a 5-year period from 1992 through 1996. The data were preprocessed at the SRS Plant and sent to Argonne for use in the MOX environmental evaluation. The data were reported in Greenwich Mean Time (GMT) and were adjusted in the analysis for local time. Winds at the 60-m level were adjusted to 10 m with a power-law equation.

As mentioned previously, two sets of meteorological conditions, representative of daytime and nighttime conditions and producing conservative emissions and dispersion, were simulated for each evaporative release scenario. Although daytime releases would have more favorable dispersion conditions than nighttime releases, a larger release rate would occur because of higher ambient temperatures and higher near ground-level wind speeds. Both cases needed to be examined in order to determine the controlling, or “worst-case,” site-specific weather conditions.

To be consistent with the ARCON96 model, the 95th percentile daytime and nighttime winds were computed from the 5 years of tower data. Wind speeds were adjusted from the measured 60-m level to the 10-m level by using the standard power-law wind profiles employed in most EPA models (e.g., ISC). The 95th percentile day and night winds are representative of winds that occurred over the measurement period. By definition, 95% of all measured day and night wind speeds at the site would cause more plume dispersion. Similar computations were performed to derive the 95th percentile temperatures, defined as ambient temperatures producing reasonable upper-bound evaporative emission rates. Because higher wind speeds also tend to increase pool evaporation, the 5th percentile wind speeds (i.e., the 5th percentile here is defined as representing the largest wind speeds measured in the 5-year period studies) were also computed. Each of the meteorological cases, including the 95th percentile concentration ARCON case used for estimating 100-m downwind involved worker exposures, is summarized in Table E.2. In addition to wind speed and temperature, the complete set of meteorological parameters used in the ALOHA simulations and the temperatures and wind speeds used in the evaporative spreadsheet calculation tool are summarized in the table. A fourth set of conditions, typical during sunrise or sunset (given in the table), was also run to see if the larger wind speed and neutral conditions would result in more conservative impacts. These conditions resulted in lower impacts and are not further discussed.

Surface roughness was assumed to be 50 cm, which is representative of a good portion of the SRS (Weber 2002). This roughness is large enough to switch the ALOHA computed dispersion coefficients to that representative of urban environments, which will enhance the horizontal and vertical spread of released contaminant as it is advected downwind.

The spill scenario assumed that a forklift punctured a liquid storage tank containing the chemical. Estimates are needed for three key parameters used in determining the evaporation rates (Equation E-1). These parameters are the ambient temperature (T_a), pool area, and vapor pressure. Varying stability conditions, temperatures, and wind speeds were modeled to determine worst-case emission and dispersion conditions. Unlimited mixing was assumed to be consistent with U.S. Environmental Protection Agency (EPA) models (e.g., TSCREEN, ISC) for these conservative nighttime dispersion conditions. The maximum mixing height value, set as a default in ALOHA, is 1,524 m (5,000 ft).

All of the tanks were assumed to be cylindrical in shape with the puncture hole assumed to be located near the tank bottom. Tank dimensions varied depending on the specific chemical inventories. The calculated spill quantities were conservatively assumed to be the full contents of each liquid storage container. The spilled liquid was assumed to spread out on a concrete surface, with a surface roughness of around 3 cm (1.2 in.), to a pool depth of 2.54 cm (1 in.). The final pool area and diameter were computed by assuming a circular pool with a uniform

Table E.2. Scenario meteorology[a,b]

Parameter	Day (95% temp/ 95% winds)	ARCON (95% conc., ARCON)	Night (95% temp/ 95% winds)	Sunrise/ Sunset (95% temp/ 5% winds)
T_a (K)	304.0	299.2	299.2	299.2
T_a (^{o}F)	87.5	78.5	78.5	78.5
u_{10} (m/s)	1.3	2.2	1.3	4.7
Stability	D	F	F	D
Frequency	27%	n/a	11%	100%
z_i (m)	416	n/a	Unlimited	Unlimited
Cloud cover	7/10	Clear to 4/10	Clear to 4/10	Clear to 4/10
RH (%)	85%	65%	65%	65%
Insolation	Slight	Night	Night	Slight

[a] T_a = ambient temperature, u_{10} = wind speed at 10 m, z_i = mixing height, RH = relative humidity.

[b] z_o = surface roughness = 50 cm, season = summer.

Table E.3. Evaporative release modeling results

		Maximum evaporation rate	Release duration[a]	SRS worker exposure	Hazard distance					
					TEEL1		TEEL2		TEEL3	
Chemical	MET	Q (kg/h)	t_d (h)	@100 m (mg/m^3)	Passive (km)	Dense (km)	Passive (km)	Dense (km)	Passive (km)	Dense (km)
Dodecane	Day	0.51	1,000		< 0.01	0.016	< 0.01	< 0.01	< 0.01	< 0.01
	ARCON	0.96	6.1	0.16	-[b]	-	-	-	-	-
	Night	0.31	2,200		0.064	0.054	0.012	0.011	< 0.01	< 0.01
Hydrazine	Day	11.5	28.8		0.41	0.84	0.13	0.26	0.05	0.1
	ARCON	17.4	19.1	2.9	-	-	-	-	-	-
	Night	8.8	37.5		0.93	1.3	0.26	0.4	0.1	0.15
Hydrazine/NaOH	Day	0.13	18,000		0.032	NA[c]	0.01	NA	< 0.010	NA
	ARCON	0.098	23,000	0.02	-	-	-	-	-	-
	Night	0.11	15,000		0.064	NA	0.020	NA	< 0.010	NA
Hydrazine/HAN	Day	30.0	69.8		0.381	NA	0.117	NA	0.045	NA
	ARCON	12.8	163.4	2.2	-	-	-	-	-	-
	Night	23.3	116.5		0.855	NA	0.233	NA	0.086	NA
Hydroxyl-amine nitrate (HAN)	Day	7.7	20.9		0.07	0.135	0.053	0.101	0.024	0.044
	ARCON	11.6	13.9	2.0	-	-	-	-	-	-
	Night	5.9	10.0		0.135	0.206	0.102	0.151	0.045	0.063
Hydrogen peroxide	Day	0.70	202.6		0.023	0.044	< 0.010	0.02	< 0.010	0.011
	ARCON	1.44	155.7	0.2	-	-	-	-	-	-
	Night	0.7	108.4		0.050	0.075	0.022	0.033	0.016	0.022
Tributyl phosphate (TBP)	Day	6.51	71.8		0.103	NA	0.079	NA	0.014	NA
	ARCON	9.81	47.7	1.7	-	-	-	-	-	-
	Night	6.6	26.1		0.233	NA	0.178	NA	0.031	NA
Nitric acid 13.6 M	Day	9.9	58.3		0.197	0.388	0.08	0.146	0.022	0.032
	ARCON	12.9	44.8	2.2	-	-	-	-	-	-
	Night	7.9	38.5		0.417	0.616	0.158	0.223	0.042	0.041
Nitric acid 2.1 M	Day	34.9	23.9		0.378	0.752	0.151	0.282	0.041	0.06
	ARCON	49.5	16.8	8.4	-	-	-	-	-	-
	Night	27.8	11.7		0.86	1.2	0.310	0.412	0.079	0.072
Nitric acid 10.1 M	Day	18.1	46.6		0.269	0.536	0.108	0.204	0.03	0.043
	ARCON	23.5	35.9	4.0	-	-	-	-	-	-
	Night	14.4	58.6		0.586	0.837	0.217	0.299	0.056	0.054

Table E.3. Continued

Chemical		Health index concentration TEEL 1 (mg/m^3)	 TEEL 2 (mg/m^3)	 TEEL 3 (mg/m^3)	Downwind concentration at SRS boundary (8.2 km) (mg/m^3)
Dodecane	Day	7.5	60	750	< 0.7
	ARCON				-
	Night				< 0.7
Hydrazine	Day	0.7	6.6	40	0.004
	ARCON				-
	Night				0.009
Hydrazine/NaOH	Day	0.6	6	40	NS[d]
	ARCON				-
	Night				NS
Hydrazine/HAN	Day	0.6	6	40	NS
	ARCON				-
	Night				NS
Hydroxyl-amine nitrate (HAN)	Day	15	26	125	NS
	ARCON				-
	Night				NS
Hydrogen peroxide	Day	12.5	60	125	NS
	ARCON				-
	Night				NS
Tributyl phosphate (TBP)	Day	6	10	300	NS
	ARCON				-
	Night				NS
Nitric acid 13.6 M	Day	2.5	15	200	NS
	ARCON				-
	Night				0.009
Nitric acid 2.1 M	Day	2.5	15	200	0.011
	ARCON				-
	Night				0.028
Nitric acid 10.1 M	Day	2.5	15	200	NS
	ARCON				-
	Night				0.015

[a] Reported duration is based on maximum spill volume and evaporation rate. However, the ALOHA model restricts the maximum release duration to one hour. At constant wind speed, the highest concentration would occur in this first hour.

[b] "-" = not applicable.

[c] NA = not available.

[d] NS = not significant (less than 0.001 mg/m^3).

depth along with the spill volume. The pool size for each of the spill scenarios ranged from 8 m^2 (hydrogen peroxide spill outside the MOX BRP building) to 435 m^2 (nitric acid spill at the WSB).

As previously mentioned, the vapor pressures, as well as other the physical properties required in estimating the evaporation rate from Equation E-1, were computed by using chemical-specific coefficients in Antione or equivalent equations, or (in the absence of temperature dependent data) obtained directly from published literature (e.g., Linde 1999; Perry and Green 1984; NIST 2001; DIPPR 1989). Adjustments for dilute solutions were accounted for by multiplying by the computed mole fraction, the ratio of the number of moles of a substance to the total amount of that substance in a mixture. The physical properties, including the mole fraction adjusted vapor pressures, and the computed chemical specific nondimensional numbers used in computing evaporation rates (e.g., Reynolds Number), are summarized in Table E.4.

Accident consequences for evaporative releases, expressed as the ambient concentration at specified downwind distances, are reported in Table E.3. These concentrations are compared with (TEEL) values, criteria levels for accidental exposures adopted by the DOE Subcommittee on Consequence Assessment and Protective Action (SCAPA) (Craig 2002). TEEL values are available for about 2,000 substances; they are derived by using a hierarchy of other available criteria values (Craig et al. 2000). If Emergency Response Planning Guidelines (ERPGs) developed by panels of toxicologists for the American Conference of Governmental Industrial Hygienists (ACGIH) are available, these are used for the TEEL values. If ERPGs are not available, TEELs usually are based on emergency planning and other guideline levels developed for the protection of workers (Craig 2002). TEEL values are developed for evaluation of different levels of effects, ranging from no or very slight adverse effects to life-threatening effects (see text box in Section 4.3.5.3 for definitions).

To assess impacts for SRS employees, concentrations greater than TEEL-3 levels at 100 m for any chemical were defined as high consequence, and levels less than TEEL-3 but greater than TEEL-2 were defined as moderate consequence. To assess impacts for the general public, SRS boundary concentrations greater than TEEL-2 levels for any chemical were defined as high consequence, and levels less than TEEL-2 but greater than TEEL-1 were defined as moderate consequence. In addition, the hazard distances (i.e., maximum distances from the release point to which chemical TEEL-1, TEEL-2, and TEEL-3 air concentrations could extend) were estimated with the ALOHA model and are listed in Table E.3.

The impacts to SRS workers, located 100 m (330 ft) from the spill, were estimated by multiplying the ARCON96 95th percentile chi/Q value (0.00061 s/m^3) by the estimated evaporation rate, assuming the same wind speed that produces the ARCON96 95th percentile chi/Q (2.2 m/s) and the 95th percentile site-specific temperature (78.5°F) derived from 5 years of data from the meteorological tower in the H-area. For evaporative releases, there would be no worker exposures above the TEEL-2 level. However, spills of hydrazine, hydrazine/HAN mixtures, and nitric acid have the potential to expose SRS employees above the TEEL-1 levels. The resulting health impacts would be temporary and mild. The 100-m (330-ft) concentration

Table E.4. Physical property data

Chemical/ property[a]	Dodecane	Nitrogen tetroxide (N_2O_4)	Nitric acid (HNO_3)	Hydrazine (H_6N_2O)	HAN[b] ($H_4N_2O_4$)
MW	170.4	92.0	63.1	50.06	96.04
ρ_l (kg/L)	0.75	1.443	1.383	1.03	1.54
ρ_v (kg/m^3)	–[c]	3.2-998.9[d]	2.012	0.95	0.981
k_m (m/s)	–	NA[e]	2.67×10^{-4} to 5.76×10^{-4}	5.26×10^{-3}	6.17×10^{-3}
D_m (m^2/s)	7.15×10^{-6}	NA	1.19×10^{-5}	1.65×10^{-5}	1.63×10^{-5}
ν_k (m^2/s)	–	NA	5.84×10^{-4}	1.28×10^{-5}	6.65×10^{-6}
P_{Vap} (Pa) (78.9 ^{o}F)	2,039	2,038.5	4,540.8 to 6,269.9[f]	1,235.5	281.5
P_{Vap} (Pa) (87.5 ^{o}F)	2,720	2,701.9	5,800.2 to 8,008.9[f]	1,637.5	373.1
N_{Sc}	–	NA	49.7	0.909	0.923
N_{sh}	–	NA	271 to 458	593	829
N_{Re}	–	NA	12,307 to 35,254	423,749	534,226

Chemical/ property[a]	Hydrazine-HAN ($H_4N_2O_4$-N_2H_4)	Hydrazine-NaOH (N_2H_4-NaOH)	Tributyl phosphate ($C_{12}H_{27}O_4P$)	Hydrogen peroxide (H_2O_2)	Chlorine (Cl)
MW	128.09	93.99	266.36	34.02	70.91
ρ_l (kg/L)	1.54[g]	2.13	0.979	1.44	1.49
ρ_v (kg/m^3)	–	–	–	2.72	4.72 to 432.5[d]
k_m (m/s)	3.82×10^{-4}	5.26×10^{-3}	8.86×10^{-4}	5.07×10^{-3}	NA
D_m (m^2/s)	–	–	–	1.62×10^{-5}	NA
ν_k (m^2/s)	–	–	–	7.92×10^{-4}	NA
P_{Vap} (Pa) (78.9 ^{o}F)	289.7	2.2	134.8	1,912.2	8.02×10^{5}
P_{Vap} (Pa) (87.5 ^{o}F)	379.0	2.6	135.3	1,978.0	9.37×10^{5}

Table E.4. Continued

Chemical/ property[a]	Hydrazine-HAN ($H_4N_2O_4$-N_2H_4)	Hydrazine-NaOH (N_2H_4-NaOH)	Tributyl phosphate ($C_{12}H_{27}O_4P$)	Hydrogen peroxide (H_2O_2)	Chlorine (Cl)
N_{Sc}	0.625	0.625	0.625	48.9	NA
N_{sh}	1,439	1,090	524	177	NA
N_{Re}	945,897	1,251,896	424,029	5,307	NA

[a] ρ_l = liquid density, ρ_v = vapor density, k_m = mass transfer coefficient, D_m = molecular diffusivity, P_{vap} = vapor pressure, ν_k = kinematic viscosity, N_{Sc} = Schmidt number, N_{Sh} = Sherwood number, N_{Re} = Reynolds number.

[b] Hydroxylamine nitrate.

[c] – = not available.

[d] Aerosol vapor mixture density from jet release is initially very high; it is diluted over time to its vapor density at ambient conditions.

[e] NA = not applicable, modeled as a pressurized release.

[f] Nitric acid (1.21 N) [4,540.8 (78.9°F), 5,800.2 (89.5°F)]; Nitric acid (7.9 N) [5,764.2 (78.9°F), 7,362.9 (89.5°F)]; Nitric acid (13.6 N) [6,269.9 (78.9°F), 8,008.9 (89.5°F)].

[g] No published value available, set equal to the HAN published density at STP.

reference level for SRS employees is consistent with the SRS Emergency Response Plan (SRS 2001), which defines the facility boundary as follows:

> "Generally, the facility boundary is the fence line for a property, protected area or a limited area, depending upon the facility. When a physical boundary is unavailable, the distance of 100 meters from the point of release or edge of the spill is used. Area/facility-specific Emergency Preparedness Hazard Assessment Documents identify facility boundaries and should be referenced."

Since the wind speed and atmospheric stability generating the upper-bound impacts for nighttime conditions were 1.3 m/s with stable conditions (i.e., PG Class F), the plume transport time or the time it would take the release to reach the nearest SRS boundary (8.2 km downwind) would be almost 2 hours. Because ALOHA restricts the maximum release duration and plume transport time to one hour or less, ALOHA impact estimates at the SRS boundary could not be made for the low wind speed assumed in the simulations. Therefore, maximum impact estimates at the SRS boundary were made by using a formula for a ground-level release producing maximum ground-level concentrations (i.e., on the plume centerline at the surface), similar to that used in ALOHA. Ground-level centerline passive plume concentrations were estimated using the following formula, derived from the standard Gaussian equation:

$C(x,0,0) = Q/\pi u\sigma_y\sigma_z$. Dense gas estimates at the fence line were estimated by increasing the wind speed from 1.3 to 2 m/s to shorten the transport time to the fence line to less than one hour. The ALOHA-estimated concentration was then multiplied by 1.3 [chi/u(2) x u(1.3)] to arrive at the estimated SRS boundary concentration. The highest concentrations at this distance occurred subsequent to transition to a purely passive plume (i.e., no negative buoyancy influences from density effects). Estimates at 100 m using the above expression compared well (no more than a 1 to 2% difference) with the ALOHA estimate at the same location.

The ALOHA estimated hazard distances are also given in Table E.3 for evaporative plumes exhibiting dense vapor cloud dispersion. These plumes disperse downwind to a transition point at which ambient air entrainment into the cloud sufficiently dilutes concentrations so that the plume continues to disperse from that point downwind as a neutrally buoyant plume. The releases considered that initially behave as dense clouds produced the largest hazard distance. The largest potential health hazard was shown to extend 1.3 km (0.8 mi) downwind for an accidental spill of 478 L (126 gal) of 35% hydrazine.

Releases of two materials, nitrogen tetroxide and chlorine, were modeled as pressurized releases. The analysis showed that these pressurized releases would potentially produce very large exposures to SRS workers at a distance of 100 m (330 ft) because the concentrated dense gas plume could extend to this distance for a short time. The concentrations within the jet plume would approach 10,000 and 1,500 mg/m^3 at 100 m (330 ft) for nitrogen tetroxide and chlorine, respectively. The TEEL-2 hazard distance for accidental releases of both substances could extend to 4 km (2.5 mi) from the release location. The high concentrations close to the source are primarily due to the release of a pressurized, two-phased vapor-aerosol, which forms a dense vapor cloud. It should be noted that building influences on the heavy vapor cloud are not accounted for in the AEROPLUME and HEGADAS simulations. Such influences on passive releases are accounted for in the WAKE model, but not the combination of building aerodynamics and density effects. The estimated 100-m (330-ft) exposure calculated with the WAKE model approached 1,600 mg/m^3 and 500 mg/m^3 for nitrogen tetroxide and chlorine, respectively. The actual concentrations would likely fall between the two modeled results for each chemical.

E.2 Radiological

Risks from radioactive materials were assessed for workers involved in facility operations (“facility workers”) at the proposed MOX facility, the PDCF, and the WSB; other SRS workers outside the restricted area of the facility site (“SRS employees”); and members of the public.

E.2.1 Normal Operations

E.2.1.1 Facility Workers

For facility workers, external radiation from the direct handling of radioactive materials and/or the close working distances to radiation sources would be the primary exposure pathway. Radiation exposures through inhalation and incidental ingestion of contaminated particulates would be possible but for the average worker would be expected to be very small compared with exposures to external radiation.

Operations that could result in potential airborne radiological emissions would be conducted under fume hoods or in gloveboxes. Even if airborne releases from the gloveboxes did occur, the use of high-efficiency particulate air (HEPA) filters and protective air circulation systems would reduce the airborne pollutants in the working place to a minimal level. Exposures from inhalation could also be prevented by implementation of as-low-as-reasonably-achievable (ALARA) practices, such as requiring workers to wear respirators while performing activities with potential for generating airborne emissions. Potential exposure from incidental ingestion of particulate matter could be reduced by workers' wearing gloves and exercising good working practices.

For the proposed MOX facility, radiation exposure was estimated on the basis of exposures received during operation of a similar facility, the MELOX plant in Marcoule, France. External dose rates at the MELOX plant were extrapolated on the basis of the plutonium composition of the MELOX MOX fuel (8.5%) and proposed facility MOX fuel (5%) (DCS 2001b). Scaling was done by using the ratios of the photon and neutron intensities for the two concentrations. An annual collective external dose of 0.10 person-Sv (10 person-rem) was estimated for the processing area. An additional annual external dose of 0.02 person-Sv (2 person-rem) was assumed for the aqueous polishing area because no data were available (DCS 2001b). Thus, an annual external exposure of 0.12 person-Sv (12 person-rem) was estimated for facility workers.

Facility workers may also receive an internal dose. At the MELOX plant, from 1996 through July 2001, 41 individuals had received an internal radiation exposure: 30 had received <10% of the annual limit on intake (ALI), 10 ranging from 10% to 33.3% ALI, and 1 ranging from 33.3% to 100% ALI. With an intake of 100% ALI, an individual receives a dose of 0.05 Sv (5 rem). Because design and management measures at the MELOX plant are similar to those planned for the proposed facility, a MOX facility worker MEI may receive a dose of 0.017 Sv (1.7 rem), corresponding to a 33% ALI, in a year. The total dose of 0.13 person-Sv (13 person-rem) over this 5-year period results in an average internal dose of less than 0.03 person-Sv (3 person-rem) per year (assuming the full 50-year dose commitment in the year of exposure) (DCS 2001b). Thus, the annual collective facility worker exposure is estimated to be 0.15 person-Sv (15 person-rem), the sum of the estimated external and internal exposures.

For the PDCF and WSB, no historical operational experience is available to provide a reasonable estimate of the worker exposures. Because these two facilities would be owned and operated by the DOE, individual facility worker exposure would be maintained below 0.005 Sv/yr (0.5 rem/yr), the SRS site guideline, which is below the DOE administrative limit of 0.02 Sv/yr (2 rem/yr) (DOE 1994). However, using best practices under the ALARA principle, the average individual dose should be kept close to or lower than the average SRS radiological worker dose of 0.00048 Sv/yr (0.048 rem/yr) (DOE undated).

The information on radiation sources, worker activities, and number of required workers is subject to a large degree of uncertainty, as are the estimated collective and MEI worker doses. However, the radiation dose to the individual worker would be monitored and maintained below the NRC annual occupational total effective dose limit of 0.05 Sv (5 rem) (*Code of Federal Regulations*, Title 10, Part 20 [10 CFR 20]).

E.2.1.2 SRS Employees

Inhalation of contaminated particulates and external exposure to the plume of routine airborne releases from the plant and to soil contaminated by deposition of those airborne releases were considered for SRS employees. Because they would be located farther from the radiation sources handled in the three facilities than would facility workers, those SRS employees would not be exposed to direct external radiation from those sources. However, secondary external radiation would be possible from the deposited radionuclides on ground surfaces and from airborne radionuclides when the emission plume from the stack of the facilities passed the locations of the SRS employees.

The GENII computer code (Napier et al. 1988) was used to estimate radiological impacts to the SRS employees on the basis of emissions data shown in Table E.5. GENII has been used for the same application in several previous environmental impact statement projects, such as the *Final Waste Management Programmatic Environmental Impact Statement for Managing Treatment, Storage, and Disposal of Radioactive and Hazardous Waste* (WM PEIS) (DOE 1997). The GENII code uses either site-specific or representative meteorological data (joint frequency data) selected to estimate the air concentrations at downwind locations. The code implements the internal dosimetry models recommended by the International Commission on Radiological Protection (ICRP) in Publication 26 (ICRP 1977) and Publication 30 (ICRP 1979). The GENII code considers the transport of radioactive material in air, soil, water, and food sources to the human body.

The SRS employee population distribution used to estimate the SRS employee dose is given in Table E.6. This distribution is centered at the proposed MOX facility and involves a total population of 13,295 site workers. A stack height of 37 m (121 ft) (as specified in Section 3.1.1 of DCS 2002a) was used as the release height for normal emissions from the proposed MOX facility. WSB emissions were included in the proposed MOX facility estimates (DCS 2002a,b). An estimated stack height of 35 m (115 ft) was used as the release height for emissions from the PDCF (LANL 1998). Five years of weather information in the form of joint frequency data (1992-1996 average [as shown in Table E.7]) was used for the air dispersion calculations. On an annual basis, the total time of external exposure to the plume and contaminated soil for all SRS employees was assumed to be 0.5 year (NRC 1977). Resuspension of contaminated soil

Table E.5. Estimated annual radiological releases from the facilities during normal operations

	Airborne releases (μCi/yr)[a]	
Isotope	**Proposed MOX facility and WSB**[b]	**PDCF**[c]
Plutonium-236	1.3×10^{-8}	9.3×10^{-11}
Plutonium-238	8.5	0.065
Plutonium-239	91	0.69
Plutonium-240	23	0.18
Plutonium-241	101	0.69
Plutonium-242	6.1×10^{-3}	4.8×10^{-5}
Americium-241	48	0.37
Uranium-234	5.1×10^{-3}	NA[d]
Uranium-235	2.1×10^{-4}	NA
Uranium-238	0.012	NA
Tritium	NA	1.1×10^{9}

[a] To convert from microcuries (μCi) to becquerels (Bq), multiply by 3.7×10^{4} (or 37,000).

[b] *Source:* DCS (2002a).

[c] *Source*: DOE (1999).

[d] NA = not applicable.

was not considered, and the soil was assumed to be previously uncontaminated. Ingestion of contaminated foodstuffs was not considered because food is not grown on-site and consumed.

The maximally exposed individual (MEI) for the SRS employees was assumed to be within the SRS boundary (but outside the facility site) at a location that would have the maximum air concentration and would thus yield the largest radiation dose. On an annual basis, the total time of annual external exposure to the plume and contaminated soil for the MEI was assumed to be 0.7 year. For the inhalation pathway, an exposure time of 1 year was assumed (NRC 1977).

E.2.1.3 Members of the Public

The GENII code was used to assess radiation exposures of members of the public outside the SRS boundaries. The exposure pathways analyzed included inhalation of contaminated particulates, external radiation from deposited radionuclides and from airborne radionuclides, and ingestion of contaminated food products (plants, meat, and dairy products). Plants grown in the area where the emission plume passed could become contaminated by deposition of

Table E.6. SRS employee population distribution centered at the proposed MOX facility on the SRS

	Population by distance (mi[a])						
Direction	**0 to 1**	**1 to 2**	**2 to 3**	**3 to 4**	**4 to 5**	**5 to 10**	**Total**
S	1,191	0	225	171	0	397	1,984
SSW	592	0	0	0	0	7	600
SW	0	0	0	0	0	0	0
WSW	0	0	0	0	0	0	0
W	0	0	1,728	110	0	0	1,839
WNW	0	0	0	0	0	0	0
NW	0	0	0	0	2,408	897	3,305
NNW	0	0	0	0	0	0	0
N	0	0	0	0	0	0	0
NNE	0	0	0	0	0	0	0
NE	0	0	0	0	0	0	0
ENE	0	0	18	0	0	5	23
E	0	438	1,863	0	0	0	2,300
ESE	0	722	754	0	0	0	1,476
SE	70	101	26	0	0	25	221
SSE	282	0	0	1,164	0	100	1,547
Total	2,135	1,260	4,614	1,446	2,408	1,432	13,295

[a] To convert from miles to kilometers, multiply by 1.61.

Source: Birch (2001), Attachment A.10.

radionuclides on the leaves or ground surfaces. Radionuclides deposited on leaves could subsequently translocate to the edible portions of the plants, and those deposited on ground surfaces could subsequently be absorbed by plant roots. Livestock and their products could become contaminated if the livestock ate the contaminated surface soil and plants.

The off-site population distribution out to 80 km (50 mi), centered at F-Area, for the SRS area used in the assessment is given in Table E.8. The annual time of external exposure to the plume and contaminated soil for the general public off-site was assumed to be 0.5 year (NRC 1977). No credit for shielding was given for inhalation exposure. Ingestion parameters are provided in Table E.9. Food production data for the area surrounding the SRS are provided in Table E.10.

For the public, the location of the MEI was considered to be at the SRS boundary as a conservative assumption. Table E.11 lists the distance from the proposed MOX facility to the SRS boundary for the 16 compass directions from which the MEI was determined. Because of the close proximity of the PDCF and WSB to the proposed MOX facility, the same MEI receptor locations were used for these facilities. The annual external exposure to the plume and contaminated soil for the public off-site MEI was assumed to be 0.7 year (NRC 1977). No credit for shielding was given for inhalation exposure. Ingestion parameters are provided in Table E.9.

Table E.7. Joint frequency distribution used for calculation of receptor dose from facility air emissions

Wind speed (m/s)	Stability class	Wind direction															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
0.89	A	0.25	0.20	0.24	0.24	0.21	0.18	0.15	0.18	0.17	0.17	0.21	0.22	0.18	0.18	0.16	0.21
	B	0	0.03	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.01	0.03	0.03	0.00	0.03	0.03	0.02
	C	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.03	0.03	0.01	0.01	0.01	0.01	0.02	0.01	0.01
	D	0.01	0.02	0.00	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.01	0.01	0.01	0.01	0.03
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0	0	0.00	0.00	0.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0.00	0.00
2.46	A	0.88	0.73	0.92	1.04	1.06	0.79	0.70	0.55	0.74	0.78	1.12	1.37	1.19	0.82	0.56	0.57
	B	0.24	0.36	0.43	0.44	0.35	0.25	0.19	0.21	0.26	0.24	0.34	0.38	0.29	0.25	0.16	0.16
	C	0.15	0.39	0.73	0.50	0.39	0.24	0.24	0.29	0.33	0.36	0.43	0.49	0.34	0.28	0.23	0.18
	D	0.09	0.25	0.59	0.34	0.31	0.27	0.34	0.37	0.42	0.39	0.38	0.33	0.30	0.22	0.26	0.21
	E	0.01	0.09	0.28	0.11	0.08	0.16	0.17	0.18	0.26	0.22	0.19	0.20	0.13	0.13	0.11	0.13
	F	0.01	0.02	0.02	0.01	0.00	0.03	0.02	0.03	0.03	0.03	0.02	0.05	0.00	0.01	0.02	0.04
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.47	A	1.03	0.66	0.53	0.50	0.44	0.30	0.26	0.20	0.37	0.43	0.60	0.70	0.71	0.48	0.24	0.36
	B	0.21	0.57	0.65	0.67	0.32	0.23	0.16	0.19	0.31	0.33	0.55	0.75	0.55	0.36	0.16	0.18
	C	0.16	0.69	1.49	0.86	0.67	0.44	0.42	0.42	0.52	0.58	0.74	0.78	0.78	0.57	0.27	0.14
	D	0.12	0.52	1.64	0.95	0.81	0.70	0.84	1.12	1.48	1.05	1.26	1.27	1.01	0.88	0.50	0.20
	E	0.06	0.64	1.08	0.81	0.62	0.62	0.82	0.98	1.20	1.10	1.06	1.12	0.63	0.47	0.42	0.24
	F	0.02	0.22	0.19	0.07	0.10	0.16	0.18	0.17	0.22	0.16	0.21	0.27	0.07	0.06	0.05	0.06
	G	0.00	0.02	0.01	0.00	0.00	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.00	0.00	0.00	0.00
6.93	A	0.21	0.18	0.03	0.03	0.01	0.02	0.02	0.01	0.02	0.04	0.05	0.10	0.09	0.11	0.03	0.09
	B	0.02	0.17	0.12	0.04	0.04	0.03	0.05	0.04	0.04	0.09	0.18	0.31	0.46	0.34	0.09	0.03
	C	0.00	0.18	0.46	0.21	0.08	0.09	0.16	0.22	0.20	0.29	0.41	0.46	0.73	0.62	0.13	0.01
	D	0.00	0.09	0.19	0.08	0.05	0.06	0.13	0.46	0.43	0.24	0.24	0.12	0.13	0.11	0.07	0.00
	E	0.00	0.09	0.06	0.09	0.07	0.05	0.05	0.09	0.13	0.10	0.19	0.07	0.02	0.02	0.01	0.00
	F	0.00	0.04	0.02	0.03	0.01	0.03	0.02	0.01	0.01	0.01	0.03	0.02	0.01	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9.61	A	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.02	0.00	0.01
	B	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.03	0.08	0.06	0.01	0.00
	C	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.04	0.04	0.05	0.05	0.08	0.18	0.10	0.02	0.00
	D	0.00	0.00	0.00	0	0.00	0.00	0.00	0.03	0.02	0.02	0.01	0.00	0.02	0.00	0.00	0.00
	E	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00
	F	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	G	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table E.7. Continued

Wind speed (m/s)	Stability class	Wind direction															
		S	SSW	SW	WSW	W	WNW	NW	NNW	N	NNE	NE	ENE	E	ESE	SE	SSE
11.2	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	D	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	F	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	G	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Source: DCS (2002a).

Table E.8. Projected off-site population distribution at the SRS for the public for the year 2030

	Population by distance (miles[a])						
Direction	**0 to 5**	**5 to 10**	**10 to 20**	**20 to 30**	**30 to 40**	**40 to 50**	**Total**
S	0	0	920	2696	11,367	6,013	20,996
SSW	0	15	1,317	3,692	8,115	4,376	17,515
SW	0	186	1,978	7,732	3,535	4,579	18,010
WSW	0	171	2,572	7,553	4,368	10,385	25,049
W	0	407	10,186	17,766	15,109	11,753	55,221
WNW	0	2,331	8,556	219,212	54,849	24,980	309,928
NW	0	1,861	25,692	137,243	15,851	5,567	186,214
NNW	0	1,978	33,320	18,925	11,627	5,648	71,498
N	0	3,500	36,210	15,530	11,294	17,670	84,204
NNE	0	397	3,010	3,515	6,925	28,857	42,704
NE	0	14	2,609	4,611	8,850	19,325	35,409
ENE	0	0	5,535	7,865	8,764	53,785	75,949
E	0	2	8,061	8,590	18,423	9,310	44,386
ESE	0	14	3,658	4,352	5,466	488	13,978
SE	0	0	951	7,673	7,409	17,619	33,652
SSE	0	0	615	1,154	1767	4,234	7,770
Total	0	10,876	145,190	468,109	193,719	224,589	1,042,483

[a] To convert from miles to kilometers, multiply by 1.61.

Source: DCS (2002a).

E.2.2 Accidents

For the proposed MOX facility, four accident events were considered for detailed analysis, as discussed in Section 4.3.5.1. In each case, the amount of material released to the atmosphere was determined by multiplying the amount of material present (material at risk [MAR]) by the fraction of material involved in the event (damage ratio), fraction of material released that is airborne and respirable, and the fraction of material transported through a confinement mechanism (leak path factor). The values used for these parameters and the initial amount of plutonium material assumed to be present for each accident considered are given in Table E.12. Table E.13 lists the activity by radionuclide estimated to be released to the environment for each hypothetical accident.

Accident events considered for the PDCF and the WSB were discussed in Section 4.3.5.1. Six accident events were considered for the PDCF as taken from DOE (1999). Three accident events for the WSB were considered (DCS 2002a,b; Bowling 2002; DCS 2003b). Table E.13 lists the activity by radionuclide estimated to be released to the environment for each hypothetical accident.

Table E.9. Ingestion parameters used in GENII for calculation of radiological exposure of the public for normal and accidental air emissions

Parameter	Value Maximally exposed individual	Population
Terrestrial food		
Consumption rate (kg/yr)[a]		
Leafy vegetables	43	21
Root vegetables	92	66
Fruit	120	60
Grain	64	67
Crop yield (kg/m^2)[b]		
Leafy vegetables	1.5	1.5
Root vegetables	4	4
Fruit	2	2
Grain	0.8	0.8
Hold time between harvest and storage (days)[b]		
Leafy vegetables	1	14
Root vegetables	5	14
Fruit	5	14
Grain	180	180
Animal products		
Consumption rate (kg/yr)		
Beef[a]	81	43
Milk[a]	230	120
Poultry[b]	18	8.5
Eggs[b]	30	20
Holdup time (days)[b]		
Beef	15	34
Milk	1	3
Poultry	1	34
Eggs	1	18
Production rate (kg/yr)	NA[c]	-[d]
Diet fraction for animal food sources[b]		
Stored feed		
Beef	0.25	0.25
Milk	0.25	0.25
Poultry	1	1
Eggs	1	1
Fresh forage		
Beef	0.75	0.75
Milk	0.75	0.75

Table E.9. Continued

Parameter	Value Maximally exposed individual	 Population
Growing time for animal food sources (days)[b]		
Stored feed		
Beef	90	90
Milk	45	45
Poultry	90	90
Eggs	90	90
Fresh forage		
Beef	45	45
Milk	30	30
Yield of animal food sources (kg/m^3)[b]		
Stored feed		
Beef	0.8	0.8
Milk	2	2
Poultry	0.8	0.8
Eggs	0.8	0.8
Fresh forage		
Beef	2	2
Milk	1.5	1.5
Storage time for animal food sources (days)[b]		
Stored feed		
Beef	180	180
Milk	100	100
Poultry	180	180
Eggs	180	180
Fresh forage		
Beef	100	100
Milk	0	0

[a] *Source*: Arnett and Mamatey (2001).

[b] GENII default values.

[c] NA = not applicable.

[d] See Section E.1.3 and Table E.8.

Table E.10. Food production data used in GENII for calculation of radiological ingestion exposure of the public for normal and accidental air emissions

Product/ direction	Production (kg/yr) by distance (mi[a])					
	0 to 5	5 to 10	10 to 20	20 to 30	30 to 40	40 to 50
Leafy vegetables						
S	0	0	0	0	0	1.0×10^5
SSW	0	0	0	0	0	1.0×10^5
SW	0	3.4×10^5	0	0	0	1.1×10^3
WSW	0	3.7×10^2	3.3×10^1	0	1.6×10^3	8.8×10^3
W	0	1.3×10^3	1.3×10^2	0	2.8×10^3	4.1×10^3
WNW	0	1.4×10^3	3.4×10^3	0	0	0
NW	0	1.4×10^3	6.3×10^3	4.7×10^3	0	0
NNW	0	1.3×10^3	6.9×10^3	8.7×10^3	8.6	2.4×10^3
N	0	1.1×10^3	6.9×10^3	1.2×10^4	1.1×10^4	4.8×10^4
NNE	0	5.9×10^2	6.9×10^3	1.2×10^4	3.1×10^5	9.6×10^5
NE	0	4.6×10^1	6.0×10^3	3.1×10^4	2.5×10^5	7.7×10^5
ENE	0	0	7.6	3.2×10^4	1.6×10^5	2.1×10^5
E	0	0	0	0	2.3×10^4	1.3×10^5
ESE	0	0	0	0	0	1.0×10^5
SE	0	0	0	0	0	1.0×10^5
SSE	0	0	0	0	0	1.0×10^5
Root vegetables						
S	0	0	1.8×10^6	3.1×10^6	4.1×10^6	6.3×10^6
SSW	0	3.1×10^3	2.1×10^6	3.4×10^6	4.3×10^6	6.7×10^6
SW	0	9.7×10^7	2.2×10^6	3.6×10^6	4.8×10^6	5.8×10^6
WSW	0	1.1×10^5	2.1×10^6	3.6×10^6	5.3×10^6	8.0×10^6
W	0	1.8×10^5	2.3×10^5	1.3×10^6	3.4×10^6	4.4×10^6
WNW	0	1.9×10^5	5.0×10^5	1.1×10^5	5.4×10^4	3.2×10^5
NW	0	2.0×10^5	8.8×10^5	8.2×10^5	4.0×10^5	1.4×10^5
NNW	0	1.9×10^5	9.6×10^5	1.3×10^6	7.3×10^5	1.2×10^6
N	0	1.5×10^5	9.6×10^5	1.6×10^6	1.7×10^6	2.4×10^6
NNE	0	8.1×10^4	9.6×10^5	1.6×10^6	2.5×10^6	3.8×10^6
NE	0	6.3×10^3	1.2×10^6	2.6×10^6	4.2×10^6	5.1×10^6
ENE	0	0	3.4×10^6	6.3×10^6	7.8×10^6	9.9×10^6
E	0	0	3.6×10^6	6.3×10^6	7.9×10^6	1.0×10^7
ESE	0	0	3.3×10^6	6.6×10^6	8.4×10^6	5.3×10^6
SE	0	0	6.4×10^7	6.8×10^6	8.8×10^6	9.2×10^6
SSE	0	0	3.8×10^7	3.0×10^7	6.7×10^6	7.8×10^6
Fruit						
S	0	0	3.9×10^5	1.1×10^6	1.7×10^6	2.5×10^6
SSW	0	6.9×10^2	4.5×10^5	8.7×10^5	1.4×10^6	2.3×10^6
SW	0	3.3×10^7	4.8×10^5	7.9×10^5	1.2×10^6	1.2×10^6
WSW	0	4.4×10^4	4.7×10^5	7.9×10^5	1.0×10^6	8.8×10^5
W	0	1.1×10^5	4.5×10^4	2.7×10^5	4.4×10^5	3.9×10^5
WNW	0	1.2×10^5	2.8×10^5	1.1×10^3	2.3×10^2	1.3×10^3
NW	0	1.2×10^5	5.3×10^5	2.8×10^6	6.6×10^6	2.2×10^6
NNW	0	1.1×10^5	5.8×10^5	2.8×10^6	1.2×10^7	1.4×10^7
N	0	9.0×10^4	5.8×10^5	9.7×10^5	5.1×10^6	4.8×10^6
NNE	0	4.9×10^4	5.8×10^5	9.7×10^5	1.0×10^6	7.4×10^5
NE	0	3.9×10^3	5.3×10^5	8.9×10^5	1.0×10^6	7.5×10^5
ENE	0	0	2.5×10^5	4.9×10^5	8.5×10^5	1.1×10^6

Table E.10. Continued

Product/ direction	Production (kg/yr) by distance (mi[a])					
	0 to 5	5 to 10	10 to 20	20 to 30	30 to 40	40 to 50
E	0	0	2.6×10^{5}	3.4×10^{5}	1.6×10^{5}	7.0×10^{5}
ESE	0	0	2.4×10^{5}	4.0×10^{5}	1.8×10^{5}	5.6×10^{4}
SE	0	0	4.3×10^{6}	3.1×10^{5}	3.7×10^{5}	3.1×10^{5}
SSE	0	0	2.6×10^{6}	2.0×10^{6}	1.1×10^{6}	1.0×10^{6}
Grains						
S	0	0	2.6×10^{6}	7.4×10^{6}	1.1×10^{7}	1.5×10^{7}
SSW	0	4.5×10^{3}	2.9×10^{6}	6.0×10^{6}	1.1×10^{7}	1.4×10^{7}
SW	0	1.1×10^{8}	3.1×10^{6}	5.1×10^{6}	8.2×10^{6}	1.0×10^{7}
WSW	0	1.4×10^{5}	3.0×10^{6}	5.1×10^{6}	8.1×10^{6}	1.5×10^{7}
W	0	2.1×10^{5}	6.4×10^{5}	2.2×10^{6}	6.1×10^{6}	7.9×10^{6}
WNW	0	2.2×10^{5}	7.6×10^{5}	7.2×10^{5}	2.6×10^{5}	6.5×10^{5}
NW	0	2.2×10^{5}	1.0×10^{6}	1.2×10^{6}	7.5×10^{5}	3.3×10^{5}
NNW	0	2.1×10^{5}	1.1×10^{6}	1.6×10^{6}	1.3×10^{6}	2.0×10^{6}
N	0	1.7×10^{5}	1.1×10^{6}	1.8×10^{6}	2.3×10^{6}	4.1×10^{6}
NNE	0	9.3×10^{4}	1.1×10^{6}	1.8×10^{6}	2.7×10^{6}	3.6×10^{6}
NE	0	7.3×10^{3}	1.3×10^{6}	3.6×10^{6}	6.1×10^{6}	6.9×10^{6}
ENE	0	0	4.0×10^{6}	8.7×10^{6}	1.4×10^{7}	1.8×10^{7}
E	0	0	4.2×10^{6}	9.0×10^{6}	1.6×10^{7}	1.9×10^{7}
ESE	0	0	3.9×10^{6}	8.9×10^{6}	1.6×10^{7}	1.2×10^{7}
SE	0	0	8.2×10^{7}	1.1×10^{7}	1.5×10^{7}	1.7×10^{7}
SSE	0	0	5.2×10^{7}	5.2×10^{7}	1.3×10^{7}	1.6×10^{7}
Beef						
S	0	0	1.2×10^{5}	4.6×10^{5}	7.3×10^{5}	9.9×10^{5}
SSW	0	2.2×10^{2}	1.5×10^{5}	3.4×10^{5}	6.9×10^{5}	9.3×10^{5}
SW	0	6.0×10^{4}	1.5×10^{5}	2.5×10^{5}	4.6×10^{5}	6.1×10^{5}
WSW	0	1.0×10^{4}	1.5×10^{5}	2.5×10^{5}	4.1×10^{5}	7.9×10^{5}
W	0	2.1×10^{4}	4.0×10^{4}	1.2×10^{5}	3.4×10^{5}	5.1×10^{5}
WNW	0	2.2×10^{4}	7.0×10^{4}	5.0×10^{4}	9.5×10^{4}	1.8×10^{5}
NW	0	2.3×10^{4}	1.1×10^{5}	1.4×10^{5}	1.6×10^{5}	2.1×10^{5}
NNW	0	2.2×10^{4}	1.1×10^{5}	1.8×10^{5}	2.3×10^{5}	3.5×10^{5}
N	0	1.7×10^{4}	1.1×10^{5}	1.9×10^{5}	3.1×10^{5}	6.5×10^{5}
NNE	0	9.6×10^{3}	1.1×10^{5}	1.9×10^{5}	2.5×10^{5}	2.9×10^{5}
NE	0	7.5×10^{2}	1.0×10^{5}	2.6×10^{5}	4.3×10^{5}	5.0×10^{5}
ENE	0	0	2.4×10^{4}	2.2×10^{5}	8.2×10^{5}	1.1×10^{6}
E	0	0	2.6×10^{4}	1.4×10^{5}	5.2×10^{5}	8.8×10^{5}
ESE	0	0	2.4×10^{4}	8.2×10^{4}	3.4×10^{5}	4.5×10^{5}
SE	0	0	4.8×10^{5}	6.4×10^{4}	2.0×10^{5}	5.2×10^{5}
SSE	0	0	3.6×10^{5}	5.8×10^{5}	4.3×10^{5}	6.7×10^{5}
Poultry						
S	0	0	0	0	0	5.4×10^{4}
SSW	0	0	0	0	0	6.7×10^{4}
SW	0	4.7×10^{7}	0	0	0	4.5×10^{1}
WSW	0	5.1×10^{4}	4.5×10^{3}	0	6.1×10^{1}	3.5×10^{2}
W	0	1.7×10^{5}	1.8×10^{4}	0	1.1×10^{2}	1.6×10^{2}
WNW	0	1.9×10^{5}	4.6×10^{5}	0	0	5.1×10^{3}
NW	0	1.9×10^{5}	8.6×10^{5}	6.4×10^{5}	0	3.0×10^{5}
NNW	0	1.8×10^{5}	9.4×10^{5}	1.2×10^{6}	1.2×10^{3}	5.4×10^{5}
N	0	1.5×10^{5}	9.4×10^{5}	1.6×10^{6}	1.7×10^{6}	3.6×10^{6}
NNE	0	8.0×10^{4}	9.4×10^{5}	1.6×10^{6}	1.3×10^{6}	5.4×10^{3}

Table E.10. Continued

Product/ direction	Production (kg/yr) by distance (mi[a])					
	0 to 5	5 to 10	10 to 20	20 to 30	30 to 40	40 to 50
NE	0	6.3×10^3	8.2×10^5	1.2×10^6	9.7×10^5	0
ENE	0	0	1.1×10^3	0	0	0
E	0	0	0	0	0	1.0×10^5
ESE	0	0	0	0	0	1.0×10^5
SE	0	0	0	0	0	1.0×10^5
SSE	0	0	0	0	0	1.0×10^5
Milk						
S	0	0	5.5×10^5	6.2×10^5	6.5×10^5	7.6×10^5
SSW	0	9.7×10^2	6.4×10^5	2.9×10^6	7.9×10^6	8.1×10^6
SW	0	3.2×10^6	6.7×10^5	1.1×10^6	3.8×10^6	2.9×10^6
WSW	0	2.2×10^4	6.6×10^5	1.1×10^6	2.0×10^6	4.4×10^6
W	0	1.2×10^4	4.9×10^4	3.8×10^5	1.8×10^6	3.5×10^6
WNW	0	1.3×10^4	3.1×10^4	0	4.7×10^4	1.2×10^6
NW	0	1.3×10^4	5.8×10^4	4.4×10^5	1.1×10^6	7.9×10^5
NNW	0	1.2×10^4	6.4×10^4	4.3×10^5	2.0×10^6	3.3×10^6
N	0	9.9×10^3	6.4×10^4	1.1×10^5	1.9×10^6	7.4×10^6
NNE	0	5.4×10^3	6.4×10^4	1.1×10^5	3.9×10^5	9.7×10^6
NE	0	4.2×10^2	5.5×10^4	6.9×10^5	1.7×10^6	1.8×10^6
ENE	0	0	7.0×10^1	1.1×10^6	4.6×10^6	5.6×10^6
E	0	0	0	9.6×10^5	4.2×10^6	5.7×10^6
ESE	0	0	0	3.2×10^5	2.6×10^6	1.6×10^6
SE	0	0	2.4×10^4	1.2×10^4	4.2×10^4	1.2×10^5
SSE	0	0	2.0×10^5	3.2×10^5	3.5×10^5	3.9×10^5
Eggs						
S	0	0	6.3×10^2	0	0	8.3×10^4
SSW	0	0	0	0	0	1.0×10^5
SW	0	6.2×10^5	0	0	0	9.1×10^1
WSW	0	0	0	0	1.2×10^2	7.0×10^2
W	0	0	0	0	2.2×10^2	3.3×10^2
WNW	0	0	0	0	0	1.0×10^5
NW	0	0	0	1.2×10^5	3.2×10^5	1.1×10^5
NNW	0	0	0	1.0×10^5	5.9×10^5	6.4×10^5
N	0	0	0	0	1.7×10^5	2.9×10^1
NNE	0	0	0	0	0	1.0×10^5
NE	0	0	4.1×10^3	4.0×10^3	1.6×10^2	1.2×10^2
ENE	0	0	4.3×10^4	5.5×10^4	5.0×10^2	6.3×10^2
E	0	0	4.5×10^4	5.6×10^4	7.1×10^1	4.0×10^2
ESE	0	0	4.2×10^4	5.8×10^4	1.2×10^2	0
SE	0	0	6.3×10^5	1.2×10^3	0	0
SSE	0	0	3.1×10^5	0	0	0

[a] To convert from miles to kilograms, multiply by 1.61.

Source: DCS (2002a).

E.2.2.1 SRS Employees

SRS employees downwind of an accident might be exposed to airborne radioactive contamination. Exposure would result primarily from external radiation from the radioactive contamination in the passing plume (cloudshine) released from the accident location and inhalation of the airborne contaminants. Short-term exposure to external radiation from ground-deposited radionuclides (groundshine) might also occur.

The GENII computer code (Napier et al. 1988) was also used to assess the radiological impacts to the sitewide population of SRS employees for each accident considered. The SRS employee population distribution used for the accident analysis is given in Table E.6, and the joint-frequency weather data are given in Table E.7. A ground-level release (1-m [3.3-ft] release height) was assumed for all accidents. To provide a conservative estimate for the impacts, 95% meteorology (meteorological conditions that produce impacts that are not exceeded 95% of the time) was used. Employees were assumed to be unshielded during passage of the contaminant plume from an accident. Both the inhalation and external exposure pathways were considered. Further external exposure to ground contamination for a period of 5.6 hours (8 hours with a shielding factor of 0.7) after the accident was also considered. Resuspension of contaminated soil was not considered, and the soil was assumed to be previously uncontaminated. Ingestion of contaminated foodstuffs was not considered because food is not grown on-site and consumed. Accident impacts to the SRS employee population are presented in Section 4.3.5.2 (see Table 4.13).

Table E.11. Centerline distance to site boundary from the proposed MOX facility stack for the primary 16 compass directions

Direction	Distance (m)
S	20,480
SSW	17,700
SW	12,130
WSW	15,000
W	9,490
WNW	9,930
NW	9,070
NNW	9,720
N	10,680
NNE	13,060
NE	16,520
ENE	19,040
E	19,150
ESE	20,030
SE	21,130
SSE	20,580

Table E.12. Source terms for detailed accident analyses

Hypothetical accident event	Quantity of plutonium at risk (kg)	Damage ratio	Respirable release fraction	Leak path factor
Internal fire	62 (polished)	1	0.0006	0.0001
Load handling	254 (polished)	1	0.0006	0.0001
Explosion	75 (unpolished)	1	0.01	0.0001
Criticality	41.5 (unpolished)	1	0.0005[a]	0.0001[b]

[a] For particulate matter, respirable release fraction = 1 for gases.

[b] For particulate matter, leak path factor = 1 for gases.

Sources: DCS (2002a, 2004a); Brown (2001).

Table E.13. Radionuclide quantities (Ci)[a] released to the atmosphere for each accident type

	Proposed MOX facility				WSB		
Isotope	Internal fire	Load handling	Explosion	Criticality	Loss of confinement	Fire	Earthquake
Pu-238	2.2×10^{-5}	9.2×10^{-5}	4.5×10^{-4}	6.0×10^{-13}	1.2×10^{-5}	2.4×10^{-4}	2.5×10^{-4}
Pu-239	1.9×10^{-4}	7.7×10^{-4}	3.8×10^{-3}	5.0×10^{-12}	8.0×10^{-5}	1.6×10^{-3}	1.6×10^{-3}
Pu-240	4.6×10^{-5}	1.9×10^{-4}	9.2×10^{-4}	1.3×10^{-12}	3.0×10^{-5}	5.7×10^{-4}	6.0×10^{-4}
Pu-241	3.4×10^{-3}	1.4×10^{-2}	6.8×10^{-2}	9.0×10^{-11}	1.4×10^{-3}	2.8×10^{-2}	3.0×10^{-2}
Pu-242	1.3×10^{-8}	5.3×10^{-8}	2.6×10^{-7}	3.5×10^{-16}	NA[b]	NA	NA
Am-241	NA	NA	2.0×10^{-3}	2.1×10^{-12}	NA	NA	NA
U-234	NA	NA	NA	NA	5.2×10^{-4}	1.0×10^{-2}	1.1×10^{-2}
U-235	NA	NA	NA	NA	9.2×10^{-6}	1.8×10^{-4}	1.9×10^{-4}
U-238	NA	NA	NA	NA	1.4×10^{-4}	2.7×10^{-3}	2.9×10^{-3}
Kr-83m	NA	NA	NA	1.1×10^{2}	NA	NA	NA
Kr-85m	NA	NA	NA	7.1×10^{1}	NA	NA	NA
Kr-85	NA	NA	NA	8.4×10^{-4}	NA	NA	NA
Kr-87	NA	NA	NA	4.3×10^{2}	NA	NA	NA
Kr-88	NA	NA	NA	2.3×10^{2}	NA	NA	NA
Kr-89	NA	NA	NA	1.3×10^{4}	NA	NA	NA
Xe-131m	NA	NA	NA	1.0×10^{-1}	NA	NA	NA
Xe-133m	NA	NA	NA	2.2	NA	NA	NA
Xe-133	NA	NA	NA	2.7×10^{1}	NA	NA	NA
Xe-135m	NA	NA	NA	3.3×10^{3}	NA	NA	NA
Xe-135	NA	NA	NA	4.1×10^{2}	NA	NA	NA
Xe-137	NA	NA	NA	4.9×10^{4}	NA	NA	NA
Xe-138	NA	NA	NA	1.1×10^{4}	NA	NA	NA
Te-134	NA	NA	NA	NA	NA	NA	NA
I-131	NA	NA	NA	2.8	NA	NA	NA
I-132	NA	NA	NA	2.9×10^{2}	NA	NA	NA
I-133	NA	NA	NA	4.1×10^{1}	NA	NA	NA
I-134	NA	NA	NA	1.1×10^{3}	NA	NA	NA
I-135	NA	NA	NA	1.1×10^{2}	NA	NA	NA
H-3	NA	NA	NA	NA	NA	NA	NA

Table E.13. Continued

	PDCF					
Isotope	Criticality	Earthquake	Explosion	Fire	Leak/spill	Tritium release
Pu-238	NA	2.62×10^{-6}	2.15×10^{-5}	8.06×10^{-8}	2.62×10^{-8}	NA
Pu-239	3.5×10^{-8}	2.22×10^{-5}	1.82×10^{-4}	6.82×10^{-7}	2.21×10^{-7}	NA
Pu-240	3.3×10^{-8}	5.43×10^{-6}	4.45×10^{-5}	1.67×10^{-7}	5.40×10^{-8}	NA
Pu-241	8.3×10^{-7}	4.04×10^{-4}	3.31×10^{-3}	1.24×10^{-5}	4.00×10^{-6}	NA
Pu-242	6.1×10^{-11}	1.55×10^{-9}	1.27×10^{-8}	4.76×10^{-11}	1.53×10^{-11}	NA
Am-241	2.0×10^{-7}	1.20×10^{-5}	9.82×10^{-5}	3.68×10^{-7}	1.18×10^{-7}	NA
U-234	NA	NA	NA	NA	NA	NA
U-235	NA	NA	NA	NA	NA	NA
Kr-83m	1.3	NA	NA	NA	NA	NA
Kr-85m	3.0	NA	NA	NA	NA	NA
Kr-85	NA	NA	NA	NA	NA	NA
Kr-87	1.9×10^{1}	NA	NA	NA	NA	NA
Kr-88	5.5×10^{1}	NA	NA	NA	NA	NA
Kr-89	NA	NA	NA	NA	NA	NA
Xe-131m	NA	NA	NA	NA	NA	NA
Xe-133m	NA	NA	NA	NA	NA	NA
Xe-133	4.5×10^{-1}	NA	NA	NA	NA	NA
Xe-135m	2.8×10^{1}	NA	NA	NA	NA	NA
Xe-135	8.0	NA	NA	NA	NA	NA
Xe-137	NA	NA	NA	NA	NA	NA
Xe-138	3.5×10^{2}	NA	NA	NA	NA	NA
Te-134	2.1×10^{1}	NA	NA	NA	NA	NA
I-131	4.3×10^{-2}	NA	NA	NA	NA	NA
I-132	3.5×10^{-1}	NA	NA	NA	NA	NA
I-133	7.5×10^{-1}	NA	NA	NA	NA	NA
I-134	9.5	NA	NA	NA	NA	NA
I-135	2.5	NA	NA	NA	NA	NA
H-3	NA	NA	NA	NA	NA	1.90×10^{5}

[a] To convert from curies (Ci) to becquerels (Bq), multiply by 3.7×10^{10}.

[b] NA = not applicable.

Radiological impacts to an MEI of the SRS employee population were assessed by assuming that the MEI was located outside the facility boundary, 100 m (330 ft) from the accident location. Inhalation exposure and external exposure from the passing radioactive cloud were evaluated. The ARCON96 computer code (Ramsdell and Simonen 1997) was used to estimate contaminant air concentrations at the MEI receptor location following an accidental release. ARCON96 was designed to model air dispersion in the vicinity of buildings. The code uses hourly meteorological data in order to estimate relative air concentrations of atmospheric releases. Ten years, 1987 to 1996, of hourly meteorological data and a building area of 6,580 m^2 (70,825 ft^2) (DCS 2001a) were used as input to the code. The 95th percentile relative concentration, the air concentration that is more than what might be expected 95% of the time, in any given direction for the 0- to 2-hour averaging period was conservatively used to estimate impacts. This 95th percentile relative concentration was calculated to be 6.1×10^{-4} s/m^3.

An inhalation rate of 3.47×10^{-4} m^3/s (NRC 1972), which includes consideration of an 8-hour shift, was then used in conjunction with inhalation dose conversion factors from Federal Guidance Report (FGR) 11 (Eckerman et al. 1988) to estimate inhalation exposure. The most conservative (largest) dose conversion factor among the clearance classes for each radionuclide was used. For external exposure, the external dose conversion factors from FGR 12 (Eckerman and Ryman 1993) were used. Estimated impacts to the SRS employee MEI are presented in Table 4.13 (Chapter 4) of this EIS. With the exception of the criticality accidents, inhalation exposure was the dominant impact. External exposure to cloudshine from the passing radioactive cloud after the criticality accident accounted for approximately 93% of the estimated dose to the MEI.

E.2.2.2 Members of the Public

Radiation exposures to members of the off-site public were assessed for hypothetical accidental releases. Impacts from a short-term exposure and one-year exposures (with and without ingestion) were evaluated for each accident. Exposure pathways evaluated for short-term exposures were inhalation, cloudshine, and groundshine. For 1-year exposures with ingestion, ingestion of contaminated crops was considered in addition to the short-term exposure pathways.

The GENII computer code (Napier et al. 1988) was used to assess the radiological impacts to the collective off-site population (members of the public) for each accident considered. The off-site population distribution used for the accident analysis is given in Table E.8, and the joint-frequency weather data are given in Table E.7. A ground-level release (1-m [3.3-ft] release height) was assumed for all accidents. To provide a conservative estimate for the impacts, 95% meteorology (weather conditions that produce impacts that are not exceeded 95% of the time) was used. For the short-term exposure, no credit was given for shielding for the inhalation and external exposures to the passing airborne plume. Exposure to groundshine was evaluated for 8 hours, but a shielding factor of 0.5 (NRC 1977) was used.

For the 1-year exposure periods, the length of time of external exposure to contaminated soil was 0.5 year (NRC 1977), and no credit was given for shielding for the inhalation exposure and external exposure to the passing airborne plume. For the 1-year exposure period with ingestion, ingestion parameters are provided in Table E.9. Food production data for the area surrounding the SRS are provided in Table E.10. The estimated impacts for each accident in the short term and after 1 year of exposure are presented in Table 4.14 (Chapter 4). No mitigative actions were assumed.

Accident impacts to an MEI member of the public were determined using the GENII code for both short-term and 1-year exposures following an accidental release. Potential MEIs were assumed to live at the site boundary, one at each of the 16 compass directions, as given in Table E.11. Exposure pathways considered in the analysis included inhalation, external exposure from the passing plume and contaminated soil, and, in the case for 1-year exposure with ingestion, ingestion of contaminated foodstuffs. The same release height and meteorology conditions as used for the population accident impacts were used for the MEI analysis. The amount of time of external exposure to contaminated soil was 8 hours (with a 0.7 shielding factor) and 0.7 year (NRC 1977) for the short-term and 1-year exposure periods, respectively. No credit for shielding was given for the inhalation and external exposures to the passing airborne plume. As a conservative assumption, potential MEIs were assumed to consume locally grown food for the 1-year exposure period with ingestion. Ingestion parameters are provided in Table E.9. The estimated impacts for each accident are given in Table 4.15 (Chapter 4) for the short-term and 1-year exposure periods. No mitigative actions were assumed.

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