DEPARTMENT OF THE NAVY
NAVAL SEA SYSTEMS COMMAND
1333 ISAAC HULL AVE SE
WASHINGTON NAVY YARD DC 20376-0001

QA: N/A

20 August 2001

Mr. J. R. Dyer, Project Manager
U. S. Department of Energy
Yucca Mountain Site
Characterization Office
P.O. Box 30307
North Las Vegas, NV 89036-0307

Dear Mr. Dyer,

Reference (a) and reference (b) requested that the NNPP submit information on a variety of topics, including Overall Activity by Nuclide and a Technical Support Document for Transportation Analysis for Naval Spent Nuclear Fuel and Special Case Waste for the Yucca Mountain Final Environmental Impact Statement. In reference (c), YMSCO also requested an update of naval spent nuclear fuel shipments to the INEEL since 1998. This information is provided in attachment (c).

Radionuclide Inventory

After discussions with the OCRWM, the NNPP provided a table of radionuclides five years after shutdown for a generic submarine container and a generic surface ship container. These calculations were provided to the OCRWM in reference (d). A note in attachment (1) to reference (d) stated that "The information contained in the table below is considered to be preliminary. The final activity will be based on ORIGEN-S."

Attachment (a) provides a revised source term, including a specific crud concentration, to allow a more accurate transportation calculation to be completed. One representative container is presented, rather than a surface ship and a submarine container. This source term will be used by the NNPP in future calculations supporting transportation, and pre- and post-closure performance. This source term is based upon detailed ORIGEN-S calculations. ORIGEN-S has been fully qualified for use with naval spent nuclear fuel in repository applications. The crud term is calculated using a procedure defined in reference (e).

This information should be included in Appendix A of the Final Environmental Impact Statement (EIS) and will be used to support transportation calculations for the Final EIS. In addition, the NNPP will use this source term in future calculations (pre- and post-closure) to support the License Application. This revised source term does not change any conclusions regarding naval spent nuclear fuel for the Site Recommendation.

Technical Support Document for Transportation Analysis

The Technical Support Document, attachment (b), details the transportation analysis results for naval spent nuclear fuel and special case waste shipments from the Idaho National Engineering and Environmental Laboratory (INEEL) to a proposed geological repository at the Yucca Mountain Site in Nevada from 2010 to 2035. The transportation analysis parameters are based primarily on the YMSCO Yucca Mountain EIS Transportation Databook issued to Naval Reactors during July 2001. Shipment numbers are based on the use of the naval spent fuel canister system.

The results for the transportation analysis of naval spent nuclear fuel and special case waste are provided in attachment (b) to this letter. Incident-free consequences for the general population, occupational population, and maximally exposed individuals are provided. The radiological accident-related risks are also provided in attachment (b).

It was determined that the YMSCO Environmental Impact Statement contractor would provide the non-radiological vehicle emission health effects for the transportation of all spent fuel shipments, including naval spent fuel shipments, to the repository. As a result, no analysis of vehicle emissions for naval spent fuel shipments is provided in attachment (b). The YMSCO Environmental Impact Statement contractor also completed calculations for appropriate population escalations for the year 2035 for all spent fuel shipments including naval shipments for the Final Environmental Impact Statement.

If there are any questions concerning the information submitted by this letter, or in the specific areas noted above, please contact Don Doherty of my staff at 202-781-6203.

John M. McKenzie
Acting Director, Regulatory Affairs
Naval Nuclear Propulsion Program

References:

(a) Repository Environmental Impact Statement Data Call (OPE-SFP-97-178), Department of Energy Memorandum, Idaho Operations Office, May 21, 1997 modified by Addendum to Repository Environmental Impact Statement Data Call, Department of Energy letter dated June 12, 1997
(b) DOE-YMSCO (S. Brocoum) letter to NNPP (G. E. Mowbray) dated March 15, 2001
(c) DOE-YMSCO (S. Brocoum) letter to NNPP (G. E. Mowbray) dated August 16, 2000
(d) Naval Reactors (R. A. Guida) letter to DOE (P. J. Dirkmaat and K. G. Picha) dated July 3, 1997
(e) SDM-77, *Shield Design Manual*, Rev. 10, dated February 1999

Attachments:

(a) Revised Source Term for Naval Spent Nuclear Fuel for Use in the Geologic Repository and Transportation Calculations
(b) Technical Support Document for Transportation Analysis for Naval Spent Nuclear Fuel and Special Case Waste for the Yucca Mountain Final Environmental Impact Statement
(c) Number of Naval Spent Fuel Container Shipments to ECF, Idaho by Origin

Copy to (see next page):

Copy to:
S. J. Brocoum, Assistant Manager, YMSCO/DOE
S. P. Mellington, Assistant Manager, YMSCO/DOE
J. T. Sullivan, YMSCO/DOE
R. Sweeney, YMSCO/DOE
J. R. Summerson, YMSCO/DOE
R. E. Spence, YMSCO/DOE
C. L. Hanlon, YMSCO/DOE
J. M. Replogle, YMSCO/DOE
P. G. Harrington, YMSCO/DOE
J. Price, YMSCO/DOE
P. R. Z. Russell, YMSCO/DOE
J. H. Carlson, DOE-OCRWM
S. E. Gomberg, DOE-OCRWM
D. Beckman, YMSCO/DOE
B. J. Schramm, Bettis (QEA)
J. H. Smyder, Bettis (QEA)
F. Pineau, KAPL

Revised Source Term for Naval Spent Nuclear Fuel for Use in the Geologic Repository and Transportation Calculations
Five Years after Shutdown Values
(All values in Curies)

Isotope	Crud	Total		Isotope	Crud	Total
ac227	0.0E+00	9.8E-05		pu238	2.7E-05	1.2E+04
am241	3.9E-05	5.0E+01		pu239	4.5E-06	1.2E+01
am242m	2.2E-07	4.6E-01		pu240	2.8E-06	1.4E+01
am243	3.3E-07	6.7E-01		pu241	8.8E-04	4.0E+03
c14	1.1E-01	1.6E+01		pu242	3.3E-08	8.0E-02
cf252	0.0E+00	1.2E-06		ra226	0.0E+00	5.4E-06
cl36	0.0E+00	6.9E-01		ra228	0.0E+00	1.8E-07
cm242	3.1E-07	1.4E+00		rh102	0.0E+00	2.8E-02
cm243	2.5E-07	7.9E-01		ru106	0.0E+00	6.0E+03
cm244	3.2E-05	6.3E+01		se79	1.7E-08	3.4E-01
cm245	2.8E-09	7.2E-03		sm151	0.0E+00	1.4E+03
cm246	1.1E-09	1.4E-03		sn126	5.0E-08	1.2E+00
cm247	3.3E-15	9.4E-09		sr90	4.0E-03	4.4E+05
cm248	1.1E-14	2.6E-08		tc99	1.1E-04	7.0E+01
co60	5.8E+00	3.7E+03		th229	0.0E+00	9.4E-06
cs134	0.0E+00	8.4E+04		th230	0.0E+00	1.8E-03
cs135	0.0E+00	4.6E+00		th232	1.1E-11	2.3E-07
cs137	4.0E-03	4.5E+05		u232	1.6E-07	5.6E-01
h3	0.0E+00	1.4E+03		u233	0.0E+00	3.1E-03
i129	4.5E-07	1.2E-01		u234	0.0E+00	1.5E+01
kr85	0.0E+00	3.6E+04		u235	0.0E+00	2.9E-01
nb93m	1.3E-01	3.6E+00		u236	0.0E+00	2.5E+00
nb94	2.2E-03	1.8E+02		u238	0.0E+00	1.2E-03
ni59	3.3E-02	6.3E+01		zr93	2.2E-05	1.1E+01
ni63	3.2E+00	7.8E+03		TOTAL	9.3E+00	1.1E+06
np237	3.3E-10	1.6E+00				
pa231	0.0E+00	5.2E-04				
pb210	0.0E+00	8.9E-07				
pd107	0.0E+00	6.0E-02				

Attachment (b) to
Ser 08U/13931

Technical Support Document for Transportation Analyses for Naval Spent Nuclear Fuel and Special Case Waste for the Yucca Mountain Final Environmental Impact Statement

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LIST OF TABLES

1 PURPOSE AND SCOPE

This Technical Support Document provides the basis for the transportation analyses for shipments of naval spent nuclear fuel and special case waste to a proposed geologic repository site at Yucca Mountain, Nevada. These transportation analyses results are being incorporated into the *Department of Energy, Yucca Mountain Repository Final Environmental Impact Statement* (YM FEIS), Chapter 6 and Appendix J.

2 TRANSPORTATION ANALYSIS

2.1 Introduction

This document details the transportation analyses for 300 naval spent nuclear fuel shipments and 55 special case waste shipments from the Idaho National Engineering and Environmental Laboratory (INEEL) to a proposed geologic repository at the Yucca Mountain Site in Nevada from 2010 to 2035. The term special case waste is used for naval non-fuel bearing wastes. The terminology being used in the YM EIS for the non-fuel bearing wastes will be Special Performance Assessment Required (SPAR) waste. SPAR waste is a Department of Energy category of greater-than-class-C low-level radiological waste. Throughout this document the term special case waste will be used.

2.2 Routing and General Approach to the Analysis

The analysis examines ten possible routes from INEEL to a proposed geologic repository at the Yucca Mountain Site. Five routes are railroads, and five routes are a combination of railroad and heavy-haul truck. Computer codes are used to calculate the radiological dose to the general population and occupational (workers) for incident-free transportation. Computer codes are also used to calculate the radiological doses to the general population and for a maximally exposed individual from the general population as a result of a potential transportation accident. In addition, dose-risk is calculated for the general population. Assuming that an accident occurs, dose-risk is the summation of the products of the accident severity fractions (probabilities) and the accident consequences expressed in dose (person-rem). Dose-risk is the expected value of population risk in person-rem. The health risk conversion factors used in this evaluation are taken from the International Commission on Radiological Protection Publication 60 which estimates 0.0005 latent cancer fatalities per person-rem for members of the public, and 0.0004 latent cancer fatalities per person-rem for workers, Reference (a).

The Department of Energy Yucca Mountain Site Characterization Office (DOE-YMSCO) is responsible for the non-radiological vehicle emission health effects for transportation of all spent fuel shipments, including naval spent fuel shipments, to the repository. Therefore, no analysis of vehicle emissions for naval spent fuel shipments is provided in this document. In addition, since shipments would be conducted through the year 2035, DOE-YMSCO will apply population escalation factors for the year 2035 to all radiological and non-radiological values for the YM FEIS, including the results presented in this document.

2.3 Transportation Analysis Codes

Computer codes are used to assess the radiological consequences and risks associated with the transportation of naval spent nuclear fuel and special case waste. Specifically, the RADTRAN risk analysis model, developed by Sandia National Laboratories, Reference (b), is used to evaluate the radiological consequences (doses) to the general population and occupational population from the routine incident-free transportation of radioactive materials. In addition, RADTRAN is extensively used to calculate the dose-risk to the general population from accidents that might occur during transportation of radioactive materials. For dose-risks, the code evaluates the range of possible accident scenarios from high probability and low consequence to low probability and high consequence.

RISKIND, a computer code developed by Argonne National Laboratory, Reference (c), is used to complement RADTRAN to evaluate the radiological consequences (doses) to an individual and to the general population for a maximum reasonably foreseeable transportation accident scenario. The RISKIND code provides scenario-specific assessments of radiological consequences of severe transportation-related accidents while the RADTRAN risk assessment considers the entire range of accident severities and their related probabilities. The RISKIND computer code is also used to calculate incident-free dose estimates for maximally exposed individuals within the general population and occupational population.

Several other computer codes are used to provide input for RADTRAN and RISKIND. These codes include INTERLINE, HIGHWAY, and ORIGEN-S. A brief description of each computer code and how it is used is provided below.

INTERLINE, developed by Oak Ridge National Laboratory, Reference (d), is used to obtain population densities for rail routes and the distance traveled in each population density.

HIGHWAY, also developed by Oak Ridge National Laboratory, Reference (e), is used to obtain population densities for truck (heavy-haul) routes and the distance traveled in each population density.

ORIGEN-S is a computer code that is a part of the Standardized Computer Analysis for Licensing Evaluation (SCALE) system of computer codes developed and maintained by Oak Ridge National Laboratory, Reference (f). The SCALE system of codes is available to the public and is widely used in commercial nuclear applications. ORIGEN-S is a point isotopic generation and decay module, which has the capability of following over 1000 unique isotopes. ORIGEN-S is used to develop the radionuclide inventory.

2.4 Technical Approach for the Assessment of Incident-Free Transportation

Incident-free doses are calculated based on the shipment external dose rate. Since there is no comparable experience for the external dose rate for a naval spent fuel shipping cask with a canister, the dose rate at 6.6 ft (2 m) is assumed to be the maximum allowed by the Nuclear Regulatory Commission for exclusive use vehicles (10.0 mrem/hr).

For incident-free transportation of naval spent nuclear fuel and special case waste, the RADTRAN computer code is used to estimate the radiological doses for the general population during transit and inspections. The general population consists of the following groups:

Public along the route (off-link exposure). Collective doses for persons living or working within 0.8 kilometer (0.5 mile) on each side of the transportation route.

Public sharing the route (on-link exposure). Collective doses for persons in vehicles sharing the transportation route; this includes persons traveling in the same or opposite directions and those in vehicles passing the shipment.

Public during stops (stops). Collective doses for people who could be exposed while a shipment was stopped en route. For truck (heavy-haul) transportation, these would include stops for refueling, food, and rest. For rail transportation, stops would occur in railyards along the route to switch railcars from inbound trains to outbound trains traveling toward the Yucca Mountain Site and to change train crews and equipment.

The RADTRAN and RISKIND computer codes are used to estimate the radiological doses during transit and inspections for the occupational population, which consists of train crews, heavy-haul crews, and heavy-haul escorts. The RISKIND computer code more accurately models radiological doses for individuals who are located very close to the cask (i.e., 1.5 meters).

Tables 1a through 1e list key input parameters provided to Naval Reactors by DOE-YMSCO, Reference (g). Population densities and link distances for various routes are also included in Reference (g). Naval Reactors provided input parameters specific to naval spent nuclear fuel shipments.

Table 1a RADTRAN Input Parameters for Rail Transportation

Parameter	Parameter value
Number of people in vehicles sharing link	3
Rural vehicle density	1 vehicle/km
Suburban vehicle density	5 vehicles/km
Urban vehicle density	5 vehicles/km
Rural rail speed in Idaho and Utah	64.37 km/hr
Rural rail speed in Nevada	50.10 km/hr
Suburban rail speed	40.25 km/hr
Urban rail speed	24.16 km/hr
Shielding factor (except stops)	1.0 (no shielding)
Gamma fraction	0.5
Neutron fraction	0.5
Shipping Cask Length	5.86 m (a)
Transport Index (dose rate at 1 meter from cask or vehicle surface)	12.54 mrem/hr (b)

(a) Current design dimension for the naval spent fuel shipping cask
(b) Calculated value using the exclusive use vehicle limit of 10.0 mrem/hr at 2 meters.

Table 1b RADTRAN Input Parameters for Rail Transportation Stop Models for Calculating Public Doses

Inspection (Classification Yard Stop) Independent of Distance Traveled	
Parameter	Parameter value
Number of Classification stops	2
Minimum distance from the shipping cask to the population (inner radius of exposure area)	400 meters
Maximum distance from the shipping cask to the population (outer radius of exposure area)	800 meters
Classification stop time	30 hours
Shielding Factor	1.0 (no shielding)
Other Rail Stops	
Parameter	Parameter value
Minimum distance from the shipping cask to the population (inner radius of exposure area)	30 meters
Maximum distance from the shipping cask to the population (outer radius of exposure area)	800 meters
Shielding Factor	1.0 (no shielding)
Stop Time	0.033 hours/kilometer. Stop time was calculated for each link by multiplying 0.033 hr/km by the length of the link in km.

Table 1c RADTRAN Input Parameters for Heavy-Haul Truck Transportation

Parameter	Parameter value
Number of crew	3
Number of people in vehicles sharing link	2
Rural vehicle density	680 vehicles/km
Suburban vehicle density	1103 vehicles/km
Urban vehicle density	5304 vehicles/km
Rural, suburban, urban freeway speed	40.25 km/hr
Distance from crew to cask	30 m
Shielding factor (except stops)	1.0 (no shielding)
"Crew view" (diameter) of shipping cask	2.15 m (a)
Gamma fraction	0.5
Neutron fraction	0.5
Shipping Cask Length	5.86 m (a)
Transport Index (dose rate at 1 meter from cask or vehicle surface)	12.54 mrem/hr (b)

(a) Current design dimension for the naval spent fuel shipping cask
(b) Calculated value using the exclusive use vehicle limit of 10.0 mrem/hr at 2 meters.

Table 1d RADTRAN Input Parameters for Heavy-Haul Transportation Stop Models for Calculating Public Doses

Parameter	Parameter value
Minimum distance from the shipping cask to the population (inner radius of exposure area)	30 meters
Maximum distance from the shipping cask to the population (outer radius of exposure area)	800 meters
Shielding Factor	1.0 (no shielding)
Stop Time	There are ten-minute inspection stops every 161 kilometers.

Table 1e Input Parameters for Heavy-Haul Transportation Stop Models for Calculating Crew Doses

Overnight Stop * (RADTRAN)	
Parameter	Parameter value
Number of guards for the overnight stop	4
Distance from cask	60 meters
Shielding Factor	1.0 (no shielding)
Stop Time	12 hours
* The crew and all escorts are assumed to receive no dose while sleeping.	

Heavy Haul Crew Drivers in Cab During Inspection Stop (RADTRAN)	
Parameter	Parameter value
Number of crew members	3
Distance from cask	30 meters
Shielding Factor	1.0 (no shielding)
Stop Time	There are ten-minute inspection stops every 161 kilometers.

Vehicle Escorts During Inspection Stop (RADTRAN)	
Parameter	Parameter value
Number of escorts	5
Distance from cask	60 meters
Shielding Factor	1.0 (no shielding)
Stop Time	There are ten-minute inspection stops every 161 kilometers.

Inspector During Walkaround Inspection Stop (RISKIND)	
Parameter	Parameter value
Number of Inspectors	1
Distance from cask	1.5 meters
Shielding Factor	1.0 (no shielding)
Stop Time	There are ten-minute inspection stops every 161 kilometers.

Maximally Exposed Individual

The RISKIND computer program is used to calculate doses to maximally exposed individuals. This analysis uses projected exposure times, the distance hypothetical individuals would be from a shipment, the number of times an exposure event could occur, and the assumed external radiation dose rate at two meters from a shipment (10 millirem per hour).

The maximally exposed individual is a hypothetical person who would receive the highest dose. Maximally exposed individuals can be postulated for different exposure scenarios. DOE-YMSCO developed the following exposure scenarios to be used in RISKIND.

Inspectors (Truck and Rail). Inspectors would be federal and state vehicle (cargo) inspectors. The analysis assumed an average exposure distance of one meter and an exposure duration of one hour for all shipments.

Railyard Crew Member. For a railyard crew member working in a rail classification yard assembling trains, the analysis assumed an average exposure distance of 10 meters and an exposure duration of two hours for all shipments.

Resident. The analysis assumed this maximally exposed individual is a resident who lives 30 meters from a point where shipments would pass. The resident would be exposed to all shipments along a particular route.

Individual Stuck in Traffic (Truck or Rail). The analysis assumed that a member of the public could be 1.2 meter from the transport vehicle carrying a shipping cask for one hour. Because these circumstances would be random and unlikely to occur more than once for the same individual, the analysis assumed the individual would be exposed only once.

Resident Near a Rail Stop. The analysis assumed a resident who lives within 200 meters of a switchyard and an exposure time of 20 hours for each occurrence. The analysis of exposure for this maximally exposed individual assumes that the same resident would be exposed to all rail shipments to the repository.

The doses for all of these scenarios have been estimated and they are provided in Section 3.2.2, Table 8.

2.5 Technical Approach for Transportation Accidents

Radioactive material releases from transportation accidents depend upon the accident scenario, the total inventory of radioactive material, the fraction of total inventory available for release into the shipping container from those accidents, and the fraction of material released from the shipping container. Depending upon the severity of the accident conditions (including impact velocity and temperature), there may be no release of radioactive material from the shipping container.

A study performed by Sandia National Laboratory for the Nuclear Regulatory Commission entitled "Reexamination of Spent Fuel Shipment Risk Estimates," Reference (h), also known as NUREG/CR-6672, reevaluated the releases from transportation accidents involving spent nuclear fuel (commercial). NUREG/CR-6672 examined very low probability accidents that went beyond regulatory requirements. The NUREG/CR-6672 evaluated potential rail and truck casks that can be used for spent fuel shipments and simplified their transportation analysis by modeling four generic casks, two small diameter truck casks and two large diameter rail casks. Based on current design information, the generic monolithic steel rail cask is the best model for the naval cask; accident categories and resultant releases evaluated by NUREG/CR-6672 are determined based on this cask type. NUREG/CR-6672 did not analyze accidents using a sealed canister within a shipping cask which is expected to provide better protection should an accident occur. The Navy will use the sealed canister system.

NUREG/CR-6672 identifies 21 accident types by cask seal failure, temperature ranges, impact velocity, and the probabilities that accidents could occur in each case. The cases as defined by the NUREG are:

Cases 1-3	collision, no fire but impact forces cause the cask seal to leak
Cases 4-15	collision, initiate fire, cask seal leak
Cases 16-19	collision, initiate fire, cask seal leak, assumes that a second failure of the cask by puncture or shear
Case 20	fire only (no collision)
Case 21	no release

The cask failures, temperatures, and impact velocities are categorized into 21 regions for a monolithic steel rail cask. Given that an accident occurs, the probability that the accident would be in each region of the matrix was calculated for a monolithic steel rail cask. Table 2 provides the NUREG/CR-6672 probabilities for monolithic steel rail cask accidents by region in the matrix.

Table 2 Accident Severity Fractions (Probabilities) for a Monolithic Steel Rail Cask

Accident Impact Velocity onto an Unyielding Surface (mph)

	Case 3 4.49×10^{-9}	Case 13 3.82×10^{-11}	Case 14 1.27×10^{-12}	Case 15 1.88×10^{-14}	Case 19 1.88×10^{-17}
120	Case 2 1.17×10^{-7}	Case 10 9.93×10^{-10}	Case 11 3.30×10^{-11}	Case 12 4.91×10^{-13}	Case 18 4.91×10^{-16}
90	Case 1 8.60×10^{-6}	Case 7 7.31×10^{-8}	Case 8 2.43×10^{-9}	Case 9 3.61×10^{-11}	Case 17 3.61×10^{-14}
60		Case 4 3.05×10^{-5}	Case 5 1.01×10^{-6}	Case 6 1.51×10^{-8}	Case 16 5.69×10^{-11}
30	Case 21 (No Release) 0.99996			Case 20 (No Impact Velocity – Fire Only) 6.32×10^{-6}	

No Fire | T_a - T_s 300C-350C | T_a - T_b 300C-750C | T_a - T_f 300C-1000C

Temperatures – Inner Wall of the Cask Shell

Accident conditions that do not result in sufficient damage to the cask or its contents for a release (99.996 percent of the accidents) are grouped into one cell at the lower left-hand corner of Table 2, Case 21. Similarly, rail case 20 is a fire only scenario where the impact is insufficient to cause a release but the fire is sufficient to release material into the environment.

Naval Spent Nuclear Fuel Source Term

Table 3 details the radionuclide inventory within a naval spent fuel shipping cask. The nuclide list is based on a typical naval core at five years after shutdown. Five years is consistent with the expected minimum time for shipments of naval fuel from INEEL to the proposed repository.

The radionuclide inventory in Table 3 was obtained using ORIGEN-S and includes the following: fuel, crud, cladding material, control rod material, and structural material.

Table 3 Radionuclides in a Naval Spent Fuel Shipping Cask

Nuclide	Activity (Curies)	Nuclide	Activity (Curies)	Nuclide	Activity (Curies)	Nuclide	Activity (Curies)
Ac-227	9.8E-05	Co-60	3.7E+03*	Pd-107	6.0E-02	Tc-99	7.0E+01
Am-241	5.0E+01	Cs-134	8.4E+04	Pu-238	1.2E+04	Th-229	9.4E-06
Am-242m	4.6E-01	Cs-135	4.6E+00	Pu-239	1.2E+01	Th-230	1.8E-03
Am-243	6.7E-01	Cs-137	4.5E+05	Pu-240	1.4E+01	Th-232	2.3E-07
C-14	1.6E+01	H-3	1.4E+03	Pu-241	4.0E+03	U-232	5.6E-01
Cf-252	1.2E-06	I-129	1.2E-01	Pu-242	8.0E-02	U-233	3.1E-03
Cl-36	6.9E-01	Kr-85	3.6E+04	Ra-226	5.4E-06	U-234	1.5E+01
Cm-242	1.4E+00	Nb-93m	3.6E+00	Ra-228	1.8E-07	U-235	2.9E-01
Cm-243	7.9E-01	Nb-94	1.8E+02	Rh-102	2.8E-02	U-236	2.5E+00
Cm-244	6.3E+01	Ni-59	6.3E+01	Ru-106	6.0E+03	U-238	1.2E-03
Cm-245	7.2E-03	Ni-63	7.8E+03	Se-79	3.4E-01	Zr93	1.1E+01
Cm-246	1.4E-03	Np-237	1.6E+00	Sm-151	1.4E+03		
Cm-247	9.4E-09	Pa-231	5.2E-04	Sn-126	1.2E+00		
Cm-248	2.6E-08	Pb-210	8.9E-07	Sr-90	4.4E+05		

* The amount of Co-60 as crud is 5.8 curies.

Naval Spent Nuclear Fuel Release Fraction

For NUREG/CR-6672 accident cases 4 and 5, no naval spent nuclear fuel is damaged, but 100 percent of the crud is available for release. For all other potential accident types where radionuclides are released to the environment (cases 1, 2, 3, and 6 through 20), ten percent of the naval fuel is damaged and 100 percent of the crud is available for release. The release fractions for crud, identified for the Pressurized Water Reactor (PWR) monolithic steel rail cask in NUREG/CR-6672, are also used for naval crud. The methodology used in NUREG/CR-6672 to develop the commercial spent nuclear fuel release fractions for the PWR monolithic steel rail cask was also applied to naval spent nuclear fuel. The consolidation method that was used to reduce the 21 NUREG/CR-6672 accident cases into six cases for commercial spent nuclear fuel was also used for naval spent nuclear fuel and is detailed in Reference (g).

Table 4 Naval Source Term Severity Fractions (Probabilities) and Release Fractions

RAIL—MONOLITHIC STEEL CASK

Severity Class	Case	Severity Fractions Rail	Release Fractions				
			Kr	Cs	Ru	Particulates	CRUD
1	21	0.99996	0.00000	0.00000	0.00000	0.00000	0.00000
2	1, 4, 5, 7, 8	4.02E-05	1.52E-02	4.55E-10	9.10E-09	9.10E-09	1.37E-03
3	20	6.32E-06	8.39E-02	1.68E-06	2.52E-08	2.52E-08	9.44E-03
4	2, 3, 10	1.22E-07	8.00E-02	8.98E-07	1.34E-06	1.34E-06	4.47E-02
5	6	1.51E-08	9.44E-02	4.00E-06	1.80E-06	1.80E-06	5.36E-03
6	9, 11, 12, 13, 14, 15, 16, 17, 18, 19	1.66E-10	9.04E-02	5.49E-06	4.67E-06	1.93E-06	2.86E-02

RADTRAN

The RADTRAN computer code is used to calculate the radiological risk to the general population under accident conditions. This code includes doses from the following four pathways:

- Internal exposure from inhalation of radioactive aerosols and suspended particles
- External exposure from immersion in the airborne radioactive material
- External exposure from radioactive material deposited on the ground and
- Internal exposure from inhalation of resuspended radioactive material deposited on the ground

The ingestion dose is calculated using state-specific food transfer factors provided by DOE-YMSCO in Reference (g) for each radionuclide based on the ground deposition results from RADTRAN.

Dose-risk is evaluated for the routes and numbers of shipments. Factors included in the evaluation are:

- Distance traveled
- Population density
- Fraction of travel in each population area
- Number of shipments
- Packages per shipment
- Activity of each nuclide
- Accident rate
- Accident severity fraction
- Fraction of each isotope released from the shipping cask
- Food transfer factors

The dose-risk to a member of the general public is the weighted product of the probabilities of an accident occurring (accident per km), the probabilities of the 21 different accident cases based on severity, and the consequences (doses) from the 21 different accident cases. The probabilities of accidents occurring are based on information from Saricks and Tompkins in Reference (i) as modified by DOE-YMSCO in Reference (g). The probabilities of the different accidents based on severity are taken from NUREG/CR-6672. RADTRAN is used to calculate dose-risk values for each of ten possible routes (five all rail and five rail to heavy-haul truck).

<u>RISKIND</u>

RISKIND is used to calculate the consequences of a maximum reasonably foreseeable accident. The consequences, expressed as radiological exposure, and the estimated number of latent cancer fatalities, are calculated for the maximally exposed individual and the general population. The RISKIND pathways for radiation exposures are similar to RADTRAN except that no ingestion dose is calculated. DOE-YMSCO decided not to include the ingestion pathway for the maximum reasonably foreseeable accident because controls would be implemented to prohibit the actual ingestion of contaminated food and water.

The analysis of maximum reasonably foreseeable accidents postulated to occur during the transportation of naval spent nuclear fuel evaluated consequences for accidents with an overall probability greater than 1.0E-07 per year. To calculate the overall probability of an accident for comparison against the probability of 1.0E-07 per year, the following values were multiplied for rural and urbanized (urban and suburban) population areas for each accident type.

- Accident rate (railroad or highway from published historic rates) for each state
- Distance traveled in the rural and urbanized areas for each state
- Number of shipments per year
- Accident severity fraction
- Meteorology probability as documented in Reference (g)

3 SUMMARY OF RESULTS

3.1 Yucca Mountain Transportation Routes Analyzed

Five rail routes and five combination rail and heavy-haul transportation routes from INEEL to Yucca Mountain are identified in Tables 5a and 5b. Distance is provided by state for Idaho and Utah and by county for Nevada.

3.1.1 Railroad Routes to Yucca Mountain, Nevada

Five possible railroad routes from the INEEL to the geologic repository site at Yucca Mountain in Nevada were defined for the YM EIS analyses for naval spent nuclear fuel and special case waste shipments. The routes include: INEEL to Beowawe (Carlin) to Yucca Mountain, INEEL to Jean to Yucca Mountain, INEEL to Caliente (Eccles) to Chalk Mountain to Yucca Mountain, INEEL to Caliente (Eccles) to Yucca Mountain, and INEEL to Apex (Valley Modified) to Yucca Mountain.

Table 5a Comparison of Alternate Transportation Rail Routes

		Distance (km)			
		Urban	Suburban	Rural	Total
All Rail Route INEEL to YM Through Beowawe/Carlin	Idaho	3.9	14.7	187.5	206.1
	Utah	0	18.9	257.0	275.9
	Eureka County NV	0	0	61.3	61.3
	Elko County NV	0	11.3	218.1	229.4
	Esmeralda County NV	0	0	41.0	41.0
	Lander County NV	0	0	158.7	158.7
	Nye County NV	0	0	291.5	291.5
					1263.9
All Rail Route INEEL to YM Through Jean	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Clark County NV	3.2	17.7	192.4	213.3
	Lincoln County NV	0	1.6	167.8	169.4
	Nye County NV	0	0	98.2	98.2
					1299.8
All Rail Route INEEL to YM Through Eccles/ Caliente/Chalk Mountain	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Lincoln County NV	0	0	214.3	214.3
	Nye County NV	0	0	188.0	188.0
					1221.2
All Rail Route INEEL to YM Through Eccles/ Caliente	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Lincoln County NV	0	0	204.8	204.8
	Esmeralda NV	0	0	4.0	4.0
	Nye County NV	0	0	360.8	360.8
					1388.5
All Rail Route INEEL to YM Through Apex/Valley Modified	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Lincoln County NV	0	1.6	167.8	169.4
	Nye County NV	0	0	59.2	59.2
	Clark County NV	0	0	150.3	150.3
					1197.8

3.1.2 Railroad to Heavy-Haul Truck Routes to Yucca Mountain, Nevada

Five possible rail to heavy-haul truck routes from the INEEL to the geologic repository at Yucca Mountain in Nevada were defined for the YM EIS transportation analyses for naval spent nuclear fuel and special case waste shipments. Three potential intermodal transfer stations at Apex (Dry Lake), Caliente, and Jean (Sloan), Nevada were considered as locations for transfers from rail to heavy-haul truck shipment. The routes include: INEEL to Apex (Dry Lake) to Yucca Mountain, INEEL to Caliente to Yucca Mountain, INEEL to Jean (Sloan) to Yucca Mountain, INEEL to Caliente to Chalk Mountain to Yucca Mountain, and INEEL to Caliente to Las Vegas to Yucca Mountain.

Table 5b Comparison of Alternate Transportation Rail to Heavy-Haul Routes

		Distance Traveled (km)			
		Urban	Suburban	Rural	Total
Rail and Heavy Haul Route INEEL to YM Through Apex/Dry Lake	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Clark County NV	0	19.9	154.8	174.7
	Lincoln County NV	0	1.6	167.8	169.4
	Nye County NV	0	0	59.4	59.4
					1222.4
Rail and Heavy Haul Route INEEL to YM Through Caliente	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Esmeralda County NV	0	0	71.6	71.6
	Lincoln County NV	0	0	213.2	213.2
	Nye County NV	0	4.7	308.5	313.2
					1416.9
Rail and Heavy Haul Route INEEL to YM Through Jean/ Sloan	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Lincoln County NV	0	1.6	167.8	169.4
	Clark County NV	3.2	59.6	198.6	261.4
	Nye County NV	0	0	59.4	59.4
					1309.1
Rail and Heavy Haul Route INEEL to YM Through Caliente/Chalk Mountain	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Lincoln County NV	0	0	211.6	211.6
	Nye County NV	0	0	135.3	135.3
					1165.8
Rail and Heavy Haul Route INEEL to YM Through Caliente/LV	Idaho	3.9	14.7	187.5	206.1
	Utah	11.4	51.2	550.2	612.8
	Lincoln County NV	0	0	214.4	214.4
	Nye County NV	0	0	59.4	59.4
	Clark County NV	0	19.9	147.3	167.2
					1259.9

3.2 Incident-Free Transportation Analysis

3.2.1 Incident-Free General and Occupational Populations

For incident-free transportation of naval spent fuel and special case waste, the health impacts for the general and occupational populations are small when compared with the risks of every day life. The all rail routing consistently results in lower doses than the rail to heavy-haul routing. For the period covered by this analysis, 2010 to 2035, no fatalities are expected. For example, the highest number of latent cancer fatalities would be approximately 0.0144 for the general population from all shipments of naval spent nuclear fuel to Yucca Mountain. That is, calculations indicate approximately one latent cancer fatality in the general population if the entire transport program for the shipment of naval spent nuclear fuel were to be repeated about 70 times.

<u>All Rail Routing</u>
Tables 6a through 6e summarize the doses to the general population and occupational population for all rail incident-free transportation. The estimated total general population doses for incident-free rail transportation of 300 naval spent nuclear fuel shipments from INEEL to Yucca Mountain range from 2.69 to 6.38 person-rem. The average annual doses to members of the general population along the route from these fuel shipments range from 0.00149 to 0.00246 rem per person per year. The estimated total general population doses for incident-free rail transportation of 55 shipments of special case waste range from 0.49 to 1.17 person-rem.

The estimated occupational population collective doses for 300 naval spent nuclear fuel shipments range from 9.59 to 10.4 person-rem; and for 55 shipments of special case waste, the collective doses range from 1.76 to 1.90 person-rem.

<u>Rail to Heavy-Haul Truck Routing</u>
Tables 7a through 7e summarize the doses to the general population and occupational population for rail to heavy-haul incident-free transportation. The estimated total general population doses for incident-free rail to heavy-haul transportation of 300 naval spent nuclear fuel shipments from INEEL to Yucca Mountain range from 13.7 to 28.8 person-rem. The average annual doses to members of the general population along the route from these fuel shipments range from 0.00181 to 0.00217 rem per person per year. The estimated total general population doses for incident-free rail to heavy-haul transportation of 55 shipments of special case waste range from 2.52 to 5.27 person-rem.

The occupational population collective doses for 300 naval spent nuclear fuel shipments range from 10.6 to 11.8 person-rem; and for 55 shipments of special case waste, the collective doses range from 1.95 to 2.15 person-rem.

Table 6a Incident-Free Consequences for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail Route - Idaho to Utah to Beowawe/Carlin Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	2.28E-01	1.14E-04	4.19E-02	2.09E-05
Eureka County Nevada	4.05E-03	2.03E-06	7.43E-04	3.72E-07
Elko County Nevada	3.37E-01	1.68E-04	6.17E-02	3.09E-05
Esmeralda County Nevada	3.36E-03	1.68E-06	6.16E-04	3.08E-07
Lander County Nevada	9.66E-03	4.83E-06	1.77E-03	8.86E-07
Nye County Nevada	2.99E-02	1.49E-05	5.48E-03	2.74E-06
Total Route	**2.69E+00**	**1.35E-03**	**4.94E-01**	**2.47E-04**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	1.15E+00	4.59E-04	2.10E-01	8.41E-05
Nevada	5.56E+00	2.22E-03	1.02E+00	4.07E-04
Total Route	**9.87E+00**	**3.95E-03**	**1.81E+00**	**7.24E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 6b Incident-Free Consequences for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail Route - Idaho to Utah to Jean Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Clark County Nevada	1.21E+00	6.04E-04	2.21E-01	1.11E-04
Lincoln County Nevada	4.29E-02	2.14E-05	7.86E-03	3.93E-06
Nye County Nevada	7.98E-03	3.99E-06	1.46E-03	7.31E-07
Total Route	**6.38E+00**	**3.19E-03**	**1.17E+00**	**5.85E-04**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	4.32E+00	1.73E-03	7.92E-01	3.17E-04
Total Route	**1.00E+01**	**4.01E-03**	**1.84E+00**	**7.35E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 6c Incident-Free Consequences for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail Route - Idaho to Utah to Eccles Node NV to Caliente/Chalk Mountain To Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Lincoln County Nevada	1.30E-02	6.51E-06	2.39E-03	1.19E-06
Nye County Nevada	1.14E-02	5.72E-06	2.10E-03	1.05E-06
Total Route	**5.15E+00**	**2.57E-03**	**9.44E-01**	**4.72E-04**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	3.98E+00	1.59E-03	7.30E-01	2.92E-04
Total Route	**9.69E+00**	**3.87E-03**	**1.78E+00**	**7.10E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 6d Incident-Free Consequences for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail Route - Idaho to Utah to Eccles Node NV to Caliente to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Esmeralda County Nevada	3.06E-04	1.53E-07	5.61E-05	2.80E-08
Lincoln County Nevada	1.25E-02	6.23E-06	2.28E-03	1.14E-06
Nye County Nevada	2.44E-02	1.22E-05	4.46E-03	2.23E-06
Total Route	**5.16E+00**	**2.58E-03**	**9.46E-01**	**4.73E-04**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	4.67E+00	1.87E-03	8.57E-01	3.43E-04
Total Route	**1.04E+01**	**4.15E-03**	**1.90E+00**	**7.61E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 6e Incident-Free Consequences for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail Route - Idaho to Utah to Apex/Valley Modified Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Clark County Nevada	1.51E-02	7.53E-06	2.76E-03	1.38E-06
Lincoln County Nevada	4.29E-02	2.14E-05	7.86E-03	3.93E-06
Nye County Nevada	3.60E-03	1.80E-06	6.60E-04	3.30E-07
Total Route	**5.18E+00**	**2.59E-03**	**9.50E-01**	**4.75E-04**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	3.88E+00	1.55E-03	7.12E-01	2.85E-04
Total Route	**9.59E+00**	**3.84E-03**	**1.76E+00**	**7.03E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 7a Incident-Free Consequences for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail to Heavy Haul Route - Idaho to Utah to Apex/Dry Lake Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Clark County Nevada	5.92E+00	2.96E-03	1.09E+00	5.43E-04
Lincoln County Nevada	4.29E-02	2.14E-05	7.86E-03	3.93E-06
Nye County Nevada	2.64E+00	1.32E-03	4.83E-01	2.42E-04
Total Route	**1.37E+01**	**6.86E-03**	**2.52E+00**	**1.26E-03**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	4.92E+00	1.97E-03	9.01E-01	3.60E-04
Total Route	**1.06E+01**	**4.25E-03**	**1.95E+00**	**7.79E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 7b Incident-Free Consequences for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail to Heavy Haul Route – Idaho to Utah to Caliente Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Lincoln County Nevada	6.58E+00	3.29E-03	1.21E+00	6.03E-04
Esmeralda County Nevada	3.18E+00	1.59E-03	5.83E-01	2.92E-04
Nye County Nevada	1.39E+01	6.93E-03	2.54E+00	1.27E-03
Total Route	**2.88E+01**	**1.44E-02**	**5.27E+00**	**2.64E-03**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	6.05E+00	2.42E-03	1.11E+00	4.43E-04
Total Route	**1.18E+01**	**4.70E-03**	**2.15E+00**	**8.62E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 7c Incident-Free Consequences for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail to Heavy Haul Route - Idaho to Utah to Jean/Sloan Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Clark County Nevada	7.84E+00	3.92E-03	1.44E+00	7.19E-04
Lincoln County Nevada	4.29E-02	2.14E-05	7.86E-03	3.93E-06
Nye County Nevada	2.64E+00	1.32E-03	4.83E-01	2.42E-04
Total Route	**1.56E+01**	**7.82E-03**	**2.87E+00**	**1.43E-03**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	5.25E+00	2.10E-03	9.63E-01	3.85E-04
Total Route	**1.10E+01**	**4.38E-03**	**2.01E+00**	**8.04E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 7d Incident-Free Consequences for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail to Heavy Haul Route – Idaho to Utah to Caliente/Chalk Mountain Node NV To Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Lincoln County Nevada	6.52E+00	3.26E-03	1.20E+00	5.98E-04
Nye County Nevada	6.00E+00	3.00E-03	1.10E+00	5.50E-04
Total Route	**1.76E+01**	**8.82E-03**	**3.23E+00**	**1.62E-03**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	5.08E+00	2.03E-03	9.31E-01	3.72E-04
Total Route	**1.08E+01**	**4.31E-03**	**1.98E+00**	**7.91E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

Table 7e Incident-Free Consequences for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General and Occupational Populations: Rail to Heavy Haul Route - Idaho to Utah to Caliente/LV Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]	Collective Dose (Person-Rem)	Estimated Latent Cancer Fatalities[a]
Idaho	2.08E+00	1.04E-03	3.82E-01	1.91E-04
Utah	3.04E+00	1.52E-03	5.57E-01	2.79E-04
Lincoln County Nevada	6.64E+00	3.32E-03	1.22E+00	6.09E-04
Clark County Nevada	7.82E+00	3.91E-03	1.43E+00	7.17E-04
Nye County Nevada	2.63E+00	1.32E-03	4.83E-01	2.42E-04
Total Route	**2.22E+01**	**1.11E-02**	**4.07E+00**	**2.04E-03**
Occupational Population (Workers)				
Idaho	3.16E+00	1.27E-03	5.80E-01	2.32E-04
Utah	2.54E+00	1.02E-03	4.66E-01	1.86E-04
Nevada	5.18E+00	2.07E-03	9.49E-01	3.80E-04
Total Route	**1.09E+01**	**4.35E-03**	**2.00E+00**	**7.98E-04**

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population.

3.2.2 Incident-Free Maximally Exposed Individual (MEI)

Table 8 summarizes the dose to the maximally exposed individuals for incident-free transportation via all rail or rail to heavy-haul truck routing.

The maximum general population MEI dose for 300 all rail shipments of naval spent nuclear fuel was estimated to be a 0.016 rem; and for 55 shipments of special case waste, a dose of 0.016 rem was estimated.

The maximum occupational MEI dose for 300 naval spent nuclear fuel shipments was estimated to be 5.40 rem; and for 55 shipments of special case waste, the estimated dose would be 0.990 rem.

Table 8 Estimated Consequences to Maximally Exposed Individuals (MEI) for Naval Spent Nuclear Fuel and Special Case Waste Shipments

	300 Naval Spent Nuclear Fuel Shipments		**55 Special Case Waste Shipments**	
General Population MEI Scenarios	**Dose (rem)**	**Estimated Latent Cancer Fatalities [a]**	**Dose (rem)**	**Estimated Latent Cancer Fatalities [a]**
Resident along Route (moving)	1.14E-04	5.70E-08	2.09E-05	1.05E-08
Individual Stuck in Traffic [b]	1.60E-02	8.00E-06	1.60E-02	8.00E-06
Resident near a Rail Stop	7.80E-03	3.90E-06	1.43E-03	7.15E-07
Worker MEI Scenarios				
Inspectors	5.40E+00	2.16E-03	9.90E-01	3.96E-04
Railyard Crew Member	5.70E-01	2.28E-04	1.05E-01	4.18E-05

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 for the general population and 0.0004 for the occupational population (workers).

[b] The individual stuck in traffic is assumed to be exposed to one occurrence.

3.3 Accident Risk Analysis

All Rail Routing
Tables 9a through 9e summarize the dose-risk to the general population for all rail routing from INEEL to the Yucca Mountain repository. The dose-risk to the general population ranges from 0.00000354 to 0.0000113 person-rem for 300 naval spent fuel shipments. The dose-risk for 55 special case waste shipments ranges from 0.00000065 to 0.00000207 person-rem.

Rail to Heavy-Haul Truck Routing
Tables 10a through 10e summarize the dose-risk to the general population for rail to heavy-haul routing. The dose-risk to the general population ranges from 0.000011 to 0.0000227 person-rem for 300 naval spent fuel shipments. The dose-risk for 55 special case waste shipments ranges from 0.00000201 to 0.00000416 person-rem.

Table 9a Accident Risk for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail Route - Idaho to Utah to Beowawe/Carlin Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	7.19E-07	3.60E-10	1.32E-07	6.59E-11
Eureka County Nevada	3.06E-10	1.53E-13	5.60E-11	2.80E-14
Elko County Nevada	9.56E-08	4.78E-11	1.75E-08	8.76E-12
Esmeralda County Nevada	4.10E-10	2.05E-13	7.52E-11	3.76E-14
Lander County Nevada	5.25E-10	2.63E-13	9.63E-11	4.81E-14
Nye County Nevada	3.89E-09	1.95E-12	7.13E-10	3.57E-13
Total Route	**3.54E-06**	**1.77E-09**	**6.50E-07**	**3.25E-10**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 9b Accident Risk for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail Route - Idaho to Utah to Jean Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Clark County Nevada	3.26E-07	1.63E-10	5.97E-08	2.99E-11
Lincoln County Nevada	1.04E-08	5.19E-12	1.90E-09	9.52E-13
Nye County Nevada	6.55E-10	3.28E-13	1.20E-10	6.01E-14
Total Route	**1.13E-05**	**5.65E-09**	**2.07E-06**	**1.04E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 9c Accident Risk for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail Route - Idaho to Utah to Eccles Node NV to Caliente/Chalk Mountain To Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Lincoln County Nevada	7.11E-10	3.56E-13	1.30E-10	6.52E-14
Nye County Nevada	6.24E-10	3.12E-13	1.14E-10	5.72E-14
Total Route	**1.10E-05**	**5.48E-09**	**2.01E-06**	**1.01E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 9d Accident Risk for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail Route - Idaho to Utah to Eccles Node NV to Caliente to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Lincoln County Nevada	6.78E-10	3.39E-13	1.24E-10	6.22E-14
Esmeralda County Nevada	3.33E-11	1.67E-14	6.11E-12	3.05E-15
Nye County Nevada	1.80E-09	9.00E-13	3.30E-10	1.65E-13
Total Route	**1.10E-05**	**5.48E-09**	**2.01E-06**	**1.01E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 9e Accident Risk for All Rail Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail Route - Idaho to Utah to Apex/Valley Modified Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Clark County Nevada	2.36E-09	1.18E-12	4.33E-10	2.17E-13
Lincoln County Nevada	1.04E-08	5.19E-12	1.90E-09	9.52E-13
Nye County Nevada	1.96E-10	9.81E-14	3.60E-11	1.80E-14
Total Route	**1.10E-05**	**5.49E-09**	**2.01E-06**	**1.01E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 10a Accident Risk for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail to Heavy Haul Route - Idaho to Utah to Apex/Dry Lake Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Clark County Nevada	5.40E-06	2.70E-09	9.90E-07	4.95E-10
Lincoln County Nevada	1.04E-08	5.19E-12	1.90E-09	9.52E-13
Nye County Nevada	1.97E-10	9.84E-14	3.61E-11	1.80E-14
Total Route	**1.64E-05**	**8.18E-09**	**3.00E-06**	**1.50E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 10b Accident Risk for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail to Heavy Haul Route – Idaho to Utah to Caliente Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Lincoln County Nevada	2.11E-08	1.06E-11	3.87E-09	1.94E-12
Esmeralda County Nevada	2.45E-08	1.22E-11	4.49E-09	2.24E-12
Nye County Nevada	2.45E-07	1.23E-10	4.50E-08	2.25E-11
Total Route	**1.13E-05**	**5.63E-09**	**2.06E-06**	**1.03E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 10c Accident Risk for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail to Heavy Haul Route - Idaho to Utah to Jean/Sloan Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Clark County Nevada	1.17E-05	5.86E-09	2.15E-06	1.07E-09
Lincoln County Nevada	1.04E-08	5.19E-12	1.90E-09	9.52E-13
Nye County Nevada	1.97E-10	9.84E-14	3.61E-11	1.80E-14
Total Route	**2.27E-05**	**1.13E-08**	**4.16E-06**	**2.08E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 10d Accident Risk for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail to Heavy Haul Route – Idaho to Utah to Caliente/Chalk Mountain Node NV To Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Lincoln County Nevada	2.34E-08	1.17E-11	4.29E-09	2.15E-12
Nye County Nevada	4.50E-10	2.25E-13	8.25E-11	4.13E-14
Total Route	**1.10E-05**	**5.49E-09**	**2.01E-06**	**1.01E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

Table 10e Accident Risk for Rail to Heavy-Haul Shipments of Naval Spent Nuclear Fuel and Special Case Waste for General Populations: Rail to Heavy Haul Route - Idaho to Utah to Caliente/LV Node NV to Yucca Mountain

General Population				
Location	300 Naval Spent Nuclear Fuel Shipments		55 Special Case Waste Shipments	
	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]	Dose-Risk [a] (person-rem)	Health Risk of Latent Cancer Fatalities [b]
Idaho	2.72E-06	1.36E-09	5.00E-07	2.50E-10
Utah	8.24E-06	4.12E-09	1.51E-06	7.55E-10
Lincoln County Nevada	2.13E-08	1.07E-11	3.91E-09	1.95E-12
Clark County Nevada	5.40E-06	2.70E-09	9.90E-07	4.95E-10
Nye County Nevada	1.97E-10	9.84E-14	3.61E-11	1.80E-14
Total Route	**1.64E-05**	**8.19E-09**	**3.00E-06**	**1.50E-09**

[a] Assuming an accident occurs, dose-risk (person-rem) = $\sum$ [(severity fraction (probability))$_i$ * (dose (person-rem))$_i$]

[b] Latent cancer fatality health risk values are determined by multiplying the dose-risk times 0.0005 for the general population.

3.4 Consequences of Maximum Reasonably Foreseeable Accident

The maximum reasonably foreseeable consequence evaluation presents the consequences for design basis accidents, defined as those accidents which have a probability of greater than 1×10^{-6} per year, and beyond design basis accidents, defined as those which have a probability of 1×10^{-6} to 1×10^{-7} per year. Accidents with a probability of less than 1×10^{-7} were not analyzed in the maximum reasonably foreseeable consequence evaluation. The only accident with a probability that met the criteria to be evaluated is a case 4 rural accident scenario with a wind speed of 4.47 meters per second and Pasquill D stability. This accident was greater than 1×10^{-7} per year for three rail to heavy-haul routes. The results for the greatest accident probability (1.26×10^{-7}) are included in Table 11. The probability of an urbanized (urban and suburban) case 4 was 8.66×10^{-9} per year which is less than the probability cutoff criterion of 1×10^{-7}.

The results of the analyses are provided in Table 11. The maximum individual dose is 0.00571 rem; and the rural population dose is 0.00685 person-rem.

Table 11 Summary of Consequences for a Maximum Reasonably Foreseeable Transportation Accident for Naval Spent Nuclear Fuel

NUREG/CR-6672 Monolithic Steel Rail Cask Accident Scenario Case 4 (collision with fire)		
	Typical Meteorology Conditions Wind Speed 4.47 meters/sec Pasquill D Stability Class	
Probability of a Case 4 Rural Accident for Naval Spent Nuclear Fuel	1.26E-07	
	Dose	Estimated Latent Cancer Fatalities [a]
Maximum Individual Dose (rem)	5.71E-03	2.86E-06
Rural Population Dose (person-rem)	6.85E-03	3.43E-06

[a] Latent Cancer Fatality values are determined by multiplying the dose times 0.0005 (see Section 2.2).

4 REFERENCES

(a) ICRP Publ. 60, Volume 21 (1-3), 1991, International Commission on Radiological Protection, *The 1990 Recommendations of the International Commission on Radiological Protection*

(b) SAND2000-1256, Sandia National Laboratories, K. S. Neuhauser, F. L. Kanipe, and R. F. Weiner 2000, *RADTRAN 5 Technical Manual*

(c) ANL/EAD-1, Argonne National Laboratory, Y. C. Yuan, et al., 1995 *RISKIND - A Computer Program for Calculating Radiological Consequences and Health Risks from Transportation of Spent Nuclear Fuel*

(d) ORNL/TM-12090, Oak Ridge National Laboratory, P. E. Johnson, et al., 1993 *INTERLINE 5.0, An Expanded Railroad Routing Model: Program Description, Methodology, and Revised User's Manual*

(e) ORNL/TM-12124, Oak Ridge National Laboratory, P. E. Johnson, et al., dated March 1993, *HIGHWAY 3.1, An Enhanced Transportation Routing Model: Program Description, Methodology and Revised User's Manual*

(f) NUREG/CR-0200, Volume 2, Section F7, Oak Ridge National Laboratory, *ORIGEN-S: Scale System Module to Calculate Fuel Depletion, Actinide Transmutation, Fission Product Buildup and Decay, and Associated Radiation Source Terms*

(g) Yucca Mountain EIS Transportation Data Book forwarded via DOE-YMSO (J. R. Summerson) letter to Naval Reactors (G. E. Mowbray) dated July 2001

(h) NUREG/CR-6672, SAND2000-0234 prepared by Sandia National Laboratories for the Spent Fuel Project Office, Office of Nuclear Material Safety and Safeguards, 2000, U. S. Nuclear Regulatory Commission *Reexamination of Spent Fuel Shipment Risk Estimates*

(i) ANL/ESD/TM-150, C. L. Saricks, M. M. Tompkins, 1999, *State Level Accident Rates of Surface Freight Transportation: A Re-examination Report*

NUMBER OF NAVAL SPENT NUCLEAR FUEL CONTAINER SHIPMENTS
TO ECF, IDAHO BY ORIGIN

Year	KSO	PSNS	NNS	PNS	NOR	TOTAL
1997	2	9		4	4	19
1998		10		1	2	13
1999		11	3	1	5	20
2000		4	10	1	1	16

PSNS = Puget Sound Naval Shipyard, Washington
KSO = Kenneth A. Kesselring Site, New York
NNS = Newport News Shipbuilding, Virginia
PNS = Portsmouth Naval Shipyard, New Hampshire
NOR = Norfolk Naval Shipyard, Virginia

The approximate total mileage numbers for shipments in 1999 and 2000 are as follows: in 1999, the 20 container shipments traveled approximately 37,000 miles and in 2000, the 16 container shipments traveled approximately 38,000 miles. Additionally, in accordance with the Navy's Agreement with the State of Idaho, the number of shipments per year of naval spent nuclear fuel transported to Idaho from various shipyards prior to 2035 will be less than a running average of 20 shipments per year. This information may be used as necessary for cumulative impact assessments for the Yucca Mountain Final Environmental Impact Statement.