APPENDIX B
DETAILED EVALUATION OF THE RADIOLOGICAL AND NONRADIOLOGICAL RISKS ASSOCIATED WITH TRANSPORTATION OF NAVAL SPENT NUCLEAR FUEL

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APPENDIX B

DETAILED EVALUATION OF THE RADIOLOGICAL AND NONRADIOLOGICAL RISKS ASSOCIATED WITH TRANSPORTATION OF NAVAL SPENT NUCLEAR FUEL

B.1 Background

A range of routes to a repository or centralized interim storage site is used for the transportation analysis in this EIS in order to determine whether different routing characteristics, such as distance or differences in population distribution, would affect the comparison of the alternative container types. Since no repository or centralized interim storage site has yet been selected, the transportation routing in this EIS uses a site being evaluated by the Department of Energy pursuant to the Nuclear Waste Policy Act as the destination point for naval spent nuclear fuel shipments. For the sake of comparing a reasonable range of alternatives the current regulations have been applied conservatively in the EIS transportation analysis.

Specific transportation routes have not been evaluated for shipment of naval spent nuclear fuel to a repository or centralized interim storage site because that will be the subject of the site-specific EIS for the particular facility. Transportation of naval spent nuclear fuel to a repository or centralized interim storage site will be addressed in the repository EIS analysis. The Navy will participate and contribute to that EIS, as appropriate. This participation will include, at a minimum, the contribution of naval spent nuclear fuel to the cumulative impact for all of the spent nuclear fuel shipments to the designated repository.

The transportation risk assessment of naval spent nuclear fuel covered in this section is limited to shipments from the Expended Core Facility, the Idaho Chemical Processing Plant, the Birch Creek Area, or the Lemhi Range Area (all located at the Idaho National Engineering Laboratory [INEL]), to a centralized interim storage site or a geologic repository. The Birch Creek and Lemhi Range Areas may not directly overlie the Snake River Plain Aquifer. The Yucca Mountain site, currently being characterized under the Nuclear Waste Policy Act, has been used as the reference destination for all shipments for analytical purposes. These shipments are planned to begin around the year 2010 and would be completed in 2035.

The shipments would be made in one of the alternative container systems evaluated in this EIS: a multi-purpose canister (the conceptual design proposed by TRW [1993] is used as an example), the standard M-140 cask (Current Technology), a high-capacity M-140 (Current Technology/Rail), a transportable storage cask (the NAC design is used as an example), a dual-purpose canister (the NUHOMS-MP187® is used as an example), or the small multi-purpose canister. Typical surface ship and submarine assemblies have been selected as representative naval fuel types in this analysis. The relative container loadings for movement from INEL to a centralized interim storage site or a geologic repository are provided in Table B.1.

TABLE B.1 Estimated Container Capacity for Naval Spent Nuclear Fuel Cargo Relative to the Multi-Purpose Canister

Container Type	Estimated Relative Container Capacity	
	Submarine	Surface Ship
Multi-Purpose Canister	1.0	1.0
No-Action Alternative	0.60	0.57
Current Technology/Rail	0.67	0.71
Transportable Storage Cask	1.2	0.64
Dual-Purpose Canister	1.1	1.0
Small Multi-Purpose Canister	0.57	0.57

Based on the projected fuel inventory at the Expended Core Facility and the Idaho Chemical Processing Plant for the time period between 2010 and 2035, 300 to 500 shipments of naval spent nuclear fuel from INEL to a centralized interim storage site or geologic repository are expected. Table B.2 provides a summary of estimated total shipments, depending on which container is employed. Since special case low-level radioactive waste might be shipped in the same containers, the estimated number of waste shipments is also provided in Table B.2.

TABLE B.2 Estimated Total Number of Shipments from INEL to a Centralized Interim Storage Site or a Geologic Repository for Each Type of Container

Alternative	Estimated Number of Naval SNF Shipments	Estimated Number of SCW Shipments	Total Estimated Number of Shipments
Multi-Purpose Canister	300	60	360
No-Action	425	55	480
Current Technology/Rail	325	55	380
Transportable Storage Cask	325	45	370
Dual-Purpose Canister	300	45	345
Small Multi-Purpose Canister	500	85	585

Notation: SNF = spent nuclear fuel; SCW = special case waste

B.2 General Descriptions

B.2.1 Spent Nuclear Fuel Shipping Containers

In addition to a multi-purpose canister, a small multi-purpose canister, the NAC-STC, and the NUHOMS-MP187®, naval spent nuclear fuel can be shipped in the M-140 or the high-capacity M-140 which are transported by railcars used only for this purpose as part of general-use freight trains. A brief description of the M-140 and the high capacity M-140 follows.

M-140 Transportation Cask. The M-140 transportation cask is a large, stainless steel shipping container that is transported in the vertical position on a specially designed well-type railcar (Figure B.1). The major components of the M-140 transportation cask include the shielded container, closure head, and protective dome. Assembly holders are installed inside the container to hold the irradiated fuel assemblies in place and can be modified to accept different sized fuel assemblies. The container is shipped dry with the exception of a small amount of residual water. Cooling fins on the outside of the container are designed to dissipate the heat generated by the fuel.

The M-140 transportation cask and rail car weigh approximately 190 tons (172,000 kg) in the loaded condition. The container is approximately 16 ft (5 m) tall with a maximum outer diameter of 10.5 ft (approximately 3 m). The container body is made from stainless steel forgings with 14-in. (approximately 36-cm) thick walls and a 12-in. (approximately 31-cm) thick bottom. The closure head and protective dome have a total thickness of 17.5 in. (approximately 45 cm) of stainless steel.

High-Capacity M-140 Transportation Cask. The high-capacity M-140 transportation cask would be the same as the standard M-140 but would have a basket that holds more assemblies.

B.2.2 Shipping Container Design Requirements

The M-140 transportation cask has been designed and built to meet the regulations specified in 49 CFR Part 173, entitled "Shippers — General Requirements for Shipments and Packagings." The M-140 transportation cask also meets the requirements of 10 CFR Part 71, entitled "Packaging of Radioactive Material for Transportation and Transportation of Radioactive Material Under Certain Conditions." These regulations require the shipping container to meet specific criteria under normal transport and accident conditions. The shipping container must be evaluated under free drop, puncture, heat, cold, pressure, water spray, and vibration for normal conditions and a series of severe hypothetical accident conditions, with the results compared against the criteria provided in 10 CFR Part 71.

The M-140 transportation cask has undergone rigorous engineering evaluations to assure compliance with 49 CFR Part 173 and 10 CFR Part 71 requirements. In addition, actual scale model or mock-up tests have been performed to verify selected engineering evaluations. This compliance has been certified by the DOE and Nuclear Regulatory Commission. All container alternatives considered in this EIS would be designed and built to meet the same design criteria when loaded with naval spent nuclear fuel.

FIGURE B.1 M-140 Transportation Cask Mounted on Railcar

B.3 Technical Approach — General

Several computer codes were used to assess the radiological risks associated with the transportation of naval spent nuclear fuel. Specifically, the RADTRAN 4 risk analysis model, developed by Sandia National Laboratories (Neuhauser and Kanipe 1992), was used to calculate the general population and transportation crew (occupational) radiological risks associated with the transportation of radioactive materials. This computer code was used extensively in the incident-free and accident risk assessments. In some cases, other methods were more appropriate than the RADTRAN 4 computer code for naval spent nuclear fuel. In these cases, other calculational models were used and are specifically identified.

The RISKIND computer code, developed by Argonne National Laboratory (Yuan et al. 1993), also specifically analyzes radiological consequences and health risks to individuals from exposure associated with transportation. A version of RISKIND which accepts fuel-specific isotopes was found to be the best code for calculation of the maximally exposed individual and general population maximum consequences for the accident scenario and was used for that purpose.

Several other computer codes were used to provide input for the RADTRAN 4 and RISKIND computer codes. The codes include INTERLINE, SPAN 4, and ORIGEN 2. A description of each computer code and how the code was used is provided below.

The INTERLINE computer code, developed by Oak Ridge National Laboratory (Johnson et al. 1993), was used to evaluate the rail routes.

The SPAN 4 computer code (Wallace 1972) was used to perform gamma exposure rate calculations for the M-140 to assess the effect of increased distance from the source on dose. SPAN 4 was developed by the Bettis Atomic Power Laboratory specifically for naval spent nuclear fuel.

ORIGEN 2, a computer code developed by Oak Ridge National Laboratory (Croff 1980), was used to simulate radiation and decay of materials that are irradiated in a nuclear reactor. The ORIGEN 2 computer code is widely accepted in the public domain and was used to independently confirm the fission product inventory for naval fuel developed using the standard Bettis Atomic Power Laboratory method. In addition, the standard Bettis Atomic Power Laboratory method has been used in Safety Analysis Reports for Packaging, and reviewed and accepted by the Nuclear Regulatory Commission.

The radiological risks associated with the transportation of spent nuclear fuel have been assessed for the general population, transportation workers (occupational), and hypothetical maximally exposed individuals under incident-free and accident conditions. The maximum consequences of the most severe hypothetical accident that is reasonably foreseeable are also provided.

The radiological impacts are first expressed as the calculated total dose for the exposed population, occupational workers, and the maximally exposed individuals. The calculated total doses are then used to estimate the hypothetical health effects, expressed in terms of estimated cancer fatalities. The health risk conversion factors used in this evaluation are taken from Publication 60 of the International Commission on Radiological Protection (ICRP 1991), which specifies 0.0005 latent

fatal cancer cases per person-rem for members of the public and 0.0004 latent fatal cancer cases per person-rem for workers.

The numerical estimates of cancer deaths and health detriment were obtained by the practice of linear extrapolation from the nominal risk estimate of 10 rad, assuming the same relationship between radiation exposure and health effects down to zero exposure. Other methods of extrapolation to the low-dose region could yield higher or lower numerical estimates of cancer deaths. Studies of human populations exposed at low doses are inadequate to demonstrate the actual level of risk. There is scientific uncertainty about cancer risk in the low-dose region below the range of epidemiologic observation, and the possibility of no risk cannot be excluded (Committee on Interagency Radiation Research and Policy Coordination 1992). In this appendix, the doses have been provided (in all cases) to allow independent evaluation using any relation between exposure and health effects.

Nonradiological risks related to the transportation of naval spent nuclear fuel are also estimated. The nonradiological risks (fatalities) are the result of vehicle exhaust emission for incident-free transportation and transportation accidents for the accident risk evaluation. The nonradiological risks associated with shipments include a return trip for the transport vehicle. Each shipment is assumed to transport three shipping containers per train. Risk factors for vehicle exhaust emissions and accident fatality rates were obtained from "Non-Radiological Impacts of Transporting Radioactive Material" (Rao et al. 1982) and "Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight" (Saricks and Kvitek 1994), respectively.

B.3.1 Technical Approach for the Assessment of Incident-Free Transportation

General Population and Occupational Dose. For incident-free transportation of naval spent nuclear fuel, the RADTRAN 4 computer code was used to calculate the radiological dose for the general population and occupational dose.

Included in the RADTRAN 4 computer code incident-free risk calculations for transport are models describing (1) doses to persons (e.g., residents) adjacent to the transport route (off-link doses), (2) doses to persons (e.g., passengers on passing trains or vehicles) sharing the transport route (on-link doses), (3) doses to persons at stops (e.g., residents or rail crew not directly involved with the shipment), and (4) doses to transportation crew members (occupational). Dose to handlers at INEL and a centralized interim storage site or repository was not considered to be part of the transportation risk analysis and is analyzed in Appendix A. The doses calculated for the first three groups were added together to estimate the general population dose estimates; the dose calculated for the fourth group (crew exposure) is the occupational dose. For rail transport, RADTRAN 4 assumes that crew dose is from exposure during periods of package inspections and is negligible during the transit time due to relatively long separation distances and massive shielding of the intervening structure.

Maximally Exposed Individual. The maximum possible radiological dose to an individual for the routine transport of naval spent nuclear fuel was estimated for transportation workers, as well as members of the general population. For rail shipments, the four individual members of the general population evaluation were: (1) a railyard worker who might be working at a distance of approximately 32.8 ft (10 m) from the shipping container for 2 hours, (2) a resident who might live approximately 98.4 ft (30 m) from the rail line where the shipping container was being transported, (3) a resident who could be living approximately 656 ft (200 m) from a rail stop where the shipping

container was sitting for 20 hours, and (4) a person stopped next to a loaded transportation cask on a railcar at a distance of approximately 19.8 ft (6 m) for one hour. The crew members were used to represent the category of transportation workers (occupational). The crew members were postulated to be the same individuals for all shipments in order to conservatively estimate doses and effects.

For predicting radiological doses to persons at a fixed distance (the maximally exposed individual) from the package during a stop, the following formula was used. Since no credit is provided for shielding, actual doses would be lower than the calculated doses.

Doses to a person at a fixed distance from the container:

$$E = T \times K \times TI/D^2 \qquad \text{(B.1)}$$

where:

E = dose

T = total exposure time

K = shipment external dose rate to exposure rate conversion factor based on package size

TI = shipment external dose rate, dose rate at approximately 3.3 ft (1 m) from the package surface

D = average distance from the center of the container to the exposed person.

The dose to individuals at a fixed distance from the route along which the shipment is being transported was calculated using the following formula for a moving radiation source traveling with a fixed velocity, V. Since no credit is provided for shielding, actual doses would be lower than the calculated doses. All other terms are the same as described for Equation B.1.

$$E = (\pi \times K \times TI) / (V \times D) \qquad \text{(B.2)}$$

B.3.2 Technical Approach for Transportation Accidents

Analytical Approaches. Two separate analytical approaches to transportation accidents are used, one is a probabilistic assessment of impacts to human health and the environment and the other is a deterministic estimate of maximum consequences of a severe hypothetical transportation accident. The results of both analytical approaches have been used for the comparison of alternatives.

General Population Accident Risk. The RADTRAN 4 computer code was used to calculate the radiological risk to the general population under accident conditions where risk includes the probability of occurrence. In the accident situation, the transportation crew dose (occupational) is considered to be part of the general population. The RADTRAN 4 computer code evaluates six pathways for radiation doses resulting from an accident. The six potential pathways are:

- Direct radiation dose from the damaged container;

- Inhalation dose from the plume of radioactive material released from the damaged container;
- Direct radiation dose from immersion in the plume of radioactive material released from the damaged container;
- Direct radiation dose from ground deposition of the radioactive material released from the damaged container;
- Inhalation dose from resuspension of the radioactive material deposited on the ground; and
- Ingestion dose from food products grown on the soil contaminated by ground deposition of radioactive material released from the damaged container.

For each pathway, a specific formula is used to determine an estimate of the radiological risk, expressed in dose, from that particular pathway with the total radiation dose equal to the sum of the dose for each pathway. The total accident radiation dose accounts for the probability of an accident occurring and the probability of an accident of a particular severity. It should be noted that all consequences are included in the risk assessment, regardless of the probability. The general equation for the population dose from all pathways is:

$$D_R = \sum_{c,r} (N_c \times L_r \times P_r \times \sum_{i,j,k} (P_j \times RF_j \times D_{i,j,k})) \qquad (B.3)$$

where:

D_R = population dose from the accident

N_c = number of naval spent nuclear fuel containers shipped of fuel type c

L_r = shipment distance

P_r = probability of a traffic accident per unit distance

P_j = probability of occurrence of accident severity category j

RF_j = fraction of curies released from shipping container by severity category j

$D_{i,j,k}$ = radiation dose resulting from accident severity category j through pathway I in population density zone k.

The accident risk evaluation was performed using neutral and stable atmospheric conditions (Pasquill Stability Classes D and F, respectively). The neutral atmospheric condition (Class D) results provide a best estimate of the risk. Stable atmospheric conditions (Class F) resulted in values approximately twice the neutral conditions, ignoring the lower probability of occurrence.

Maximum Consequence of an Accident. In addition to the estimation of the radiological risk of an accident described above, an evaluation of the consequences of an accident of the highest severity that is reasonably foreseeable was performed. The consequences, expressed as radiological

dose, were calculated for the maximally exposed individual and the general population. Doses to the general population were calculated for each of the three population density regions (rural, suburban, and urban). The maximally exposed individual was assumed to be in the population area which resulted in the highest dose.

The RISKIND computer code, modified by its authors to accept the fission product inventory unique to naval spent nuclear fuel, was used to calculate the maximum consequences. The pathways evaluated by RISKIND are identical to those used in the RADTRAN 4 computer code for the risk evaluation.

The maximum consequence evaluation presents the consequences for accidents which have a probability of greater than 1×10^{-7} per year. Accidents with a probability of occurrence of less than 1×10^{-7} were not analyzed in the maximum consequence evaluation.

To determine the overall probabilities, the following conditions had to be determined:

the probability of an accident,
the fraction of travel in each population area,
the probability of the meteorological conditions, and
the probability of the consequences.

As described later in Section B.5, a study performed by Lawrence Livermore National Laboratory entitled "Shipping Container Response to Severe Highway and Railway Accident Conditions" (NRC 1987) grouped accidents into categories by strain and container mid-wall temperatures and calculated the probabilities of accidents of each category. Section B.5 also describes the consequences associated with each accident category for the naval spent nuclear fuel. The probabilities were summed for the categories which have the same consequences.

The probability of the accident was calculated by multiplying the national average rail accident rate times the total distance traveled times the number of shipments per year. The total number of containers shipped from INEL to a centralized interim storage site or a geologic repository is estimated to be 300 to 500 (360 to 585 for special case waste and naval spent nuclear fuel together) depending on the shipping container and fuel type. Table B.3 provides a proposed shipping schedule by year, although accident probability was based on the total number of container shipments. Based on past experience at Expended Core Facility and Idaho Chemical Processing Plant, one container shipment per month is reasonable and Table B.3 implies that an average of about two containers per month or fewer (300 to 500 shipments between 2010 and 2035) would be made during the periods of peak shipments.

For the purpose of analysis, Table B.3 presents a schedule of shipments of naval spent nuclear fuel (a subsequent Table B.4 includes special case waste as well as naval spent nuclear fuel). Table B.3 is consistent with the expectation that naval fuel will be among the earliest placed in the centralized interim storage site or geologic repository. While this shipment schedule was used as the basis for the transportation analysis, there would be little difference in impacts if the schedule were accelerated or delayed, taking into account that spent nuclear fuel from nuclear powered warships cannot be shipped until the vessels are refueled or defueled.

TABLE B.3 Naval Spent Nuclear Fuel Containers Shipped to a Centralized Interim Storage Site or a Geologic Repository, 2010 to 2035[a,b]

Year	MPC	No-Action	Current Technology/Rail	Transportable Storage Cask	Dual-Purpose Canister	Small MPC
2010	1	1	1	1	1	1
2011	1	2	1	1	1	3
2012	3	4	2	2	3	5
2013	6	7	4	4	6	8
2014	8	8	6	6	8	13
2015	9	10	8	8	9	15
2016	10	12	9	9	10	17
2017	11	15	11	11	11	19
2018	12	17	13	13	12	21
2019	14	19	15	15	14	23
2020	15	22	17	17	15	25
2021	15	22	17	17	15	25
2022	15	22	17	17	15	25
2023	15	22	17	17	15	25
2024	15	22	17	17	15	25
2025	15	22	17	17	15	25
2026	15	22	17	17	15	25
2027	15	22	17	17	15	25
2028	15	22	17	17	15	25
2029	15	22	17	17	15	25
2030	15	22	17	17	15	25
2031	15	22	17	17	15	25
2032	15	22	17	17	15	25
2033	15	22	17	17	15	25
2034	15	22	17	17	15	25
2035	0	0	0	0	0	0
TOTAL	300	425	325	325	300	500

[a] Table is not additive across rows. Each column represents the total shipments for the year depending on the alternative selected.
[b] All container shipments are by rail.

Table B.4 presents a projected shipping schedule that includes the additional special case waste shipments. As indicated in the table, the total shipments (naval spent nuclear fuel and special case waste) would range from a low of approximately 360 to a high of approximately 585. Even with the additional shipments of special case waste, the environmental impacts for any of the alternatives selected remain minimal in each case, therefore, the differences among the alternatives also remain negligible.

TABLE B.4 Naval Spent Nuclear Fuel and Special Case Waste Containers (Cumulative) Shipped to a Centralized Interim Storage Site or a Geologic Repository, 2010 to 2035[a,b]

Year	MPC	No-Action	Current Technology/Rail	Transportable Storage Cask	Dual-Purpose Canister	Small MPC
2010	1	1	1	1	1	1
2011	1	2	1	1	1	3
2012	3	4	2	2	3	5
2013	6	7	4	4	6	8
2014	8	8	6	6	8	13
2015	9	10	8	8	9	15
2016	10	12	9	9	10	17
2017	11	15	11	11	11	19
2018	12	17	13	13	12	21
2019	14	19	15	15	14	23
2020	15	22	17	17	15	25
2021	15	22	17	17	15	25
2022	19	25	20	18	16	28
2023	19	25	20	19	17	28
2024	19	25	20	19	17	28
2025	19	25	20	21	19	31
2026	19	25	20	21	19	32
2027	20	27	22	21	19	32
2028	20	27	22	21	19	33
2029	20	27	22	21	19	33
2030	20	27	22	21	19	33
2031	20	27	22	21	19	33
2032	20	27	22	21	19	33
2033	20	27	22	21	19	33
2034	20	27	22	21	19	33
2035	0	0	0	0	0	0
TOTAL	360	480	380	370	345	585

[a] Table is not additive across rows. Each column represents the total shipments for the year depending on the alternative selected.
[b] All container shipments are by rail.

The fraction of travel in each population area (rural, suburban, and urban) was obtained from the INTERLINE computer program, which is discussed in Section B.4. Given an origin and destination, INTERLINE provides the route of railroad travel as well as weighted population densities in the rural, suburban, and urban areas.

To calculate the probability of the meteorological conditions, Pasquill Class D was considered to be equivalent to 50% meteorology; that is, 50% of the time, conditions are expected

to be more severe, and 50% of the time, conditions are expected to be less severe. Pasquill Class F was considered to be equivalent to 95% meteorology; that is, 5% of the time, it is more severe, and 95% of the time, it is less severe. Analyses performed by the National Oceanic and Atmospheric Administration (Doty et al. 1976) confirm that this assumption is reasonable.

The overall probability of the consequence of an accident for each population area was then calculated by multiplying the accident probability times the consequence times the fraction of distance traveled. Starting with the highest consequences, the overall probabilities were then compared to the 1×10^{-6} per year or greater criterion for the design basis accidents and 1×10^{-7} per year or greater criterion for the beyond design basis accidents. If the overall probability was greater than 10 times the criterion (1×10^{-6} or 1×10^{-7}), the most severe Pasquill Class F results were presented. If not, and the overall probability was greater than the criterion (1×10^{-6} or 1×10^{-7}), Pasquill Class D was presented. If the overall probability was less than the cutoff, the probabilities having the next most severe consequences were compared to the same criterion and this step was repeated until all consequences were evaluated.

Careful attention was paid to ensure that the probabilities were not calculated for such small categories that the resulting probabilities were less than the criterion and results would inadvertently present less severe consequences. When the highest consequence accident did not meet the criterion, the probability of the next highest accident was determined by summing both the accident consequence being evaluated and the probability of the higher consequence accidents previously shown to have a probability less than the criterion. This same technique was applied to the fraction of travel (urban fraction is equivalent to highest consequence, suburban fraction is next highest, etc.) as demonstrated in the following example:

Probability of the accident of Consequence A	-	1.17×10^{-7}
Fraction of distance traveled in rural area	-	0.85
Fraction of distance traveled in suburban area	-	0.11
Fraction of distance traveled in urban area	-	0.04

The urban fraction was multiplied by the probability, and the resultant probability of an accident of Consequence A in an urban area was 4.68×10^{-9}. The consequences of this accident would not be evaluated. For the suburban area, the suburban and urban fractions were added (0.15) and then multiplied by the probability (1.17×10^{-7}), resulting in 1.76×10^{-8}. Again, the consequences of this accident would not be evaluated since the probability is less than 1×10^{-7}. Likewise, for the rural area, the rural, suburban, and urban fractions were added and multiplied by the probability. Using this technique, the probabilities would indicate that the rural probability was 1.17×10^{-7}, which is greater than the 1×10^{-7} criterion and the Consequence A results would be presented. If the fractions were used at face value, however, the probability of an accident of Consequence A would have been 4.68×10^{-9} in an urban area, 1.29×10^{-8} in a suburban area, and 9.95×10^{-8} in a rural area. When individually compared to the 1×10^{-7} criterion, this accident would not have been presented for any area.

Accident results are presented in Tables B.11 and B.12 for both the maximally exposed individual and the general population. The transportation crew is considered to be part of the general population under accident conditions, so a member of the transportation crew could be the maximally exposed individual.

B.3.3 Technical Approach for Transportation Air Quality Issues

The air emissions from rail transportation of spent nuclear fuel were estimated for each alternative over the 25 years of shipping within the 40-year analysis period. The air quality assessment includes an estimate of the total quantity of pollutants emitted by the combustion of fossil fuels in rail engines. The pollutants considered included particulates, carbon monoxide, nitrogen oxides, and hydrocarbons.

Emissions were calculated using Environmental Protection Agency (EPA) techniques by considering the total train round-trip shipment mileage for each alternative and emission factors developed by the EPA for pollutant sources (EPA 1985). The locomotive emissions represent average emissions for locomotives in the United States, assumed to represent the railroad emissions in this project from regular freight trains – each consisting of approximately 63 cars, 3 of which contain spent nuclear fuel casks. In practice, the railcars containing spent nuclear fuel casks would likely have empty buffer cars on either end of them (a total of 4). Consequently, the Department of Energy (DOE) might be responsible for, at most, 7 of the 63 cars on the train. However, for this analysis, it was assumed that the DOE would be responsible for emissions from the entire train.

In addition to the computation of total emissions by pollutant for each of the six alternatives for the entire 25 years of shipping within the 40-year analysis period, a separate calculation was made for emissions of ozone, carbon monoxide, and particulate matter through key nonattainment areas. Nonattainment areas are regions of the country (typically urban areas) in which pollutant levels exceed standards set by state regulations or the EPA. The issue of conformity with state regulations (for ozone) was evaluated by comparing emissions to de minimis levels of precursor pollutants (such as 100 tons per year for carbon monoxide). De minimis refers to the emission levels (different for each pollutant) below which the conformity regulations do not apply. In such areas, the addition of pollutants above these de minimis levels (even at moderate levels) would exacerbate already unhealthy air quality. The five nonattainment areas with the largest pollutant emission totals were used to compare the alternatives.

B.3.4 Analysis of Uncertainties

An extensive discussion of uncertainty analysis related to this Environmental Impact Statement can be found in Volume 1, Appendix D, Attachment F, Section F.1.5 of the Programmatic SNF and INEL EIS (DOE 1995). In summary, the calculations in this EIS have been performed in such a way that the estimates of risk provided are unlikely to be exceeded during either normal operations or in the event of an accident. For routine operations, the results of monitoring of actual operations provide clearly realistic source terms, which, when combined with conservative estimates of the effects of radiation, produce estimates of risk which are very unlikely to be exceeded. The effects for all alternatives have been calculated using the same source terms and other factors, so this EIS provides an appropriate means of comparing potential impacts on human health and the environment.

The analyses of hypothetical accidents provide more opportunities for uncertainty, primarily because the calculations must be based on sequences of events and models of effects which have not occurred. The models have attempted to provide estimates of the probabilities, source terms, pathways for dispersion and exposure, and the effects on human health and the environment which are as realistic as possible. However, in many cases, the very low probability of the accidents postulated has required the use of models or values for input which produce estimates of

consequences and risks which are higher than would actually occur because of the desire to provide results which will not be exceeded. In summary, the risks presented in this appendix are believed to be at least 10 to 100 times larger than what would actually occur.

The use of conservative analyses is not an important problem or disadvantage in this EIS since all of the alternatives have been evaluated using the same methods and data, allowing a fair comparison of all of the alternatives on the same basis. Furthermore, even using these conservative analytical methods, the risks for all of the alternatives are small, which greatly reduces the significance of any uncertainty analysis parameters.

B.4 Routing Analysis

In order to assess the radiological risks associated with transportation, it was necessary to determine route characteristics based on the origin and destination of each shipment.

For naval spent nuclear fuel shipments, the origin is the INEL (either the Expended Core Facility, the Idaho Chemical Processing Plant, the Birch Creek Area or the Lemhi Range Area). For analytical purposes, the destination is the Yucca Mountain Site. The potential rail route has been generated and analyzed using the INTERLINE computer code (Johnson et al. 1993). Included in the rural segment of the route is 17 mi (approximately 27 km) from the INEL location to Scoville, Idaho.

INTERLINE is an interactive computer program designed to simulate routing using the U.S. rail system. The INTERLINE code used is the latest available from Oak Ridge National Laboratory and contains the 1990 census data. The INTERLINE database consists of networks representing various competing rail companies in the United States. The routes used for the transportation evaluation were identified by the standard INTERLINE model, which simulates the selection procedure that railroad companies would use to direct shipments of spent nuclear fuel. The code is updated periodically to reflect current track conditions and has been benchmarked against reported mileages and observations. INTERLINE also provides the weighted population densities for rural, suburban, and urban populations for each state and averaged over all states along the shipment route and the percentage of mileage traveled in each population density. The distance traveled, weighted population density, and percentage of distance in each population density are input values in the RADTRAN 4 code.

Three routes were used in the evaluation: the most direct, an alternate eastern route, and an alternate western route. It is anticipated that the most direct route would be used a majority of the time; however, the eastern and western routes bound the possible rail routes that could be used during actual shipments. There was very little impact from the different routes. A comparison of the three routes is shown in Table B.15. The two alternate routes are significantly longer and pass through areas containing higher overall population densities than the most direct route.

A discussion of the transportation risks of shipping naval spent nuclear fuel from the Expended Core Facility to the Idaho Chemical Processing Plant was included in the Programmatic SNF and INEL EIS (DOE 1995; Volume 1, Appendix D, Attachment A, Section A.7.2). The risks associated with shipping fuel from the Idaho Chemical Processing Plant to the Expended Core Facility are identical with the risks from the Expended Core Facility to the Idaho Chemical Processing Plant. If fuel would be shipped from the Idaho Chemical Processing Plant or the Expended Core Facility to the Birch Creek or Lemhi Range Area, the risk would be approximately three to eight times the risk of shipping from the Expended Core Facility to the Idaho Chemical Processing Plant.

If no rail spur existed into the centralized interim storage site or geologic repository, heavy-haul trucks would be needed to transport the containers. The effect of these truck shipments would be expected to be small due to 1) the distance traveled; 2) the small number of shipments; and 3) the highly regulated requirements for heavy-haul truck movement, including speed of truck, escort requirements, limited use of high-traffic roads, etc. It is expected there will be a negligible increase in dose to the general population; however, there will be a slight increase in occupational dose. The use of heavy-haul trucks will cause some localized traffic congestion (movements occurring approximately 1 to 3 times per month). In addition, the use of trucks would necessitate additional container handling, which could require additional equipment at the rail/truck junction.

No rail link to the Yucca Mountain Site currently exists, and that if it were to become the site of a repository or centralized interim storage facility, heavy-haul transport might be used in place of a rail connection. However, the resolution of that issue will depend on the site eventually selected and the evaluation of the environmental impacts and other factors specific to that site. The routes, distances, and potentially affected populations would be the same for all of the alternative container systems considered for naval spent nuclear fuel because the shipments will use the same route--the route selected for shipment of commercial spent nuclear fuel and high-level radiological waste to the repository or centralized interim storage site. Similarly, all container systems considered would have the same design dose rate, a maximum of 10 millirem per hour at 2 meters, as required by the regulations. The key difference in the alternatives for the purposes of comparing the impacts associated with heavy-haul transport for naval spent nuclear fuel using the alternative container systems is the number of shipments.

B.5 Input Parameters

The major input parameters and models used to evaluate the radiological risks are provided in this section. Standard RADTRAN 4 computer code values, as well as actual data gathered from historical naval spent nuclear fuel shipments, were used as the basis for the input parameters.

B.5.1 Incident-Free Impacts

Shipment External Dose Rate. Incident-free impacts are directly proportional to the shipment external dose rate, which is the maximum total radiation level (gamma + neutron) at approximately 3.3 ft (1 m) from the cask. Information from actual past shipments of naval spent nuclear fuel in the M-140 container shows that typically the shipment external dose rate at approximately 3.3 ft (1 m) for containers used to transport naval spent nuclear fuel prior to examination is less than 1.0 mrem/h and that the maximum measured neutron radiation level is slightly higher than the gamma radiation level. The M-140 and the high capacity M-140 are considered to be typical shipping containers for naval spent nuclear fuel. Since more naval spent nuclear fuel would be loaded into the high capacity M-140 after examination, the external dose associated with that alternative will be slightly higher. Specifically, the shipment external dose rate was assumed to be 2.0 mrem/h (1.0 mrem/h gamma and 1.0 mrem/h neutron). Since there is no comparable experience for the external dose rate for the remaining containers, the dose rate at approximately 6.6 ft (2 m) is assumed to be the maximum allowable by the Nuclear Regulatory Commission for over-the-road shipment by exclusive use vehicle (10.0 mrem/h). The resulting shipment external dose rate at approximately 3.3 ft (1 m) from the surface of the container is 13.3 mrem/h (total), with gamma and neutron radiation contributing equal amounts. These shipment external dose rate values provide a conservative estimate of radiation dose to the public.

Transportation Distances and Population Densities. Section B.4 of this appendix provides a description of the general methodology used for determining transportation distances and the population densities along the transportation routes.

Train Speed. The RADTRAN 4 computer code provides standard values for train speeds that are dependent on the population density zone. For rural areas, the standard value is 40 mi/h (approximately 64 km/h). For suburban areas, the standard value is 25 mi/h (approximately 40 km/h), and for urban areas, the standard value is 15 mi/h (approximately 24 km/h). However, naval spent nuclear fuel shipments are required to be transported at speeds not to exceed 35 mi/h (approximately 56.3 km/h). Government escort logs from historical naval spent nuclear fuel shipments support use of 15 mi/h (approximately 24.1 km/h). This 15 mi/hr (approximately 24.1 km/h) train speed estimate was used in the analysis in this section. It should be noted that use of the slower speed results in a conservatively higher estimation of radiation dose than would be calculated if a higher speed were assumed.

Train Stop Time. The RADTRAN 4 computer code provides standard values for train stop times that are either dependent or independent of the distances traveled. These values are considered to be appropriate for general freight shipments and were used in the analyses in this EIS.

Number of Train Crew Members. The standard RADTRAN 4 computer code value for the number of train crew members is five, and this number was used for the analyses in this EIS. However, RADTRAN 4 assumes crew exposure is only received during package inspections. Therefore, crew exposure is assumed to be negligible during transit due to the relatively long separation distance between the crew and the container and massive shielding provided by intervening structures. Therefore, for rail shipments, RADTRAN 4 assigns crew exposure to one individual, the inspector.

Effective Package Dimension and Shipment External Dose Rate Conversion Factors. An effective package dimension was developed for the M-140 and high-capacity M-140 containers, which would be shipped in the vertical position. An effective package dimension for use in RADTRAN 4 was selected that most closely agreed with the radiation levels at various distances from the shipment predicted using a SPAN 4 model with explicit package dimensions. The remaining containers will be shipped in the horizontal position and are adequately represented as line sources. The length of the internal cavity was selected as the effective package dimension for these containers. (If the internal cavity length is used as the effective package dimension for the M-140, general population exposure increases by about 20%. However, since the M-140 is shipped in the vertical position; use of the internal cavity length is not appropriate and the selected effective package dimension is still conservative.)

The effective package dimension to dose rate conversion factors were calculated using the standard equation in the RADTRAN 4 computer code.

The values used for the effective package dimension and the shipment external dose rate to personnel dose rate conversion factors are provided in Table B.5.

TABLE B.5 Effective Package Dimensions and Shipment External Dose Rate Conversion Factors for the Alternative Shipping Containers

Alternative	Effective Package Dimension (ft)	(m)	Shipment External Dose Rate to Personnel Dose Rate Conversion Factor
Multi-Purpose Canister	15	4.6	10
No-Action Alternative	11	3.2	6.8
Current Technology/Rail	11	3.2	6.8
Transportable Storage Cask	14	4.2	9.4
Dual-Purpose Canister	16	4.8	10
Small Multi-Purpose Canister	15	4.6	10

Train Stop Shield Factors. For train stops, the standard RADTRAN 4 computer code gamma and neutron radiation shield factors are both assigned as 0.1. This value includes the presence of substantial railyard steel structures equivalent to approximately 4 in. (approximately 10.2 cm) of steel. With 4 in. (approximately 10.2 cm) of steel, gamma radiation is reduced by more than a factor of 10; however, the 4 in. (approximately 10.2 cm) of steel only reduces neutron radiation by a factor of approximately 2. Therefore, a shield factor of 0.5 was conservatively used for neutron radiation. In order to incorporate this shielding into the RADTRAN 4 computer code, separate gamma and neutron radiation exposure calculations were performed.

Radiation Dose Decrease Due to Distance. The RADTRAN 4 computer code provides standard values for determining the gamma and neutron radiation dose decrease at increasing distance from the source. For gamma radiation, the RADTRAN 4 computer code uses the $1/x^2$ decrease due to distance. The RADTRAN 4 computer code also specifically calculates the decrease in neutron dose at increased distances. The adequacy of the RADTRAN 4 radiation dose decrease was evaluated. The gamma radiation decrease factor used by RADTRAN 4 was consistent with the results predicted for naval spent nuclear fuel. The RADTRAN 4 prediction for neutron radiation slightly overpredicts the decrease in dose at far distances for the shipping containers used for naval shipments. Using the same basic equation used by RADTRAN 4, a value of 2.0×10^{-10} was used for the RADTRAN 4 constant a_4 in lieu of 0. The value of 2.0×10^{-10} produces results which are slightly higher than the standard method and agree with measurements of neutron dose rates from naval spent nuclear fuel shipments.

Shipment Storage Time. Naval spent nuclear fuel is not stored while being shipped; therefore, there was no intermediate shipment storage time associated with any of the alternatives.

Standard RADTRAN 4 Computer Code Values Used. The following standard RADTRAN 4 computer code value was reviewed and determined to reflect the best estimate of current railroad industry practice:

- Number of inspections of the shipping container and railcar.

The following standard RADTRAN 4 computer code estimates of the populations that could be affected by the shipment of naval spent nuclear fuel were also used for the six alternatives:

- Number of people per vehicle sharing the transport route (on-link);
- Traffic count passing a specific point — rural, suburban, and urban zones;
- Average exposure distance when stopped; and
- Persons exposed while stopped.

B.5.2 Accident Risk

Accident during Transportation of Spent Nuclear Fuel. This section discusses the input parameters used to calculate the radiological impacts for accidents during transportation of naval spent nuclear fuel. The transportation distances, population densities, and the percentages of travel in each population density described in Section B.4 were also used for the accident analyses. Unless otherwise described in this section, the standard values provided by the RADTRAN 4 and RISKIND computer codes were used.

Accident Probability. The range of accidents analyzed produces effects at least as large as the effects of a hypothetical heavy-haul transportation accident at an intersection in a major city on a week day during rush hour or an extremely severe terrorist attack. Such an event would be expected to produce impacts which would be within the scope of the accidents analyzed for an urban population density. Severe hypothetical accidents have also been analyzed for the rural and suburban population densities.

The probability of a rail accident was obtained from "Longitudinal Review of State-Level Accident Statistics for Carriers of Interstate Freight" (Saricks and Kvitek 1994). The probabilities are provided both by state and a national average. The state-specific probabilities were used for the accident risk assessment. Past naval spent nuclear fuel shipments have traveled approximately 1.2 million miles (approximately 2 million km) by rail without an accident, which is consistent with the national average of 5.57×10^{-8} accident per kilometer.

Accident Severity Categories and Probabilities. In the "Shipping Container Response to Severe Highway and Railway Accident Conditions" (NRC 1987), often referred to as the "modal study," Lawrence Livermore National Laboratory categorized the potential damage to shipping containers according to the magnitude of the thermal and mechanical forces that could result from an accident. The structural and thermal forces were categorized into 20 regions. Given that an accident occurs, the probability that the accident would be in each region of the matrix was calculated for rail shipments. Table B.6 provides the probabilities for rail accidents by region in the matrix.

TABLE B.6 Accident Severity Probabilities for Rail Shipments

Structural Response (maximum strain on inner shell, %)					
S_3 (30)	R(4,1) 1.8×10^{-9}	R(4,2) 3.3×10^{-13}	R(4,3) 2.1×10^{-13}	R(4,4) 1.6×10^{-13}	R(4,5) 3.5×10^{-14}
S_2 (2)	R(3,1) 5.5×10^{-4}	R(3,2) 1.0×10^{-7}	R(3,3) 6.3×10^{-9}	R(3,4) 5.2×10^{-8}	R(3,5) 5.3×10^{-8}
S_1 (0.2)	R(2,1) 2.7×10^{-3}	R(2,2) 5.0×10^{-7}	R(2,3) 3.3×10^{-7}	R(2,4) 2.5×10^{-7}	R(2,5) 1.1×10^{-8}
	R(1,1) 9.9×10^{-1}	R(1,2) 1.2×10^{-3}	R(1,3) 8.0×10^{-4}	R(1,4) 6.1×10^{-4}	R(1,5) 1.2×10^{-4}
		T_1 (500)	T_2 (600)	T_3 (650)	T_4 (1050)

Thermal Response (lead mid-thickness temperature, °F)

Naval Spent Nuclear Fuel Integrity Following an Accident. Detailed structural and thermal analyses were performed for the shipping containers used for naval spent nuclear fuel shipments up to an equivalent strain of 30% and mid-wall temperature of 1050°F. For these cases, the naval spent nuclear fuel would not be damaged. For the thermal and structural regions above 1050°F and 30% strain, the modal study defines the upper limits as unbounded. The naval spent nuclear fuel was postulated to be damaged, and the fraction of the fission products and the corrosion products that would be released to the container are presented in Table B.7.

Cask Release Fractions. The cask release fractions were derived based on the results presented in the modal study (NRC 1987) and the results of the structural and thermal analyses described above. Although naval spent nuclear fuel is stronger than the fuel types included in the study, the analysis of naval spent nuclear fuel used the release fractions for the category which included boiling water reactor and pressurized water reactor assemblies from the modal study (see Table B.7).

TABLE B.7 Fraction of Fission Products and Corrosion Products from Fuel that Are Available for Release from the Interior Cavity of a Container following an Accident

	Damage Fraction[a]					
Cask Response Region	Inert Gas	Iodine	Cesium	Ruthenium	Particulates	Corrosion Products
R(1,1)	0.0	0.0	0.0	0.0	0.0	0.0
R(1,2), R(1,3)	0.0	0.0	0.0	0.0	0.0	1.0
R(2,1), R(2,2), R(2,3)	0.0	0.0	0.0	0.0	0.0	1.0
R(1,4), R(2,4), R(3,4)	0.0	0.0	0.0	0.0	0.0	1.0
R(3,1), R(3,2), R(3,3)	0.0	0.0	0.0	0.0	0.0	1.0
R(1,5), R(2,5), R(3,5) R(4,5), R(4,1), R(4,2) R(4,3), R(4,4)	6.3×10^{-1}	4.3×10^{-2}	2.0×10^{-3}	4.8×10^{-4}	2.0×10^{-5}	1.0

[a] The damage fraction represents the fraction of the nuclide inventory released to the interior of the shipping container that would be available to be released through the damaged portion of the shipping container into the atmosphere following an accident of the given severity.

Analyses of the risks for hypothetical accidents for naval spent nuclear fuel used the following conditions:

- The fraction of fission and corrosion products released from naval spent nuclear fuel to the interior of the shipping container for the most likely but least severe accidents (lower left region R (1,1) of Table B.6) would be zero. This accounts for approximately 99.4% of all possible accidents.

- For the 0.6% of all accidents more severe than those in region R(1,1), 100% of the available corrosion products are assumed to be released to the interior of the shipping container.

- Based on analyses of accident conditions, accidents producing up to 30% strain and 1050°F mid-wall temperature (regions R(1,2), R(1,3), R(2,1), R(2,3), R(1,4), R(2,4), R(3,4), R(3,1), R(3,2), and R(3,3)) would not cause any damage to naval spent nuclear fuel and thus no fission products would be released from the fuel to the interior of the shipping container for accidents in these categories.

- For the most severe accidents, those accidents producing greater than 30% strain and 1050°F mid-wall temperature — regions R(1,5), R(2,5), R(3,5), R(4,5), R(4,1), R(4,2), R(4,3), and R(4,4) — 10% of the naval spent nuclear fuel might be damaged to the extent that fission products could be released from the fuel to the interior of the shipping container.

- The modal study states that experimental data show that only a fraction of the fission products released from damaged fuel to the interior of a container in an accident would be available to escape from the container due to the differing physical and chemical characteristics of the elements present. Approximately 63% of the fission products present in the form of noble gases, 4.3% of the iodine, 0.2% of the cesium, 0.048% of the ruthenium, and 0.002% of the solid fission products could be released to the interior of the container from the 10% of the fuel that might be damaged in an accident. The remainder would be contained by the fuel, cladding, or other materials.

- For all accidents other than the least severe accidents in region R(1,1), the damage to the shipping container might be great enough that 10% of the portion of the corrosion products or fission products released to the interior of the container could escape to the environment through the damaged area. The remainder would be trapped inside the container.

This means that there would be no release of radioactive material to the environment in about 99.4% of all accidents, potential for release of 10% of the corrosion products in about 0.6% of all accidents, and the possibility for release of 10% of the corrosion products and less than 1% of the fission products in a very small percentage of accidents (less than 0.02% of all accidents).

Table B.8 lists the amounts of radionuclides which could be released to the environment from a multi-purpose canister loaded with submarine or surface ship spent nuclear fuel assemblies. Each type of shipping container considered under the alternatives in this EIS contains different numbers of assemblies, and the relative release from each container type can be calculated by multiplying the data in this table by the appropriate relative capacity in Table B.1. This listing includes all radionuclides that would result in at least 99% of the possible exposure.

TABLE B.8 Radionuclides that Would Be Released from a Multi-Purpose Canister Shipment of Naval Spent Nuclear Fuel

Accidents Releasing Fission Products			Accidents Releasing Corrosion Products		
	Activity (Ci)			Activity (Ci)	
Nuclide	Surface Ship Assemblies	Submarine Assemblies	Nuclide	Surface Ship Assemblies	Submarine Assemblies
Tritium (H-3)	7.1×10^{-1}	6.2	Cobalt-58	2.6×10^{-9}	1.7×10^{-8}
Cesium-134	8.1×10^{-1}	1.5×10^{1}	Cobalt-60	6.1×10^{-1}	3.8×10^{-1}
Cesium-137	8.6×10^{-1}	8.2×10^{1}	Manganese-54	1.0×10^{-3}	1.0×10^{-3}
Strontium-90	8.5×10^{-1}	8.1×10^{-1}	Nickel-63	3.8×10^{-1}	2.2×10^{-1}
Ruthenium-106	1.2×10^{-1}	1.9×10^{-1}	Strontium-90[a]	4.6×10^{-4}	2.7×10^{-4}
Cerium-144	5.0×10^{-3}	4.4×10^{-2}	Iron-55	5.8×10^{-1}	3.9×10^{-1}
Plutonium-238	4.3×10^{-2}	4.3×10^{-2}			
Plutonium-241	1.2×10^{-2}	1.2×10^{-2}			
Curium-244	5.1×10^{-4}	5.1×10^{-4}			

[a] Strontium-90 is a fission product from trace elements in structural material that has plated out onto the fuel assembly along with activated corrosion products.

Plume Release Height. For the accident risk assessment, a ground level release was used. For the maximum consequence assessment, a plume release height of approximately 32.8 ft (10 m) was used.

Direct Exposure from a Damaged Shipping Container. A radiation level following the accident at the 10 CFR Part 71 regulatory limit of 1 rem at approximately 3.3 ft (1 m) from the container surface was used.

Food Transfer Factors. U.S. average food transfer factors were derived for the isotopes related to naval spent nuclear fuel in accordance with the methods described in the Nuclear Regulatory Commission's Regulatory Guide 1.109 (NRC 1977).

Distance from the Accident Scene to the Maximally Exposed Individual. No shielding was accounted for as the plume passes for the calculation of the exposure to the maximum individual. This location was determined using RISKIND based on the atmospheric stability and plume release height used. The maximally exposed individual could be a member of the rail crew or the general population.

RISKIND Population Density. The standard national average for each population density from the RADTRAN 4 computer code was used for the RISKIND maximum consequences assessment (6 people per square kilometer for rural, 719 for suburban, and 3,861 for urban).

Radionuclide Inventory. The amounts of radionuclides that would be released from a multi-purpose canister shipment are provided in Table B.8 and factor in damage fractions and cask release fractions described above in this section. The radionuclides listed result in 99% of the

exposure in all pathways. This inventory does not include the accident severity or the probability of occurrence. The amount of radionuclides that would be released from the other five alternative containers can be determined by applying the Table B.1 ratios.

B.6 Summary of Results

B.6.1 Incident-Free Risk

This section summarizes the results of the calculations for the radiological and nonradiological impacts of the incident-free transportation of naval spent nuclear fuel from INEL to a centralized interim storage site or a geologic repository location. Table B.9 shows the radiological impact on the general population, transportation workers (occupational), and the maximally exposed individual for one shipment of one cask. The projected number of fatalities from nonradiological sources for one shipment of one cask is provided for comparison purposes.

Table B.10 presents results for the predicted total number of shipments (see Table B.2) of each type of representative naval spent nuclear fuel and of special case waste in any of the six alternative containers. The results in this table were obtained by multiplying the corresponding entries in Table B.9 by the number of shipments (assuming three casks per shipment) for each type of container. The general population dose, occupational dose, and occupational maximally exposed individual are expected to affect the same individuals for all shipments.

If the number of shipments would be increased beyond the maximum for each alternative as a result of changing requirements, the risk would be calculated, as noted above, by multiplying the Table B.9 entry by the number of shipments.

All results are based on the most direct rail route. Using an alternate route could raise the risk by a factor of between 3 and 5. The increase is mainly due to the additional length of the route, and not because of population increase.

B.6.2 Accident Risk

This section summarizes the results of the calculations for radiological and nonradiological risks from accidents which could occur during shipments of naval spent nuclear fuel. The risks are provided for the general population in terms of exposure and estimated cancer fatalities. The risks are presented for 50% meteorological conditions, Pasquill Stability Class D.

Table B.11 provides the accident risk for one shipment of one container with its recommended cargo. The risk due to nonradiological sources is the same for each shipment regardless of the number or type of assemblies in the shipping container.

If the number of shipments would be increased beyond the maximum for each alternative as a result of changing requirements, the risk would be calculated, as noted above, by multiplying the Table B.11 entry by the number of shipments.

Because it is impossible to predict the specific location of a transportation accident, neutral weather conditions (Pasquill Stability Class D) were assumed. Since neutral meteorological conditions are the most frequently occurring atmospheric conditions in the United States, these conditions are most likely to be present in the event of a transportation accident.

TABLE B.9 Incident-Free Risk for One Shipment of One Cask

Alternative (Equipment)	General Population		Occupational Population		MEI, General Population[b]		MEI, Occupational		Estimated Nonradiological Fatalities
	Collective Dose (person-rem)	Latent Cancer Fatalities	Collective Dose (person-rem)	Latent Cancer Fatalities	Dose (rem)	Latent Cancer Fatalities	Dose (rem)	Latent Cancer Fatalities	
Multi-Purpose Canister (125-ton MPC)	0.042	2.1×10^{-5}	0.030	1.2×10^{-5}	0.0037	1.9×10^{-6}	0.030	1.2×10^{-5}	4.3×10^{-6}
No-Action (standard M-140)	0.0042	2.1×10^{-6}	0.0037	1.5×10^{-6}	0.00038	1.9×10^{-7}	0.0037	1.5×10^{-6}	4.3×10^{-6}
Current Technology/Rail (high-capacity M-140)	0.0042	2.1×10^{-6}	0.0037	1.5×10^{-6}	0.00038	1.9×10^{-7}	0.0037	1.5×10^{-6}	4.3×10^{-6}
Transportable Storage Cask (NAC-STC)[a]	0.039	1.9×10^{-5}	0.029	1.2×10^{-5}	0.0035	$1.7 \text{ x } 10^{-6}$	0.029	1.2×10^{-5}	4.3×10^{-6}
Dual-Purpose Canister (NUHOMS-MP187®)[a]	0.043	2.1×10^{-5}	0.031	1.2×10^{-5}	0.0038	1.9×10^{-6}	0.031	1.2×10^{-5}	4.3×10^{-6}
Small Multi-Purpose Canister (75-ton MPC)	0.042	2.1×10^{-5}	0.030	1.2×10^{-5}	0.0037	1.9×10^{-6}	0.030	1.2×10^{-5}	4.3×10^{-6}

[a] NAC-STC and NUHOMS-MP187® are representative casks for these alternatives.

[b] A person stopped next to a loaded transportation cask on a railcar is the maximally exposed individual (MEI); a resident living near the rail stop would receive a total exposure that is about a factor of 55 less (see Section B.3.1).

TABLE B.10 Incident-Free Risk for the Total Predicted Number of Shipments

Alternative (Equipment)	Number of SNF and SCW Casks	General Population		Occupational Population		MEI, General Population[c]		MEI, Occupational		Estimated Nonradiological Fatalities[a]
		Collective Dose (person-rem)	Latent Cancer Fatalities	Collective Dose (person-rem)	Latent Cancer Fatalities	Dose (rem)	Latent Cancer Fatalities	Dose (rem)	Latent Cancer Fatalities	
Multi-Purpose Canister (125-ton MPC)	360	15.0	7.5×10^{-3}	10.9	4.4×10^{-3}	1.3	6.7×10^{-4}	10.9	4.4×10^{-3}	5.2×10^{-4}
No-Action (standard M-140)	480	2.0	1.0×10^{-3}	1.8	7.2×10^{-4}	0.18	9.0×10^{-5}	1.8	7.2×10^{-4}	6.9×10^{-4}
Current Technology/ Rail (high-capacity M-140)	380	1.6	8.0×10^{-4}	1.4	5.7×10^{-4}	0.14	7.1×10^{-5}	1.4	5.7×10^{-4}	5.5×10^{-4}
Transportable Storage Cask (NAC-STC)[b]	370	14.4	7.2×10^{-3}	10.8	4.3×10^{-3}	1.3	6.4×10^{-4}	10.8	4.3×10^{-3}	5.3×10^{-4}
Dual-Purpose Canister (NUHOMS-MP187®)[b]	345	14.8	7.4×10^{-3}	10.6	4.2×10^{-3}	1.3	6.6×10^{-4}	10.6	4.2×10^{-3}	5.0×10^{-4}
Small Multi-Purpose Canister (75-ton MPC)	585	24.3	1.2×10^{-2}	17.7	7.1×10^{-3}	2.2	1.1×10^{-3}	17.7	7.1×10^{-3}	8.4×10^{-4}

[a] The number of shipments assumes 3 casks per train or 3 casks per shipment.
[b] NAC-STC and NUHOMS-MP187® are representative casks for these alternatives.
[c] A person stopped next to a loaded transportation cask on a railcar is the maximally exposed individual (MEI); a resident living near the rail stop (Scenario 3) would receive a total exposure that is about a factor of 55 less (see Section B.3.1).
Notation: SNF = Spent Nuclear Fuel; SCW = special case waste

TABLE B.11 Accident Risk for One Shipment of One Container with the Estimated Cargo

Alternative/ Cask and Fuel Type	General Population Collective Dose (person-rem)	Latent Cancer Fatalities	Estimated Traffic Fatalities[a]
Multi-Purpose Canister (125-ton MPC with submarine assemblies)	1.7×10^{-5}	8.5×10^{-9}	4.5×10^{-4}
Multi-Purpose Canister (125-ton MPC with surface ship assemblies)	1.8×10^{-5}	8.9×10^{-9}	4.5×10^{-4}
No-Action (M-140 with submarine assemblies)	1.0×10^{-5}	5.1×10^{-9}	4.5×10^{-4}
No-Action (M-140 with surface ship assemblies)	1.0×10^{-5}	5.1×10^{-9}	4.5×10^{-4}
Current Technology/Rail (high-capacity M-140 with submarine assemblies)	1.1×10^{-5}	5.7×10^{-9}	4.5×10^{-4}
Current Technology/Rail (high-capacity M-140 with surface ship assemblies)	1.3×10^{-5}	6.4×10^{-9}	4.5×10^{-4}
Transportable Storage Cask (NAC-STC[b] with submarine assemblies)	2.1×10^{-5}	1.1×10^{-8}	4.5×10^{-4}
Transportable Storage Cask (NAC-STC[b] with surface ship assemblies)	1.1×10^{-5}	5.7×10^{-9}	4.5×10^{-4}
Dual-Purpose Canister (NUHOMS-MP187®[b] with submarine assemblies)	1.9×10^{-5}	9.7×10^{-9}	4.5×10^{-4}
Dual-Purpose Canister (NUHOMS-MP187®[b] with surface ship assemblies)	1.8×10^{-5}	8.9×10^{-9}	4.5×10^{-4}
Small Multi-Purpose Canister (75-ton MPC with submarine assemblies)	9.7×10^{-6}	4.8×10^{-9}	4.5×10^{-4}
Small Multi-Purpose Canisters (75-ton MPC with surface ship assemblies)	1.0×10^{-5}	5.1×10^{-9}	4.5×10^{-4}

[a] This assumes that shipment will be made via general freight and 3 out of 63 cars (the average length of a freight train) carry spent nuclear fuel.

[b] NAC-STC and NUHOMS-MP187® are representative casks for these alternatives.

Table B.12 provides the accident risk for the total number of shipments (assuming 3 casks per shipment) given in Table B.2. All results are based on the most direct rail route. Using an alternate route could raise the risk by a factor of between 3 and 5.

B.6.3 Maximum Consequences of Accidents

The accident risk calculations discussed in Section B.3 include the probability of occurrence. This section summarizes the consequences for the most severe reasonably foreseeable accident in either a rural, suburban, or urban population zone. The consequences (in terms of dose) to the maximally exposed individual (MEI) are also presented. In an accident situation, the transportation crew is considered to be part of the general population and could be the MEI for purposes of analyses. Separate calculations for the transportation crew are not necessary.

Table B.13 provides a summary of the maximum consequences of a severe hypothetical accident. All results are based on the most direct rail route. The maximum number of expected latent cancer fatalities ranges from approximately 0.3 to 5.5.

B.6.4 Transportation Air Quality

Table B.14 presents the total air pollutant emissions for each of the six alternatives over a 25-year shipment period. In addition, the total emissions for ozone, carbon monoxide, and particulate matter are detailed. The difference among the alternatives is based on the total number of shipments needed to transport the fuel.

Figures B.2, B.3, and B.4 are U.S. maps showing the nonattainment areas for ozone, carbon monoxide, and particulate matter, respectively.

Annual emissions are very small for each alternative, if one considers that the Table B.14 totals represent a 25-year shipment period within the 40-year period analyzed for this EIS. The emissions are below de minimis levels (de minimis refers to the emission levels below which the conformity regulations do not apply), thereby avoiding the need to address federal conformity issues involving emissions. Annual emissions would likely be less than the de minimis levels, and as such, a conformity evaluation for this federal action would not be required in any state.

The most-direct route and the two alternate routes each pass through nonattainment areas; however in each case, the levels due to rail transportation are extremely low and de minimis.

TABLE B.12 Accident Risk for the Total Number of Shipments of Each Container of Naval Nuclear Spent Fuel with the Recommended Cargo

Alternative/ Cask and Fuel Type	Number of Casks	General Population Collective Dose (person-rem)	Latent Cancer Fatalities	Estimated Traffic Fatalities[a]
Multi-Purpose Canister (125-ton MPC with submarine assemblies)	300	0.0051	2.5×10^{-6}	0.045
Multi-Purpose Canister (125-ton MPC with surface ship assemblies)	300	0.0053	2.7×10^{-6}	0.045
No-Action (M-140 with submarine assemblies)	425	0.0043	2.2×10^{-6}	0.064
No-Action (M-140 with surface ship assemblies)	425	0.0043	2.2×10^{-6}	0.064
Current Technology/Rail (high-capacity M-140 with submarine assemblies)	325	0.0037	1.8×10^{-6}	0.049
Current Technology/Rail (high-capacity M-140 with surface ship assemblies)	325	0.0041	2.1×10^{-6}	0.049
Transportable Storage Cask (NAC-STC[b] with submarine assemblies)	325	0.0068	3.4×10^{-6}	0.049
Transportable Storage Cask (NAC-STC[b] with surface ship assemblies)	325	0.0037	1.9×10^{-6}	0.049
Dual-Purpose Canister (NUHOMS-MP187®[b] with submarine assemblies)	300	0.0058	2.9×10^{-6}	0.045
Dual-Purpose Canister (NUHOMS-MP187®[b] with surface ship assemblies)	300	0.0053	$2.7 \text{ x } 10^{-6}$	0.045
Small Multi-Purpose Canister (75-ton MPC with submarine assemblies)	500	0.0048	$2.4 \text{ x } 10^{-6}$	0.076
Small Multi-Purpose Canister (75-ton MPC with surface ship assemblies)	500	0.0051	2.5×10^{-6}	0.076

[a] This assumes that shipment will be made via general freight and 3 out of 63 cars (the average length of a freight train) carry spent nuclear fuel.

[b] NAC-STC and NUHOMS-MP187® are representative casks for these alternatives.

TABLE B.13 Summary of Maximum Consequences of a Severe Hypothetical Accident

Alternative/ Cask and Fuel Type	MEI		Rural Population		Suburban Population		Urban Population	
	Dose (rem)	Latent Cancer Fatalities	Collective Dose (person-rem)	Latent Cancer Fatalities	Collective Dose (person-rem)	Latent Cancer Fatalities	Collective Dose (person-rem)	Latent Cancer Fatalities
Multi-Purpose Canister (125-ton MPC with submarine assemblies)	7.1	0.0036	2600	1.3	1600	0.8	8800	4.4
Multi-Purpose Canister (125-ton MPC with surface ship assemblies)	6.9	0.0035	2200	1.1	1300	0.7	7100	3.6
No-Action (M-140 with submarine assemblies)	1.3	0.0006	840	0.42	10	0.0	51	0.03
No-Action (M-140 with surface ship assemblies)	1.2	0.0006	680	0.34	15	0.01	79	0.04
Current Technology/Rail (high-capacity M-140 with submarine assemblies)	1.5	0.0008	930	0.47	11	0.01	57	0.03
Current Technology/Rail (high-capacity M-140 with surface ship assemblies)	1.5	0.0008	840	0.42	18	0.01	98	0.05
Transportable Storage Cask (NAC-STC[a] with submarine assemblies)	8.8	0.0044	3200	1.6	2000	1.0	10900	5.5
Transportable Storage Cask (NAC-STC[a] with surface ship assemblies)	4.4	0.0022	1400	0.70	850	0.4	4600	2.3
Dual-Purpose Canister (NUHOMS-MP187®[a] with submarine assemblies)	8.1	0.0041	3000	1.5	1900	1.0	10100	5.1
Dual-Purpose Canister (NUHOMS-MP187®[a] with surface ship assemblies)	6.9	0.0035	2200	1.1	1300	0.7	7100	3.6
Small Multi-Purpose Canister (75-ton MPC with submarine assemblies)	4.1	0.0020	1500	0.74	3000	1.5	5000	2.5
Small Multi-Purpose Canister (75-ton MPC with surface ship assemblies)	3.9	0.0020	1300	0.62	2300	1.2	4100	2.1

[a] NAC-STC and NUHOMS-MP187® are representative casks for these alternatives.

TABLE B.14 Transportation Air Pollutant Emissions for Program Duration in Salt Lake City, Utah

Alternative	Number of Naval SNF and SCW Shipments	Vehicular Emissions (Tons) for Each Pollutant							
		Particulates	Sulfur Dioxides	Carbon Monoxide	Hydrocarbons	Nitrogen Oxides	Aldehydes	Organic Acids	Total
Multi-Purpose Container	360	0.14	0.31	0.70	0.51	2.00	0.30	0.04	3.99
No-Action Alternative	480	0.18	0.41	0.94	0.68	2.66	0.40	0.05	5.31
Current Technology/Rail	380	0.14	0.32	0.74	0.54	2.11	0.31	0.04	4.21
Transportable Storage Cask	370	0.14	0.32	0.72	0.52	2.05	0.31	0.04	4.10
Dual Purpose Container	345	0.13	0.29	0.67	0.49	1.91	0.28	0.04	3.82
Small Multi-Purpose Container	585	0.22	0.50	1.14	0.82	3.25	0.48	0.06	6.48

Notation: SNF = Spent Nuclear Fuel; SCW = special case waste

TABLE B.15 Comparison of Alternate Transportation Routes

	Most Direct Route[a]	Eastern Route[b]	Western Route[c]
Total Distance of Route in miles (km)	860 (1400)	2500 (4100)	2300 (3600)
Percent Travel that is Urban	1.2%	1.2%	2.0%
Percent of Travel that is Suburban	5.8%	6.1%	7.9%
Percent of Travel that is Rural	93.0%	92.7%	90.1%
Average Population Density in Person/Square Mile (person/square kilometer)	130 (50)	160 (61)	240 (92)

[a] Route goes from INEL to Pocatello to Salt Lake City to Yucca Mountain
[b] Route goes from INEL to Pocatello to Denver to Albuquerque to Las Vegas to Yucca Mountain
[c] Route goes from INEL to Pocatello to Boise to Sacramento to Las Vegas to Yucca Mountain

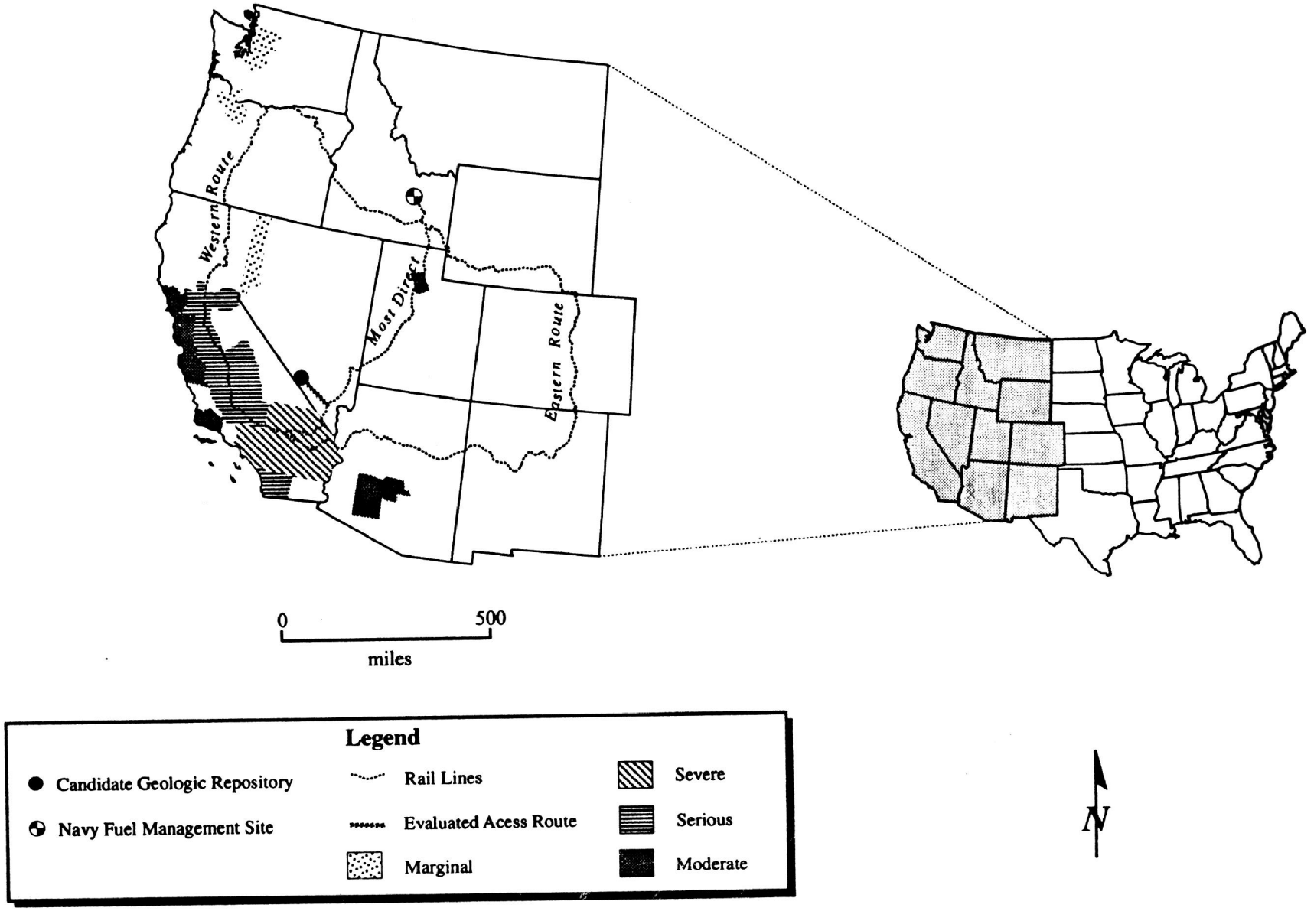

FIGURE B.2 Location of Ozone Nonattainment Areas

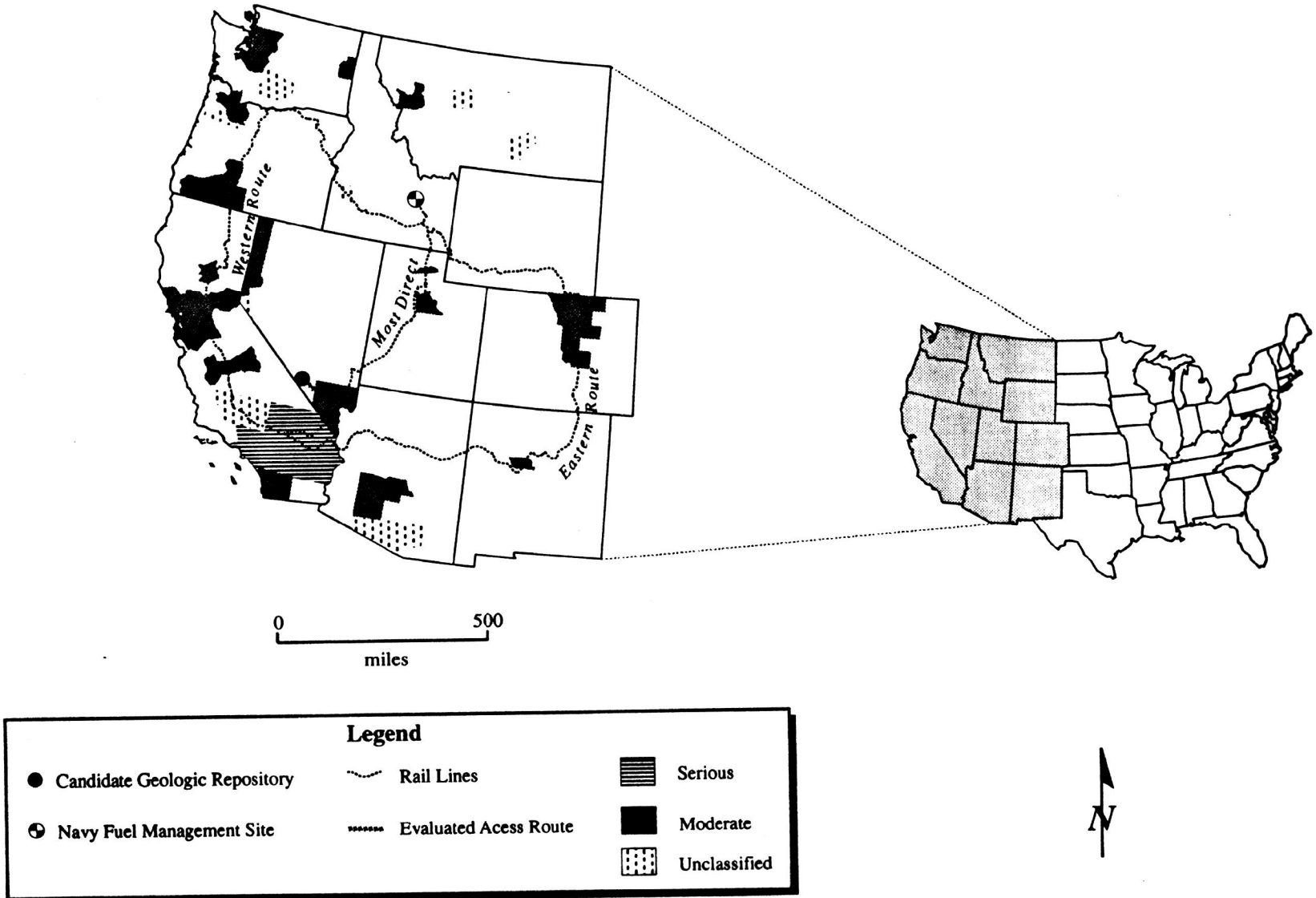

FIGURE B.3 Location of Carbon Monoxide Nonattainment Areas

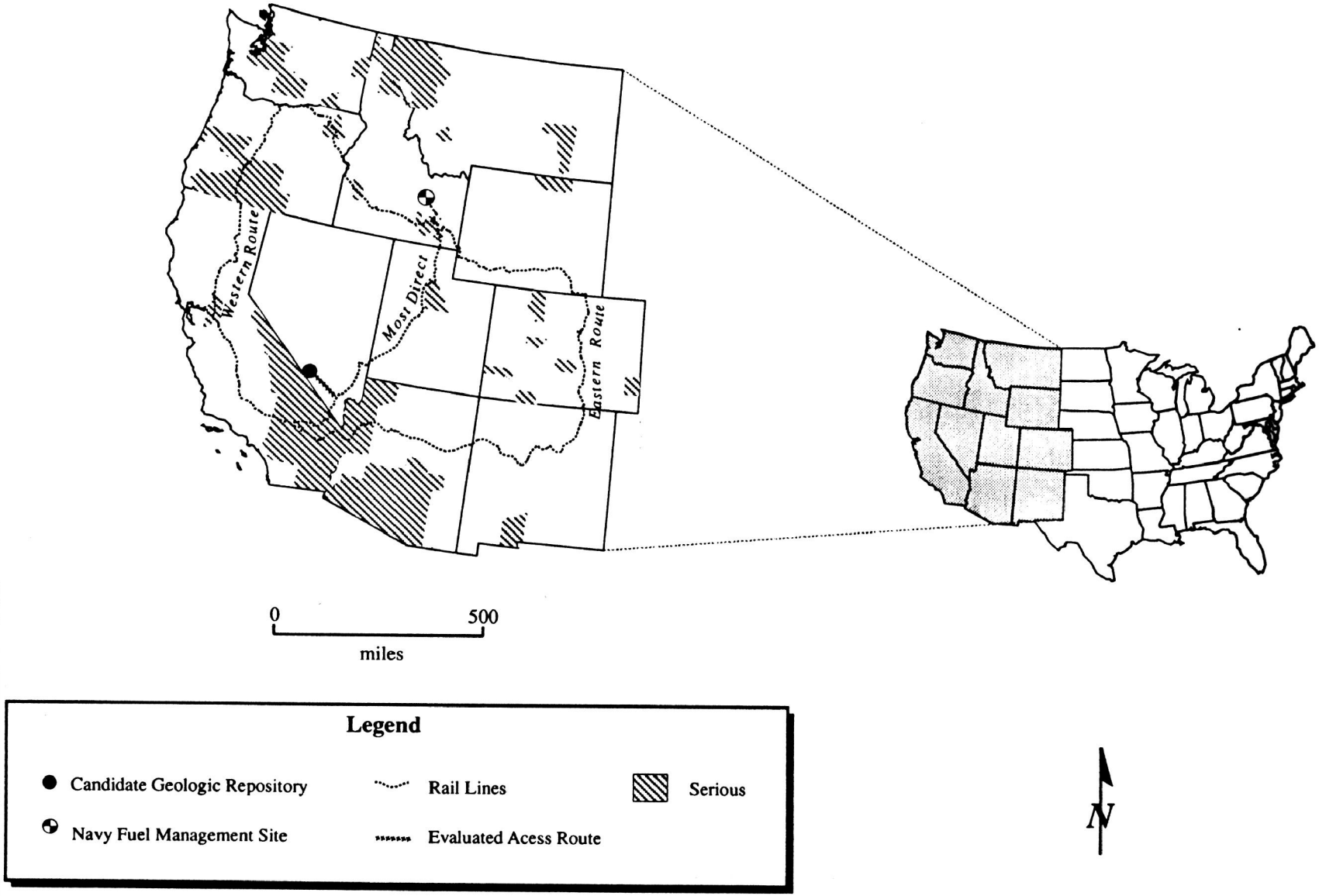

FIGURE B.4 Location of Particulate Matter Nonattainment Areas