PNNL-29365

Environmental Impacts from Transportation of Fuel and Wastes to and from Non-LWRs

March 2020

Steven J. Maheras

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

The U.S. Nuclear Regulatory Commission (NRC) has generically evaluated the environmental impacts of the transportation of fuel and waste in Table S-4 of Title 10 of the *Code of Federal Regulations* Part 51, Section 52 (10 CFR 51.52) for light water reactor (LWR) fuel that meets certain entry conditions specified in 10 CFR 51.52(a). However, Section 51.52 only applies to LWRs and does not mention non-LWR license applicants when discussing the requirement to provide information about the transportation of nuclear fuel and waste to and from the reactor in an applicant's Environmental Report (ER). Nevertheless, the NRC must still evaluate transportation impacts to meet its obligations under the National Environmental Policy Act (NEPA) and, therefore, requires that the relevant information be provided in an applicant's ER. Therefore, the applicant's ER should contain a full description and detailed analysis of the environmental effects of the transportation of fuel and wastes to and from the reactor, including values for the environmental impact under normal conditions of transport and for the environmental risk from accidents during transport. Section 6.2 in NRC Regulatory Guide 4.2 (NRC 2018) provides detailed guidance for LWR applicants on how to estimate transportation-related impacts for LWRs.

This report provides additional guidance for estimating transportation-related impacts for non-LWRs in the following areas:

- the applicability of NRC and U.S. Department of Transportation (DOT) regulations to the shipment of non-LWR fuel and waste
- the absence of certified packages for shipping the unirradiated fuel, spent fuel, and radioactive waste associated with non-LWRs
- the external dose rates associated with the shipment of non-LWR unirradiated fuel, spent fuel, and radioactive waste
- transportation routing for non-LWR shipments
- the chemical and physical forms associated with the non-LWR unirradiated fuel, spent fuel, and radioactive waste
- the number of shipments associated with unirradiated fuel, spent fuel, and radioactive waste shipments
- the radionuclide inventory per shipment for non-LWR unirradiated fuel, spent fuel, and radioactive waste
- the conditional probabilities and release fractions associated with transportation accidents involving non-LWR fuel and waste shipments
- the comparison of transportation risk assessment results to various criteria.

Acronyms and Abbreviations

BISO	bistructural isotopic
BWR	boiling water reactor
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EBR-II	Experimental Breeder Reactor II
EIS	environmental impact statement
ER	environmental report
HALEU	high assay low enriched uranium
HEU	high (or highly) enriched uranium
HLW	high-level radioactive waste
HRCQ	highway route controlled quantity
IAEA	International Atomic Energy Agency
LEU	low enriched uranium
LWR	light water reactor
MEU	medium enriched uranium
MTU	metric ton(s) uranium
MW(e)	megawatt(s) electric
MW(t)	megawatt(s) thermal
MWd	megawatt day(s)
NRC	U.S. Nuclear Regulatory Commission
PWR	pressurized water reactor
TRISO	tristructural isotopic

Contents

Tables

1.0 Introduction

The U.S. Nuclear Regulatory Commission (NRC) has generically evaluated the environmental impacts of the transportation of fuel and waste in Table S-4 of Title 10 of the *Code of Federal Regulations* Part 51, Section 52 (10 CFR 51.52) for light water reactor (LWR) fuel that meets certain entry conditions specified in 10 CFR 51.52(a). Section 51.52 discusses LWRs but does not mention non-LWR license applicants when discussing the requirement to provide information about the transportation of nuclear fuel and waste to and from the reactor in an applicant's Environmental Report (ER). However, the NRC must still evaluate transportation impacts to meet its obligations under the National Environmental Policy Act (NEPA) and, therefore, requires that the relevant information be provided in an applicant's ER. The NRC can request that an applicant provide this information under 10 CFR 51.41, which states that the Commission has the authority to request that an applicant provide such information as may be useful to aid it in complying with Section 102(2) of NEPA. Further, 10 CFR 51.45(c) states that an applicant's ER should contain sufficient data to aid the Commission in developing an independent analysis during its environmental review. Section 6.2 of NRC Regulatory Guide 4.2 (NRC 2018) provides detailed guidance for LWR applicants on estimating transportation-related impacts for LWRs.

The NRC uses the information in the ER and other information to prepare an analysis of the radiological and nonradiological environmental impacts from normal operating and accident conditions resulting from (1) shipment of unirradiated fuel to the proposed reactor site and alternative sites, (2) shipment of spent fuel to an interim storage facility or a permanent geologic repository, and (3) shipment of radioactive wastes to offsite disposal facilities. These environmental impacts are presented in the NRC's environmental impact statement (EIS) for the reactor.

The purpose of this report is to provide additional guidance for estimating transportation-related impacts for non-LWRs.

2.0 Analytical Steps for Assessing Incident-Free and Accident Radiological and Nonradiological Impacts for Non-LWRs

A full description and detailed analysis of transportation impacts should include the following:

- Transportation of unirradiated fuel. The analysis should include the radiological impacts associated with the normal conditions of transport and the nonradiological impacts associated with transportation accidents.
- Transportation of spent fuel. The analysis should include the radiological impacts associated with the normal conditions of transport and the radiological and nonradiological impacts associated with transportation accidents.
- Transportation of radioactive waste. The analysis should include the radiological impacts associated with the normal conditions of transport and the nonradiological impacts associated with transportation accidents.

The transportation impacts analysis should use the latest versions of transportation computer codes, e.g., the NRC-approved RADTRAN computer code (Weiner et al. 2013, 2014) and routing code WebTRAGIS (Peterson 2018). The following data should be provided by the applicant in the ER:

- the reactor type and rated core thermal power
- the fuel assembly description
- the average irradiation level of spent fuel
- the capacity of the onsite storage facilities to store spent fuel and the minimum storage time between spent fuel removal from the reactor and its transportation offsite
- the treatment and packaging procedures for radioactive wastes other than spent fuel
- a general description of transportation packaging systems to be used for unirradiated fuel, spent fuel, and other radioactive wastes (e.g., packaging system capacity, approximate dimensions, and weight). At this stage, information on specific transportation packages may not be available. In this case, the ER should provide conceptual descriptions of the transportation packages.
- the radiation dose rates for loaded packages
- shipping route information based on the locations of fuel-fabrication facilities and potential destinations for shipments of spent fuel and radioactive waste
- the transport mode for new fuel shipment to the plant
- the transport mode for spent fuel shipments offsite
- the transport mode for other radioactive waste shipments offsite
- the data related to the shipping route (e.g., distances and population densities in urban, suburban, and rural population density zones by State) from the fuel-fabrication plant to the reactor and from the reactor to the facilities to which spent fuel and radioactive waste will most likely be sent, if applicable

- the average heat load for spent fuel packages in transit
- the maximum gross vehicle weight for truck and rail shipments of unirradiated fuel, spent fuel, and radioactive waste.

The methods and data used to estimate transportation impacts should be described and the following should be provided:

- Descriptions of the method(s) used to estimate routine (incident-free) radiological impacts, including impacts on populations and maximally exposed individuals.
- Descriptions of the method(s) used to estimate accident nonradiological and radiological impacts, including nonradiological traffic accidents, injuries, and fatalities, and radiological accident risks. Nonradiological impacts should be estimated using round-trip distances.
- Specification of input parameters and sources used in the impact assessment. Parameters and source documents should be defensible, and where assumptions are used to fill in missing or highly uncertain data, the assumptions should be conservative and reasonable (i.e., the assumptions should tend to overstate transportation impacts yet not be so conservative that they could mask the true environmental impacts of the reactor and lead to invalid conclusions).
- Presentation of results, including population doses, maximally exposed individual doses, and health effects for transportation crews and the general public for the following:
  - Workers and the public under normal transport conditions. Results should be presented for workers, onlookers, and persons along the route.
  - Maximally exposed individuals under normal transport conditions. Results should be presented for truck crew members, inspectors, residents along the transport routes, and persons at a truck service station.
  - Members of the public under radiological and nonradiological accident conditions.
  - Annual radiological and nonradiological transportation impacts. Results should be presented for the proposed site and the alternative sites.
- Sufficient descriptions of key models, assumptions, parameters, conditions, input data, resulting output, and approaches used to estimate transportation impacts to allow for the NRC staff's evaluation. If relevant information is contained in other supporting documentation (i.e., in a Final Safety Analysis Report, design control document, or other references), indicate where in those documents the information can be found.

In general, the analytical steps (i.e., methods) for assessing the incident-free and accident radiological and nonradiological impacts for non-LWRs are similar to those used for LWRs outlined above. NUREG-2125 (NRC 2014) and Section 6.2 in recent NRC EISs for new reactors (e.g., NRC 2019a) provide methods and data useful for transportation risk assessments. In addition, an overview of transportation analysis methods and data is provided by Chen et al. (2002) and the International Atomic Energy Agency (IAEA 2003). Weiner et al. (2013, 2014) also provide methods and data useful for transportation risk assessments, specifically when using the RADTRAN computer code, which is available at https://ramp.nrc-gateway.gov/.

NRC EISs for new reactors have analyzed shipments of unirradiated fuel, spent fuel, and radioactive waste by truck. Weiner et al. (2013, 2014) and Ostmeyer (1986) provide additional information about estimating transportation impacts by rail. Weiner et al. (2013, 2014) also provide additional information about estimating transportation impacts by barge and by air.

References such as Hirao and Ito (2016), IAEA (2001), and Sprung et al. (1998) provide methods and data useful for maritime transportation risk assessments.

Some significant differences between the transportation risk assessments conducted for LWRs and non-LWRs are likely. Most of these differences will probably be due to the lack of information for shipping non-LWR fuel and waste, specifically in the following areas:

- Issues associated with complying with NRC and U.S. Department of Transportation (DOT) regulations for shipments of non-LWR fuel and waste.
- The absence of certified packages for shipping the unirradiated fuel, spent fuel, and radioactive waste associated with non-LWRs. This is particularly important for packages in which unirradiated fuel, spent fuel, or radioactive waste containing high assay low enriched uranium (HALEU)[1] would be shipped.
- The external dose rates associated with the shipments of non-LWR unirradiated fuel, spent fuel, and radioactive waste.
- The transportation routing for non-LWR shipments.
- The chemical and physical form associated with the non-LWR unirradiated fuel, spent fuel, and radioactive waste.
- The number of shipments associated with unirradiated fuel, spent fuel, and radioactive waste shipments.
- The radionuclide inventory per shipment for non-LWR unirradiated fuel, spent fuel, and radioactive waste.
- The conditional probabilities and release fractions associated with transportation accidents involving non-LWR fuel and waste shipments. It should be noted that ERs and NRC EISs typically evaluate transportation accidents that exceed the hypothetical accident conditions in 10 CFR 71.73.
- The comparison of transportation risk assessment results to various criteria.

These areas are discussed in following sections.

2.1 Issues Associated with Compliance with Transportation Regulations

The NRC and DOT radioactive material transportation regulations contained in 10 CFR Part 71 and 49 CFR Part 173 would be applied to shipments of unirradiated fuel, spent fuel, and radioactive waste to and from non-LWRs. However, there could be issues associated with demonstrating compliance with these regulations:

- In general, NRC certificates of compliance for transportation packages do not authorize transport of fissile material by air. Therefore, if an applicant was to propose shipping unirradiated fuel, spent fuel, or radioactive waste to or from non-LWRs by air, it could be difficult to certify packages that would meet NRC standards in 10 CFR Part 71 for shipments by air (see 10 CFR 71.55(f), 71.64, 71.74, and 71.88).

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[1] HALEU has enrichments that range from 5% to 20% (NEI 2018).

- If an applicant were to propose shipping unirradiated fuel, spent fuel, or radioactive waste containing HALEU, it could be difficult to meet NRC standards in 10 CFR Part 71 because of the lack of criticality benchmarks for higher uranium enrichments (NEI 2018).
- If an applicant were to propose shipping unirradiated fuel, spent fuel, or radioactive waste with a chemical form that exhibited hazardous chemical characteristics, it could be difficult to meet the NRC standards in 10 CFR Part 71.
- If an applicant were to propose shipping irradiated non-LWR fuel within the reactor vessel, it could be difficult for the reactor vessel package and its spent fuel contents to meet the NRC standards in 10 CFR Part 71 for shipments in Type B packages. The NRC regulations in 10 CFR 71.41(c) and (d) may assist the applicant in shipping a reactor vessel and its spent fuel contents.
- If an applicant were to propose shipping unirradiated plutonium-based[2] non-LWR fuel within the reactor vessel, it could be difficult for the reactor vessel package and its unirradiated plutonium-based non-LWR fuel to meet the NRC standards in 10 CFR Part 71 for shipments in Type B packages. The NRC regulations in 10 CFR 71.41(c) and (d) may assist the applicant in shipping reactor vessel and its unirradiated plutonium-based fuel contents. This could also be the case for shipping unirradiated HALEU non-LWR fuel where the HALEU was derived from an irradiated uranium source such as Experimental Breeder Reactor II (EBR-II) spent fuel (Eidelpes et al. 2019).

2.2 Absence of Certified Transportation Packages

A large number of transportation packages are certified by the NRC for shipping unirradiated LWR fuel, irradiated LWR fuel, and radioactive waste (see https://rampac.energy.gov/home/package-certification-information/certificates/nrc). A few transportation packages are certified by the NRC for the shipping non-LWR fuel, such as the TN-FSV (Docket No. 71-9253), which is certified by the NRC for shipping high- temperature gas-cooled reactor spent fuel. Transportation packages would need to be certified for shipping HALEU and the chemical form of the non-LWR fuel or waste would need to be considered. Jarrell (2018) provides additional information on the transport of unirradiated HALEU.

Transportation packages would also need to be certified for shipping the unique waste streams from non-LWRs. These unique waste streams could include the following (IAEA 2019):

- sodium-cooled fast reactors – sodium-wetted combustible waste, sodium-wetted metallic waste including sodium heat pipes, and bulk sodium from cooling system components
- gas-cooled reactors – ceramic waste
- lead-cooled fast reactors – lead-wetted combustible waste, lead-wetted metallic waste, and bulk lead from cooling system components
- molten salt fast reactors – activated or fuel contaminated metallic and carbide waste, and salt waste from cleaning operations
- very high temperature reactors – graphite prismatic fuel assembly skeletons and tritiated water.

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[2] Conventional LWR fuel is uranium based.

In the ER, the applicant should provide a general description of the transportation packaging systems to be used for unirradiated fuel, spent fuel, and other radioactive wastes (e.g., packaging system capacity, approximate dimensions, and weight). The ER also should describe the radioactive or hazardous contents of the packaging system.

2.3 External Dose Rates

Detailed assessments of the external dose rates related to the transportation packaging systems associated with non-LWR shipments are not likely to be available, because detailed package designs are not likely to be available. One approach for estimating external dose rates would be to use maximum external dose rates from NRC (10 CFR 71.47) and DOT regulations (49 CFR 173.441). Another approach would be to use external dose rates for similar packages, to the extent that this information is available in the 10 CFR Part 71 safety analysis reports for the packages.

Chen et al. (2002) also provide the default external dose rates associated with shipments of different radioactive waste types (see Table 1).

Table 1. Default external dose rates associated with shipments of different radioactive waste types.

Waste Type	External Dose Rate (Truck)	External Dose (Rail)
Unirradiated fuel[(a)]	0.1 mrem/hr at 1 m	0.1 mrem/hr at 1 m
Low-level radioactive waste	1 mrem/hr at 1 m	1 mrem/hr at 1 m
Mixed low-level radioactive waste	1 mrem/hr at 1 m	1 mrem/hr at 1 m
Contact-handled transuranic waste	4 mrem/hr at 1 m	5.1 mrem/hr at 1 m
Remote-handled transuranic waste	10 mrem/hr at 1 m	20 mrem/hr at 1 m
High-level radioactive waste	10 mrem/hr at 2 m	10 mrem/hr at 2 m
Spent nuclear fuel	10 mrem/hr at 2 m	10 mrem/hr at 2 m

Source: Chen et al. (2002), Table 6.2. These external dose rates represent external dose rates that have been used in previous transportation risk assessments and do not represent data for specific packages.

a. Source: AEC (1972)

2.4 Transportation Routing

The WebTRAGIS computer code (Peterson 2018) contains highway, railroad, and waterway networks, which contain nodes that correspond to the locations of existing commercial nuclear power plants, U.S. Department of Energy (DOE) sites, and other nuclear facilities. WebTRAGIS also contains preferred route designations for highway route controlled quantity (HRCQ) shipments, commercial truck restrictions, and nonradioactive hazardous material route designations.

For highway shipments of unirradiated fuel, spent fuel, and radioactive waste, the WebTRAGIS HRCQ option is generally used. For rail shipments, the WebTRAGIS Dedicated Train option is generally used. Abkowitz and Bickford (2018) provide information about the development of rail accident rates for dedicated trains.

It should be noted that the WebTRAGIS networks do not contain constraints that would apply if a shipment is overweight or overdimension. In addition, WebTRAGIS does not generate rail routes that incorporate the requirements contained in 49 CFR 172.820.

WebTRAGIS does not contain a network that allows routing by air, but it does contain nodes for commercial airports (designated by their location identification code), and military airports (also designated by their location identification code). Use of these airport nodes along with knowledge of the great circle distance between the airports (e.g., see https://www.greatcirclemapper.net/) would enable a route to be drawn and a flight time to be estimated.

2.5 Chemical and Physical Form

The chemical and physical form of the radioactive material contained in the unirradiated fuel, spent fuel, and radioactive waste associated with non-LWRs may not be known at this time. As discussed in NRC Regulatory Guide 4.2, Section 6.2, the ER should describe treatment and packaging procedures for radioactive wastes and provide a description of the unirradiated and spent fuel. This should include the chemical and physical forms.

There could be instances in which radionuclides present in non-LWR unirradiated fuel, spent fuel, or radioactive waste are not present in the RADTRAN radionuclide library. The absorption type used in RADTRAN for specific radionuclides also may not be appropriate for the chemical form of the radionuclides released during an accident, or the particle size used in RADTRAN for specific radionuclides may not be appropriate for the particle size released during an accident.

Radionuclides may be added to RADTRAN and dose conversion factors for alternative solubility classes or particle sizes may be specified using the DEFINE function. The syntax of the DEFINE function is described below (see Weiner et al. 2009):

> [DEFINE] {Radionuclide Name} {Half-life (days)} {Photon Energy (MeV/disintegration)} {Cloudshine dose factor (rem-m3/ Ci-second)} {Groundshine dose factor (rem-m3/uCi-day)} {50-yr committed effective dose equivalent for inhalation (rem/Ci inhaled)} {50-yr committed effective gonad dose for inhalation (rem/Ci inhaled)} {1-yr lung dose for inhalation (rem/Ci inhaled)} {1-yr marrow dose for inhalation (rem/Ci inhaled)} {Class A waste concentration (Ci/m3)} {NONE}

2.6 Number of Shipments

The impacts presented in Table S-4 in 10 CFR 51.52 are based on WASH-1238 (AEC 1972) and Supplement 1 to WASH-1238 [NUREG 75/038 (NRC 1975)], for a 1,100-MW(e) LWR with an 80 percent capacity factor. NRC Regulatory Guide 4.2 (NRC 2018) describes a procedure for normalizing the number of shipments to a 1,100-MW(e) LWR with an 80 percent capacity factor or a net electrical output of 880 MW(e) and a transportation package capacity of 0.5 MTU per shipment over a 40-year plant license. For shipments of radioactive waste, the number of shipments is normalized to the 880 MW(e) reference reactor and a shipment capacity of 2.34 m^3 per shipment is used to estimate the number of shipments.

For shipments to and from a non-LWR, the normalization procedure described above may not be valid for various reasons given the differences in the potential designs of non-LWRs and LWRs. In lieu of using the procedure above to normalize the number of shipments of unirradiated fuel, spent fuel, and radioactive waste, the applicant may compare the number of shipments estimated for the non-LWR directly to the number of shipments from Table S-4 (see Table 2). As discussed in Section 6.2 of NRC Regulatory Guide 4.2, in the ER, the applicant should provide a general description of transportation packaging systems to be used for unirradiated fuel, spent fuel, and other radioactive wastes (e.g., packaging system capacity, approximate dimensions, and weight) and the external dose rates associated with these shipments.

Table 2. Annual number of shipments for the 880 MW(e) reference reactor.

Material	Annual Number of Shipments for the 880 MW(e) Reference Reactor
Unirradiated fuel (truck)	6
Spent fuel (truck)	60
Spent fuel (rail)	10
Radioactive waste (truck)	46

Source: NRC (1975), Table S-5.

2.7 Radionuclide Inventories

As discussed in Section 2.6, shipments of spent fuel from LWRs have been normalized to a package content of 0.5 MTU per shipment. For shipments of spent fuel from non-LWRs, the package content could be different than 0.5 MTU. Under these circumstances, the applicant should provide a general description of the transportation packaging systems to be used for spent fuel (e.g., packaging system capacity, approximate dimensions, and weight) and an estimate of the radionuclide inventory based on the characteristics of the spent fuel that will be shipped (e.g., burnup, enrichment, decay time, MTU in the package).

Estimating the radionuclide inventory for unirradiated fuel is not typically required. However, if mixed oxide fuel is used, then the radionuclide inventory should be provided, based on the description of transportation packaging systems to be used for unirradiated fuel.

2.8 Conditional Probabilities and Release Fractions

For shipments of unirradiated LWR fuel containing low enriched uranium, NRC EISs have not analyzed the radiological impacts from transportation accidents. This is because there is no significant difference in the consequences of transportation accidents severe enough to result in a release of unirradiated fuel particles to the environment because the enrichment, fuel form, cladding, and packaging for current-generation LWRs are similar to those analyzed in WASH-1238 (AEC 1972). This conclusion would be the same for HALEU derived from unirradiated uranium, based on the unlimited A_2 value for enriched uranium in 10 CFR Part 71, Appendix A.

If HALEU derived from irradiated uranium were used as fuel for a non-LWR, then the radiological impacts of transportation accidents involving unirradiated fuel should be analyzed. This is because HALEU derived from an irradiated uranium source such as EBR-II spent fuel can contain Pu-239 and Pu-240, which have A_2 values of 0.027 Ci, and therefore transport of this unirradiated fuel could require a Type B container (Eidelpes et al. 2019). For the same reason, if plutonium-based fuel were used as fuel for a non-LWR, then the radiological impacts of transportation accidents involving unirradiated fuel should also be analyzed.

NUREG-2125 (NRC 2014) evaluated transportation accidents involving three NRC-certified transportation packages containing pressurized water reactor (PWR)[3] spent fuel. Two of these transportation packages were rail transportation packages: (1) a transportation package with steel gamma shielding[4] and an inner welded canister for the spent fuel and (2) a transportation package with lead gamma shielding[5] that can transport spent fuel within an inner welded canister or without an inner canister. The third transportation package evaluated in NUREG-2125 was a truck transportation package with depleted uranium[6] gamma shielding. This transportation package did not contain an inner welded canister.

If these transportation packages were involved in a fire, their plastic neutron shielding material could melt, resulting in a slightly elevated amount of radiation emanating from the transportation package. If the lead shielded rail transportation package was involved in an exceptionally severe long-lasting fire, there could be a reduction in the effectiveness of the gamma shielding. Even in the worst-case fires analyzed, no transportation package experienced a seal failure that could have led to a release of radioactive material from the spent fuel transportation package.

For transportation accidents involving impacts, the steel shielded rail transportation package with the inner welded canister and the depleted uranium-shielded truck transportation package would have no release and no loss of gamma shielding effectiveness even under the most severe impacts studied in NUREG-2125. The lead shielded transportation package was found to experience some loss of gamma shielding effectiveness during severe impacts. Also, when spent fuel is transported without an inner welded canister (i.e., uncanistered) some release of radioactive material could occur during exceptionally severe impacts. Table 3 lists the release fractions and conditional probabilities associated with these transportation accidents based on two seal materials (metal and elastomer). The total conditional probability that an accident will lead to a release for the transportation package using metal seals is 1.08×10^{-9} and for the transportation package using elastomer seals it is 3.58×10^{-10}.

ERs and EISs for LWRs have generally used the conditional probabilities and release fractions of Sprung et al. (2000) to estimate the radiological impacts of transportation accidents involving spent fuel. These release fractions are for BWR and PWR spent fuel in truck and rail transportation packages and may not be appropriate for non-LWR spent fuel. Table 4 lists additional spent fuel types that may be appropriate for non-LWR spent fuel. Table 5 through Table 20 list the associated accident severity categories, conditional probabilities, and release fractions for these fuel types for truck and rail transport.

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[3] NUREG-2125 did not evaluate transportation accidents involving boiling water reactor (BWR) spent fuel.

[4] This transportation package was referred to as the rail-steel cask in NUREG-2125.

[5] This transportation package was referred to as the rail-lead cask in NUREG-2125.

[6] Depleted uranium is uranium with a U-235 percentage lower than the 0.7 percent (by mass). Typically, the U-235 percentage in depleted uranium is 0.20-0.25 percent.

Table 3. Release fractions and conditional probabilities for uncanistered spent fuel in a rail steel-lead transportation package (NRC 2014).

	Package Orientation	End	Corner	Side	Side	Side	Side	Corner
	Impact Speed (kph) (mph)	193 (120)	193 (120)	193 (120)	193 (120)	145 (90)	145 (90)	145 (90)
	Seal	Metal	Metal	Elastomer	Metal	Elastomer	Metal	Metal
Package to Environment Release Fraction	Gas	0.80	0.80	0.80	0.80	0.80	0.80	0.80
	Particles	0.70	0.70	0.70	0.70	0.70	0.70	0.64
	Volatiles	0.50	0.50	0.50	0.50	0.50	0.50	0.45
	Crud	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Rod to Package Release Fraction	Gas	0.12	0.12	0.12	0.12	0.12	0.12	0.12
	Particles	4.8×10^{-6}	4.8×10^{-6}	4.8×10^{-6}	4.8×10^{-6}	4.8×10^{-6}	4.8×10^{-6}	2.4×10^{-6}
	Volatiles	3.0×10^{-5}	3.0×10^{-5}	3.0×10^{-5}	3.0×10^{-5}	3.0×10^{-5}	3.0×10^{-5}	1.5×10^{-5}
	Crud	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Conditional Probability for Combined Rod to Package Release Fraction	5.96×10^{-12}	3.57×10^{-11}	1.79×10^{-11}	1.79×10^{-11}	3.40×10^{-10}	3.40×10^{-10}	1.13×10^{-10}
Source: Table E-16 in NUREG-2125 (NRC 2014). Aerosolized fraction and respirable fraction = 1.0								

Table 4. Spent fuel groups, spent fuel descriptions, and release fraction groups.

Spent Fuel Group	Spent Fuel Description	Release Fraction Group
1	Uranium Metal, Zirconium Clad, LEU	1
2	Uranium Metal, Non-Zirconium Clad, LEU	1
3	Uranium-Zirconium	1
4	Uranium-Molybdenum	1
5	Uranium Oxide, Zirconium Clad (Intact), HEU	2
6	Uranium Oxide, Zirconium Clad (Intact), MEU	2
7	Uranium Oxide, Zirconium Clad (Intact), LEU	2
8	Uranium Oxide, Stainless Steel/Hastelloy Clad (Intact), HEU	2
9	Uranium Oxide, Stainless Steel Clad (Intact), MEU	2
10	Uranium Oxide, Stainless Steel Clad (Intact), LEU	2
11	Uranium Oxide, Non-Aluminum Clad (Non-Intact or Declad), HEU	3
12	Uranium Oxide, Non-Aluminum Clad (Non-Intact or Declad), MEU	3
13	Uranium Oxide, Non-Aluminum Clad (Non-Intact or Declad), LEU	3
14	Uranium Oxide, Aluminum Clad, HEU	3
15	Uranium Oxide, Aluminum Clad, MEU and LEU	3
16	Uranium-Aluminum, HEU	4
17	Uranium-Aluminum, MEU	4
18	Uranium Silicide	4
19	Thorium/Uranium Carbide, TRISO or BISO-Coated Particles in Graphite	5
20	Thorium/Uranium Carbide, Mono-Pyrolytic Carbon-Coated Particles in Graphite	6
21	Plutonium/Uranium Carbide, Nongraphite Clad, Not Sodium Bonded	3
22	Mixed Oxide, Zirconium Clad	2
23	Mixed Oxide, Stainless Steel Clad	2
24	Mixed Oxide, Non-Stainless Steel/Non-Zirconium Clad	2
25	Thorium/Uranium Oxide, Zirconium Clad	2
26	Thorium/Uranium Oxide, Stainless Steel Clad	2
27	Uranium-Zirconium Hydride, Stainless Steel/Incoloy Clad, HEU	7
28	Uranium-Zirconium Hydride, Stainless Steel/Incoloy Clad, MEU	7
29	Uranium-Zirconium Hydride, Aluminum Clad, MEU	7
30	Uranium-Zirconium Hydride, Aluminum Clad, Declad	7
34	Miscellaneous	1
HLW	High-Level Radioactive Waste	HLW

The spent fuel descriptions were taken from Appendix G in DOE (2008), pp. G-30-G-34.
LEU = low enriched uranium (< 20% enrichment), MEU = medium enriched uranium (50% enrichment), HEU = high enriched uranium (> 75% enrichment).
TRISO-coated particles consist of an isotropic pyrocarbon outer layer, a silicon carbide layer, an isotropic carbon layer, and a porous carbon buffer inner layer. BISO-coated particles consist of an isotropic pyrocarbon outer layer and a low-density, porous carbon buffer inner layer.

Table 5. Accident severity categories, conditional probabilities, and release fractions for release fraction group 1 (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	5.66×10^{-5}	3.54×10^{-7}	2.29×10^{-8}	1.83×10^{-9}	5.71×10^{-6}
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	7.86×10^{-4}	1.42×10^{-7}	6.63×10^{-8}	5.80×10^{-8}	1.93×10^{-4}
5	6.99×10^{-8}	4.00×10^{-3}	7.87×10^{-5}	4.72×10^{-6}	3.20×10^{-8}	6.35×10^{-5}
6	2.24×10^{-10}	7.70×10^{-3}	2.74×10^{-4}	7.57×10^{-5}	3.68×10^{-7}	1.13×10^{-3}

Source: Jason Technologies (2001), Table 5-32.
Aerosolized fraction and respirable fraction = 1.0

Table 6. Accident severity categories, conditional probabilities, and release fractions for release fraction group 1 (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	2.84×10^{-4}	1.71×10^{-6}	3.91×10^{-7}	1.10×10^{-8}	2.96×10^{-5}
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	2.13×10^{-3}	2.36×10^{-6}	3.55×10^{-6}	3.55×10^{-6}	1.18×10^{-2}
5	1.10×10^{-7}	4.00×10^{-3}	7.87×10^{-5}	1.77×10^{-5}	9.68×10^{-8}	1.61×10^{-4}
6	8.52×10^{-10}	4.68×10^{-2}	9.63×10^{-4}	2.47×10^{-4}	2.73×10^{-6}	7.17×10^{-3}

Source: Jason Technologies (2001), Table 5-33.
Aerosolized fraction and respirable fraction = 1.0

Table 7. Accident severity categories, conditional probabilities, and release fractions for release fraction group 2 (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.06×10^{-5}	1.36×10^{-1}	4.09×10^{-9}	1.02×10^{-7}	1.02×10^{-7}	1.36×10^{-3}
3	5.86×10^{-6}	8.39×10^{-1}	1.68×10^{-5}	6.71×10^{-8}	6.71×10^{-8}	2.52×10^{-3}
4	4.95×10^{-7}	4.49×10^{-1}	1.35×10^{-8}	3.37×10^{-7}	3.37×10^{-7}	1.83×10^{-3}
5	7.49×10^{-8}	8.35×10^{-1}	3.60×10^{-5}	3.77×10^{-6}	3.77×10^{-6}	3.16×10^{-3}
6	3.00×10^{-10}	8.40×10^{-1}	2.40×10^{-5}	2.14×10^{-5}	5.01×10^{-6}	3.17×10^{-3}

Source: Jason Technologies (2001), Table 5-24.
Aerosolized fraction and respirable fraction = 1.0

Table 8. Accident severity categories, conditional probabilities, and release fractions for release fraction group 2 (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.96×10^{-1}	5.87×10^{-9}	1.34×10^{-7}	1.34×10^{-7}	1.37×10^{-3}
3	4.91×10^{-5}	8.39×10^{-1}	1.68×10^{-5}	2.52×10^{-7}	2.52×10^{-7}	9.44×10^{-3}
4	5.77×10^{-7}	8.00×10^{-1}	8.71×10^{-6}	1.32×10^{-5}	1.32×10^{-5}	4.42×10^{-3}
5	1.10×10^{-7}	8.35×10^{-1}	3.60×10^{-5}	1.37×10^{-5}	1.37×10^{-5}	5.36×10^{-3}
6	8.52×10^{-10}	8.47×10^{-1}	5.71×10^{-5}	4.63×10^{-5}	1.43×10^{-5}	1.59×10^{-2}

Source: Jason Technologies (2001), Table 5-26.
Aerosolized fraction and respirable fraction = 1.0

Table 9. Accident severity categories, conditional probabilities, and release fractions for release fraction group 3 (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	2.16×10^{-5}	6.47×10^{-11}	1.62×10^{-9}	1.62×10^{-9}	5.39×10^{-6}
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	7.72×10^{-4}	2.32×10^{-9}	5.79×10^{-8}	5.79×10^{-8}	1.93×10^{-4}
5	6.99×10^{-8}	4.00×10^{-3}	3.14×10^{-7}	3.20×10^{-8}	3.20×10^{-8}	6.35×10^{-5}
6	2.24×10^{-10}	6.02×10^{-3}	2.80×10^{-7}	5.16×10^{-7}	5.16×10^{-7}	1.12×10^{-3}

Source: Jason Technologies (2001), Table 5-34.
Aerosolized fraction and respirable fraction = 1.0

Table 10. Accident severity categories, conditional probabilities, and release fractions for release fraction group 3 (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.15×10^{-4}	3.44×10^{-10}	7.15×10^{-9}	7.15×10^{-9}	2.38×10^{-5}
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	2.13×10^{-3}	2.36×10^{-6}	3.55×10^{-6}	3.55×10^{-6}	1.18×10^{-2}
5	1.10×10^{-7}	4.00×10^{-3}	3.14×10^{-7}	9.68×10^{-8}	9.68×10^{-8}	1.61×10^{-4}
6	8.52×10^{-10}	1.67×10^{-2}	2.68×10^{-6}	2.29×10^{-6}	2.04×10^{-6}	6.15×10^{-3}

Source: Jason Technologies (2001), Table 5-35.
Aerosolized fraction and respirable fraction = 1.0

Table 11. Accident severity categories, conditional probabilities, and release fractions for release fraction group 4 (truck).

Accident severity category	Conditional probability	Release fraction				
		Inert gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	5.66×10^{-5}	1.77×10^{-5}	1.83×10^{-9}	1.83×10^{-9}	5.71×10^{-6}
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	2.13×10^{-3}	2.36×10^{-6}	3.55×10^{-6}	3.55×10^{-6}	1.18×10^{-2}
5	6.99×10^{-8}	4.00×10^{-3}	3.14×10^{-7}	9.68×10^{-8}	9.68×10^{-8}	1.61×10^{-4}
6	2.24×10^{-10}	1.67×10^{-2}	2.68×10^{-6}	2.29×10^{-6}	2.04×10^{-6}	6.15×10^{-3}

Source: Jason Technologies (2001), Table 5-38.
Aerosolized fraction and respirable fraction = 1.0

Table 12. Accident severity categories, conditional probabilities, and release fractions for release fraction group 4 (rail).

Accident severity category	Conditional probability	Release fraction				
		Inert gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	2.84×10^{-4}	8.53×10^{-5}	1.10×10^{-8}	1.10×10^{-8}	4.11×10^{-5}
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	2.13×10^{-3}	2.36×10^{-6}	3.55×10^{-6}	3.55×10^{-6}	1.18×10^{-2}
5	1.10×10^{-7}	4.00×10^{-3}	3.53×10^{-3}	9.68×10^{-8}	9.68×10^{-8}	4.26×10^{-4}
6	8.52×10^{-10}	4.68×10^{-2}	2.92×10^{-2}	2.73×10^{-6}	2.73×10^{-6}	1.03×10^{-2}

Source: Jason Technologies (2001), Table 5-39.
Aerosolized fraction and respirable fraction = 1.0

Table 13. Accident severity categories, conditional probabilities, and release fractions for release fraction group 5 (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	0.0	0.0	0.0	0.0	0.0
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	7.50×10^{-4}	5.63×10^{-10}	5.63×10^{-10}	5.63×10^{-10}	0.0
5	6.99×10^{-8}	0.0	0.0	0.0	0.0	0.0
6	2.24×10^{-10}	3.52×10^{-3}	2.72×10^{-9}	2.64×10^{-9}	2.64×10^{-9}	0.0

Source: Jason Technologies (2001), Table 5-40.
Aerosolized fraction and respirable fraction = 1.0

Table 14. Accident severity categories, conditional probabilities, and release fractions for release fraction group 5 (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.02×10^{-4}	6.12×10^{-11}	6.12×10^{-11}	6.12×10^{-11}	0.0
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	4.77×10^{-3}	7.89×10^{-8}	7.89×10^{-8}	7.89×10^{-8}	0.0
5	1.10×10^{-7}	0.0	0.0	0.0	0.0	0.0
6	8.52×10^{-10}	1.70×10^{-3}	2.84×10^{-8}	2.62×10^{-8}	2.62×10^{-8}	0.0

Source: Jason Technologies (2001), Table 5-41.
Aerosolized fraction and respirable fraction = 1.0

Table 15. Accident severity categories, conditional probabilities, and release fractions for release fraction group 6 (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	5.19×10^{-1}	3.89×10^{-7}	3.89×10^{-7}	3.89×10^{-7}	0.0
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	5.17×10^{-1}	3.88×10^{-7}	3.88×10^{-7}	3.88×10^{-7}	
5	6.99×10^{-8}	7.64×10^{-1}	6.32×10^{-6}	5.73×10^{-7}	5.73×10^{-7}	0.0
6	2.24×10^{-10}	6.00×10^{-1}	2.33×10^{-6}	2.24×10^{-6}	4.50×10^{-7}	0.0

Source: Jason Technologies (2001), Table 5-42.
Aerosolized fraction and respirable fraction = 1.0

Table 16. Accident severity categories, conditional probabilities, and release fractions for release fraction group 6 (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	5.14×10^{-1}	3.70×10^{-7}	3.70×10^{-7}	3.70×10^{-7}	0.0
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	4.77×10^{-1}	7.89×10^{-6}	7.89×10^{-6}	7.89×10^{-6}	0.0
5	1.10×10^{-7}	7.64×10^{-1}	6.32×10^{-6}	5.73×10^{-7}	5.73×10^{-7}	0.0
6	8.52×10^{-10}	7.45×10^{-1}	7.57×10^{-6}	5.82×10^{-6}	3.02×10^{-6}	0.0

Source: Jason Technologies (2001), Table 5-43.
Aerosolized fraction and respirable fraction = 1.0

Table 17. Accident severity categories, conditional probabilities, and release fractions for release fraction group 7 (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	2.16×10^{-5}	6.47×10^{-9}	1.62×10^{-7}	1.62×10^{-7}	5.39×10^{-6}
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	7.92×10^{-4}	2.32×10^{-7}	5.79×10^{-6}	5.79×10^{-6}	1.93×10^{-4}
5	6.99×10^{-8}	1.97×10^{-2}	1.97×10^{-2}	2.51×10^{-5}	1.61×10^{-6}	2.27×10^{-4}
6	2.24×10^{-10}	1.33×10^{-2}	9.11×10^{-3}	4.04×10^{-4}	3.22×10^{-5}	1.37×10^{-3}

Source: Jason Technologies (2001), Table 5-44.
Aerosolized fraction and respirable fraction = 1.0

Table 18. Accident severity categories, conditional probabilities, and release fractions for release fraction group 7 (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	1.15×10^{-4}	3.44×10^{-8}	7.15×10^{-7}	7.15×10^{-7}	2.38×10^{-5}
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	2.13×10^{-3}	2.36×10^{-4}	3.55×10^{-4}	3.55×10^{-4}	1.18×10^{-2}
5	1.10×10^{-7}	1.97×10^{-2}	1.97×10^{-2}	8.99×10^{-5}	1.93×10^{-6}	7.15×10^{-4}
6	8.52×10^{-10}	7.98×10^{-2}	7.91×10^{-2}	5.43×10^{-4}	1.76×10^{-4}	8.58×10^{-3}

Source: Jason Technologies (2001), Table 5-45.
Aerosolized fraction and respirable fraction = 1.0

Table 19. Accident severity categories, conditional probabilities, and release fractions for HLW release fraction group (truck).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99993	0.0	0.0	0.0	0.0	0.0
2	6.22×10^{-5}	0.0	3.35×10^{-8}	3.35×10^{-8}	3.35×10^{-8}	0.0
3	5.59×10^{-6}	0.0	0.0	0.0	0.0	0.0
4	5.16×10^{-7}	0.0	2.37×10^{-7}	2.37×10^{-7}	2.37×10^{-7}	0.0
5	6.99×10^{-8}	0.0	9.29×10^{-8}	9.29×10^{-8}	9.29×10^{-8}	0.0
6	2.24×10^{-10}	0.0	6.56×10^{-7}	6.56×10^{-7}	2.98×10^{-7}	0.0

Source: Jason Technologies (2001), Table 5-47.
Aerosolized fraction and respirable fraction= 1.0

Table 20. Accident severity categories, conditional probabilities, and release fractions for HLW release fraction group (rail).

Accident Severity Category	Conditional Probability	Release Fraction				
		Inert Gas	Cesium	Ruthenium	Particulates	Crud
1	0.99991	0.0	0.0	0.0	0.0	0.0
2	3.87×10^{-5}	0.0	6.22×10^{-8}	6.22×10^{-8}	6.22×10^{-8}	0.0
3	4.91×10^{-5}	0.0	0.0	0.0	0.0	0.0
4	5.77×10^{-7}	0.0	7.89×10^{-6}	7.89×10^{-6}	7.89×10^{-6}	0.0
5	1.10×10^{-7}	0.0	9.29×10^{-8}	9.29×10^{-8}	9.29×10^{-8}	0.0
6	8.52×10^{-10}	0.0	2.74×10^{-6}	2.74×10^{-6}	2.74×10^{-6}	0.0

Source: Jason Technologies (2001), Table 5-48.
Aerosolized fraction and respirable fraction = 1.0

Chen et al. (2002) also provide conditional probabilities and release fractions for transuranic waste in Type B packages (see Table 21) and for generic Type A and Type B packages, as well as aerosolized and respirable fractions for released material (see Table 22 and Table 23). The generic Type A and Type B package conditional probabilities and release fractions in Table 22 were originally used by the NRC to estimate the risks from transportation accidents in NUREG-0170 (1977). Since NUREG-0170 was published in 1977, the estimates of the releases of radioactive material from transportation packages during accidents have become increasingly refined, resulting in the more realistic release fractions contained in NUREG-2125 (NRC 2014) and Sprung et al. (2000).

Table 21. Total respirable release fractions for transuranic waste in Type B packages.

Accident Severity Category	Conditional Probability	Contact-Handled Transuranic Waste (TRUPACT-II) Release Fraction	Remote-Handled Transuranic Waste (RH-72B) Release Fraction
I	5.5×10^{-1}	0	0
II	3.6×10^{-1}	0	0
III	7.0×10^{-2}	8×10^{-9}	6×10^{-9}
IV	1.6×10^{-2}	2×10^{-7}	2×10^{-7}
V	2.8×10^{-3}	8×10^{-5}	1×10^{-4}
VI	1.1×10^{-3}	2×10^{-4}	1×10^{-4}
VII	8.5×10^{-5}	2×10^{-4}	2×10^{-4}
VIII	1.5×10^{-5}	2×10^{-4}	2×10^{-4}

Source: Chen et al. (2002), Tables 6.22 and 6.26.

Table 22. Type A and Type B package release fractions.

Severity Category	Conditional Probability	Type A Package Release Fraction	Type B Package Release Fraction
		Truck	
I	5.5×10^{-1}	0	0
II	3.6×10^{-1}	0.01	0
III	7.0×10^{-2}	0.1	0.01
IV	1.6×10^{-2}	1	0.1
V	2.8×10^{-3}	1	1
VI	1.1×10^{-3}	1	1
VII	8.5×10^{-5}	1	1
VIII	1.5×10^{-5}	1	1
		Rail	
I	5.0×10^{-1}	0	0
II	3.0×10^{-1}	0.01	0
III	1.8×10^{-1}	0.1	0.01
IV	1.8×10^{-2}	1	0.1
V	1.8×10^{-3}	1	1
VI	1.3×10^{-4}	1	1
VII	6.0×10^{-5}	1	1
VIII	1.0×10^{-5}	1	1

Source: Chen et al. (2002), Tables 6.22 and 6.24.

Table 23. Aerosolized and respirable fractions for released materials.

Material	Aerosolized Fraction	Respirable Fraction
Immobile	1×10^{-6}	0.05
Loose chunks	0.01	0.05
Large powder	0.05	0.05
Small powder/nonvolatile liquids	0.1	0.05
Spent fuel particulates	1	0.05
Volatile solid	1	1
Other	1	1
Gas	1	1
Flammable	1	1

Source: Chen et al. (2002), Table 6.25.

2.9 Comparison of Transportation Risk Assessment Results to Criteria

Comparison of transportation risk assessment results to the criteria in Table S-4 may not be valid for various reasons given the differences between the potential designs of non-LWRs and LWRs. In lieu of comparing incident-free doses, radiological accident risks, and nonradiological transportation accidents, injuries, and fatalities to the criteria in Table S-4, the applicant's ER may contain comparisons to quantities such as the following:

- the number of nonradiological transportation accidents, injuries, and fatalities that occur annually in the United States
- the collective radiation dose as compared to the collective background radiation dose[7]
- the individual radiation dose as compared to the background radiation dose for a person exposed along a transportation route
- the radiation dose standards for workers and members of the public contained in 10 CFR Part 20
- for radiological accident risks, the risk of a latent cancer fatality for the population exposed along a transportation route in comparison to one-tenth of one percent (0.1 percent) of the sum of cancer fatality risks resulting from all other causes for this same population (51 FR 30028).

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[7] The average U.S. resident receives about a 311 mrem/yr effective dose equivalent from natural background radiation (i.e., exposures from cosmic radiation; naturally occurring radioactive materials, such as radon; and global fallout from testing of nuclear explosive devices) (NCRP 2009).

3.0 References

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