Pacific Northwest NATIONAL LABORATORY

PNNL-30166 Rev. 1

# Concept of Operations for Microreactor Transportation

September 2020

Steven J. Maheras
Harold E. Adkins, Jr.

U.S. DEPARTMENT OF ENERGY

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

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Richland, Washington 99354

# Summary

This report fulfills the M4 milestone M4MR-20PN0303022, “Complete Documentation of Concept of Transportation Operations.”

Microreactors are very small nuclear reactors with a power output of 20 MWe or less and are designed to be factory-built, modular in nature, and highly portable. The Idaho National Laboratory (INL) has been identified as a potential location to demonstrate microreactors and two microreactor concepts currently under consideration for demonstration at the INL include a tristructural isotropic (TRISO) fueled high-temperature gas reactor and a sodium cooled reactor using a SNAP-10A style fuel pin design. The objective of this report is to identify a concept of operations (CONOPS) for shipping these microreactors.

Section 2 of this report describes previous U.S. Army and U.S. Air Force nuclear reactors and describes previous reactor transportability tests. Section 3 of this report discusses microreactor modal transportation options and the implications of transporting a microreactor before and after it has been operated. Section 3 also presents modal-specific transport information, possible generic container considerations, and related cargo container and tie-down information.

Section 4 of this report presents detailed schedules of U.S. Department of Transportation (DOT) and U.S. Nuclear Regulatory Commission (NRC) regulations that are relevant to the shipment of microreactors. This section concentrates on the transport of fissile material packages and Type B packages, which would be most applicable to the transport of the fuel and/or a fueled microreactor before and after irradiation. This section also presents a schedule for the air shipment of fissile material and Type B packages by military aircraft.

Sections 5 of this report discusses onsite transportation at the INL. The emphasis of this section is on the process used to establish safety equivalency for onsite shipments at the INL that do not meet DOT or NRC regulatory requirements and on possible locations that have been identified for demonstration of microreactors.

Sections 6 of this report identifies issues associated with the transport of microreactors. Potential areas for issues include issues associated with the microreactor fuel type, issues that result from fissile material and Type B packaging requirements, issues stemming from microreactor shielding and weights, transportation mode specific issues (highway, rail, barge/ship, and air), and issues associated with packaging evaluations (structural, thermal, containment, shielding, and criticality). The concept of defense-in-depth and how it applies to transport of these reactors is also discussed.

Presented in Sections 7 of this report is a discussion of options to address the issues identified in the previous section and provide a recommended approach for resolution, along with rough estimates of durations and costs.

# Acronyms and Abbreviations

| | |
|---|---|
| AAR | Association of American Railroads |
| AEC | Atomic Energy Commission |
| ANPP | Army Nuclear Power Program |
| ASME BPVC | American Society of Mechanical Engineers Boiler and Pressure Vessel Code |
| ASTM | American Society for Testing and Materials |
| ATR | Advanced Test Reactor |
| ANSI | American National Standards Institute |
| Bq | Becquerels |
| TBq | Terabecquerels |
| Ci | Curies |
| CFA | Central Facilities Area |
| CFR | Code of Federal Regulations |
| CO | Certifying Official |
| CoC | Certificate of Compliance |
| COI | Certificate of Inspection |
| CONOPS | Concept of operations |
| CSI | Criticality Safety Index |
| CVSA | Commercial Vehicle Safety Alliance |
| DoD | U.S. Department of Defense |
| DOE | U.S. Department of Energy |
| DOE-NE | U.S. Department of Energy Office of Nuclear Energy |
| DOT | U.S. Department of Transportation |
| EBR-II | Experimental Breeder Reactor II |
| ETP | equal time point |
| FMCSA | Federal Motor Carrier Safety Administration |
| GIS | geographic information system |
| HAC | hypothetical accident conditions |
| HADR | Humanitarian Assistance and Disaster Relief |
| HALEU | high-assay low enriched uranium |
| HRCQ | highway route controlled quantity |
| HTGR | high-temperature gas reactor |
| IAEA | International Atomic Energy Agency |
| INL | Idaho National Laboratory |
| INTEC | Idaho Nuclear Technology and Engineering Center |
| IP | Industrial Package |
| ISO | International Organization for Standardization |

| | |
|---|---|
| LEU | low enriched uranium |
| LSA | low specific activity |
| MATB | Microreactor Applications Test Bed |
| mCi | milliCuries |
| MCMIS | Motor Carrier Management Information System |
| MCR | Military Compact Reactor |
| MFC | Materials and Fuels Complex |
| ML-1 | Mobile Low Power Plant 1 |
| MOU | Memorandum of Understanding |
| MOX | Mixed Oxide |
| MTR | Materials Test Reactor |
| MWe | megawatt electrical |
| NCT | normal conditions of transport |
| NEPA | Nuclear Energy for Propulsion of Aircraft |
| NNSA | National Nuclear Security Administration |
| NORAD | North American Air Defense Command |
| NRC | U.S. Nuclear Regulatory Commission |
| OCO | Overseas Contingency Operations |
| PHMSA | Pipeline and Hazardous Materials Safety Administration |
| PM | Portable Medium Power Plant |
| RNA | Regulated Navigation Areas |
| REV | Rail escort vehicle |
| RQ | Reportable Quantities |
| QA | quality assurance |
| SARP | Safety Analysis Report for Packaging |
| SCO | surface contaminated object |
| SNF | spent nuclear fuel |
| TRISO | Tristructural isotropic |
| TSD | Transportation Safety Document |
| uCi | microcuries |
| USCG | U.S. Coast Guard |

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# 1.0 Introduction

Advanced reactors involve designs that leverage coolants such as molten salt, high-temperature gas, and liquid metal as opposed to traditional light-water reactors (LWR) that use water in primary and secondary heat exchange loops. Advanced reactor designs are targeted to be inherently safer, incorporating features such as reduced reactivity with increasing temperature. Some may not require safety-related backup electrical systems to operate. Advanced reactor designs are being considered that will offer a broad range of sizes and associated application-specific power outputs, from more than 1,000 megawatts (like traditional reactors) down to < 1 megawatt. This will allow selection and tailoring of the application to be performed based on specific or localized energy demands.

A subset of these advanced reactors, providing 20 megawatt electrical (MWe) or less, are commonly referred to as microreactors. Microreactors are very small nuclear reactors designed to be factory-built, modular in nature, and ideal for providing a test bed for component and subsystem development and demonstration. These are anticipated to lend themselves well to mobile or transportable applications.

The U.S. Department of Energy (DOE) is supporting the U.S. advanced reactor industry through funding, legislation, and regulatory development in order to actively pursue several microreactor design concepts. The U.S. Department of Defense (DoD) also shares great interest in microreactor design concepts as its military operations become more energy intensive and require portable, compact power sources. Remote rural communities in the U.S. that rely on diesel generators for electricity are also considering microreactors as a source of reliable, zero-carbon energy capable of operation for several years without refueling. These reactors are typically intended for independent operation applications, including power for remote locations, mobile backup power, mining operations, military installations, space missions, desalination, and emergency power supplies in support of disaster relief operations.

Idaho National Laboratory (INL) has been identified to support demonstrations of microreactor technology due to its well-established track record for nuclear facility operations, existing green field sites, and world-class nuclear research and development experimental facilities. INL has capabilities to support demonstration needs and a well-characterized site with a controlled emergency planning zone. They also have mechanisms for the necessary Nuclear Regulatory Commission (NRC) licensing and DOE-authorization of its facilities as appropriate. INL is collaborating with major stakeholders and other national laboratories to develop, test, and demonstrate near-term microreactor definitions with an objective to significantly enhance the technology readiness level for direct application in the next three to five years.

The two reactor concepts currently selected for demonstration at INL fall under the category of advanced microreactors and are in support of Project Pele and INL's Microreactor Applications Test Bed (MATB). The microreactor being designed and developed for Project Pele is a 1 to 3 MWe tristructural isotropic (TRISO) fueled high-temperature gas reactor (HTGR) that will use high-assay low enriched uranium (HALEU)[1] as the fuel composition. The Project Pele concept is a small mobile nuclear reactor that can make the DoD's domestic infrastructure resilient to an electric grid attack and fundamentally change the logistics of Overseas Contingency Operations (OCO), both by making higher density energy sources available and by drastically simplifying the complex fuel logistic lines, which currently support existing power generators operating

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

mostly on diesel fuel. It would enable a more rapid response during Humanitarian Assistance and Disaster Relief (HADR) operations and could also reinvigorate the commercial nuclear industry through commercial investment and development of demand-centric, modular, and scalable high energy density power for industrial and technology parks or other localized need. The Office of the Under Secretary of Defense for Research and Engineering, acting through the Strategic Capabilities Office (SCO), is leading this initiative to respond to these needs.

Project Pele is specifically aimed at providing a ruggedized reactor definition enclosed in a standard certified 20' long ISO-688 freight container due to the Army's significant familiarity with deploying these containers. The Project Pele microreactors will likely leverage all conventional modal transportation options available (highway, railway, barge/ship, and high capacity airlift such as C-17) under its deployment scenarios. While developers of advanced reactors and microreactors share a common goal of providing enhanced load-following characteristics and lowering overall construction and operating costs to be more competitive with other forms of energy generation, transportability of an operating unit offers an entire suite of additional compounding challenges.

The MATB design concept is a sodium cooled 20 kWe reactor utilizing a SNAP-10A reactor style pin design. The MATB design concept uses sodium bonded uranium zirconium hydride (UZrH) fuel produced using HALEU. It is specifically targeted to provide a test platform for component and subsystem development as well demonstration. It will be utilized to elevate the technology readiness level of nuclear derived electric power generation and associated enhancing technologies. MATB is currently anticipated to be a fixed reactor definition that takes advantage of an accommodating research and testing safety environment. Its components are envisioned to be shop fabricated and delivered by truck. Final assembly, fueling, and operation will be conducted within the research and testing safety environment. It will remain there until final decommissioning, dismantlement, and separation of the final spent fuel load, and then dispositioned. Dispositioning of the inventory of spent fuel and activated/radioactive hardware will likely be performed using a series of Class 7 (radioactive) materials packagings.

In support of the Project Pele and MATB demonstrations, the DOE Office of Nuclear Energy (DOE-NE) is supporting research and development as well as programmatic efforts in multiple areas related to microreactor technology. This includes the safe and secure storage, transportation, and disposition of spent nuclear fuel (SNF) generated in microreactor technology demonstrations. Modes of transportation that are being considered include, but are not limited to, road, rail, barge/ship, and air. The required transport definition and associated transportation and packaging regulatory requirements will change during the course of the reactor demonstration itself based on initiation of a neutron fluence during demonstration. As such, Type AF and Type B packaging definitions, and possibly risk and dose consequence model evaluations, and a formulation of a defense-in-depth methodology will likely need to be considered as part of a successful demonstration.

The objective of this report is to identify a concept of operations (CONOPS) regarding microreactor transport. Just as in the traditional sense for any CONOPS document, this document describes the characteristics of a reactor packaged and readied for transport and its associated transportation-ready features and requirements (codified and other) from the viewpoint of individuals who will use that system. The objective of the combined (packaged) system is twofold; 1) to protect the safety and health of the public, workers, and the environment, and 2) provide for a successful demonstration that leverages new reactor technology applications and concepts, bundles them in a ruggedized configuration suitable for shipment during applicable phases, and adequately communicates the potential pathways of successful transportation initiatives. When more detailed information on possible origins, destinations, favorable transport modes, and reactor definitions are known, documentation will be updated to reflect a more detailed framework.

Section 2 of this report describes previous U.S. Army and U.S. Air Force nuclear reactors.

Section 3 of this report identifies and discusses microreactor modal transportation options applicable to the INL demonstration candidates and discusses the prior and post operation implications. It considers transportation being conducted via highway, railway, barge/ship, and air. It also presents modal-specific transport information, possible generic container considerations, and related cargo container and tie-down information.

Section 4 of this report summarizes transportation regulations relevant to reactor transportation options. It presents detailed schedules of requirements for transport based on specific need as well as the applicable U.S. Department of Transportation (DOT) and NRC regulations related to the transportation of Class 7 (radioactive) materials. This section concentrates on the transport of fissile material packages and Type B packages, which would be most applicable to the transport of the fuel and/or a fueled microreactor before and after irradiation. It would also apply to any activated hardware and other radioactive material that exists after separation of the SNF from associated components. This section introduces military specifications that are thought to be most applicable regarding microreactor air transport since the specifications and standards currently do not specifically address shipment of microreactors. As such, the pertinent information relating to the movement of hazardous materials within the DoD is presented.

Section 5 of this report discusses onsite transportation at INL. The emphasis is on the transport of advanced reactor and microreactor definitions targeted for demonstration, containing irradiated fuel, from one site to another at INL.

Section 6 of this report identifies issues associated with the transport of advanced reactor and microreactor definitions fueled but-never-operated, those previously operated and intact, and those previously operated and defueled. Potential areas for issues include fissile material and Type B packaging applications, issues stemming from microreactor shielding and weights, issues associated with use and disposition of the current proposed microreactor fuel types, transportation mode specific issues (highway, rail, barge, and air), and necessary packaging evaluations (structural, thermal, containment, shielding, and criticality). Defense-in-Depth as well as associated issues stemming from this approach will also be discussed.

Presented in Section 7 of this report is a discussion of options to address the issues identified in the previous section and provide a recommended approach for resolution, along with rough estimates of durations and costs.

# 2.0 Previous Army and Air Force Nuclear Reactors

This section discusses previous U.S. Army and U.S. Air Force nuclear reactors, and truck, air, and rail transportability studies conducted for the ML-1 nuclear power plant.

## 2.1 Army Nuclear Power Program

The Army Nuclear Power Program (ANPP) was a joint program between the DoD and the Atomic Energy Commission (AEC). The ANPP was initiated in 1954; during its lifetime, it designed, constructed, operated, and deactivated nine nuclear power plants. By 1977, due to changing military requirements and funding limitations, major program activities had ceased when the last ANPP facility was deactivated.

The following nuclear reactors were constructed and operated as part of the ANPP (DOE 2001).

- The Gas Cooled Reactor Experiment (GCRE) 2.2 MW thermal gas-cooled reactor located at the National Reactor Testing Station (later renamed the Idaho National Laboratory [INL]) and was designed by Aerojet General Corporation (Aerojet-General Nucleonics 1966) to test gas-cooled reactor behavior, evaluate components, test fuel elements, and obtain technical information. This reactor reached initial criticality in 1959 and was shut down in 1962. Although some spent fuel was retained at INL, most was sent to the Savannah River Site (SRS).

- The Mobile Low Power Plant (ML-1) was a 3.3 MW thermal gas-cooled reactor located at INL and was designed by Aerojet General Corporation to test an integrated reactor package that was transportable by military semitrailers, railroad flatcars, and barges. This reactor reached initial criticality March 30,1961 and was shut down in 1965. The spent fuel from this reactor was sent to SRS.

- The Mobile High Power Plant (MH-1A) was a 45 MW thermal pressurized water reactor located in Virginia, designed by Martin Marietta Corporation, and installed on a converted Liberty ship named Sturgis. It remained moored at Gatun Lake in the Panama Canal from 1968 until 1977. This reactor reached initial criticality January 24,1967 and was shut down in 1977. This reactor had a total of five cores and used low enriched uranium (LEU) in the range of 4 to 7 percent with the total amount of uranium-235 supplied being 541.4 kg. The spent fuel from this reactor was sent to SRS.

- The Portable Medium Power Plant (PM-1) was a 9.37 MW thermal pressurized water reactor located in Sundance, Wyoming, designed by the Martin Company, and provided electric power to the 731st Radar Squadron of the North American Air Defense Command (NORAD). This plant reached initial criticality February 25,1962 and was shut down in 1968. The reactor had two cores, with the total amount of uranium-235 supplied being 60.8 kg. PM-1 operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first core was sent to SRS and the fuel from the second core was sent to the Portable Medium Power Plant (PM-3A) located in McMurdo Sound, Antarctica.

- The Portable Medium Power Plant (PM-2A) was a 10 MW thermal pressurized water reactor located at Camp Century, Greenland, and was designed by the American Locomotive Company to demonstrate the ability to assemble a nuclear power plant from prefabricated components in a remote, arctic location. The pressure vessel was subsequently used to investigate neutron embrittlement in carbon steel. This plant reached initial criticality October 3,1960 and was shut down 1963-1964. This reactor had one core with the total amount of uranium-235 supplied being 18.2 kg. PM-2A operated at a uranium-235 enrichment of 93 percent. The spent fuel from this reactor was sent to SRS.

- The Portable Medium Power Plant (PM-3A) was a 9.51 MW thermal pressurized water reactor located at McMurdo Sound, Antarctica, and was designed by the Martin Company to provide electric power and steam heating to the Naval Air Facility at McMurdo Sound. This plant reached initial criticality March 3, 1962 and was shut down in 1972. The reactor had a total of five cores with a total amount of uranium-235 supplied being 121.6 kg. PM-3A operated at a uranium-235 enrichment of 93 percent. The spent fuel from all five reactors was sent to SRS.

- The Stationary Medium Power Plant (SM-1) was a 10 MW thermal pressurized water reactor located at Ft. Belvoir, Virginia designed by the American Locomotive Company and was the first reactor developed under the ANPP. This plant was used to train Army nuclear plant operators. SM-1 was also the first reactor built with a containment structure. It reached initial criticality on April 8, 1957 and was shut down from 1973-1975. This reactor had a total of three cores with the total amount of uranium-235 supplied being 72.7 kg. SM-1 operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first core was sent to INL, and the fuel from the second and third cores were sent to SRS.

- The Stationary Medium Power Plant (SM-1A) was a 20.2 MW thermal pressurized water reactor located at Ft. Greely, Alaska and was designed by the American Locomotive Company. It was the first field facility developed under the ANPP. This site was selected to develop construction methods in a remote, arctic location. SM-1A reached initial criticality March 13, 1962 and was shut down in 1972. This reactor had a total of four cores with the total amount of uranium-235 supplied being 117.1 kg. SM-1A operated at a uranium-235 enrichment of 93 percent. The spent fuel from the first and second cores was sent to SRS, and the fuel from the third and fourth cores was sent to INL.

- The Stationary Low Power Plant (SL-1) was a 2.2 MW thermal boiling water reactor located at INL and was designed by the Argonne National Laboratory to gain experience in boiling water reactor operations, develop performance characteristics, train military crews, and test components. The SL-1 reactor reached initial criticality on August 11, 1958 and had only one core. Combustion Engineering was awarded a contract by the AEC to operate the SL-1 and in turn employed the Army's military operating crew to continue running the plant. On January 3, 1961, the SL-1 was destroyed in an accident that caused the deaths of the three-man operating crew.

The following nuclear reactors were designed as part of the ANPP but were never built.

- The Mobile Low Power Plant (ML-1A) was to be a gas-cooled reactor and the first planned field unit for the ML-1 series of reactors.

- The Portable Low Power Plant (PL-1) was to be a boiling water reactor to supply power for remote locations, providing 3 MW thermal power. The plant was to be based on a low enriched tubular core with pelletized fuel. It would have been air transportable in 11 packages. The design for this plant was completed on June 30, 1961.

- The Portable Low Power Plant (PL-2) was also intended to be a boiling water reactor and supply power for remote locations, providing 10 MW thermal power. The plant was to use LEU pelletized fuel in a tubular core. It also would have been air transportable in 11 packages. The design for this plant was also completed June 30, 1961.

- The Portable Low Power Plant (PL-3) was to be a pressurized water reactor and supply power for remote locations, providing 9.3 MW thermal power. This plant was to be based on high-enriched plate-type fuel.

- The Stationary Medium Power Plant (SM-2) was also intended to be a pressurized water reactor and the prototype for the SM-2 series of reactors to provide 28 MW thermal power. This plant was to be based on high-enriched plate-type fuel.

- The Stationary Medium Power Plant (SM-2A) was to be a pressurized water reactor and was intended to be the first planned field unit for the SM-2 series of reactors.

- The Military Compact Reactor (MCR) was to be a liquid-metal-cooled reactor. The development for this reactor ran from December 1955 to December 1965. The initial concept was for this reactor to power heavy overland cargo haulers in remote areas. This concept was changed to providing a source of mobile electric power for field forces. Later, it was transferred to the Nuclear Power Energy Depot program, which investigated ways to produce synthetic fuels in combat zones.

## 2.2 Aircraft Nuclear Propulsion Program

The Aircraft Nuclear Propulsion (ANP) Program was a joint program between the U.S. Air Force and AEC. The ANP Program had its origins in the Nuclear Energy for Propulsion of Aircraft (NEPA) project which began in 1946. The ANP Program was established in 1951 and was terminated in 1961.

As part of the ANP Program, the Aircraft Shield Test Reactor (ASTR) was developed (Nance and Perry 1958, Schaeffer 1992). The ASTR was to serve as a radiation source for supplying shielding information not obtainable at ground facilities. This 1 MW thermal reactor consisted of 34 plate-type fuel elements containing 4.8 kg of highly enriched uranium and used demineralized water as the moderator, reflector, and coolant. The ASTR and its shielding weighed 35,000 lb. (Jacobsen 1997). The ASTR was flight tested in a modified Convair B-36H that was redesignated the XB-36H and then the NB-36H and called the Nuclear Test Aircraft or NTA. The NB-36H also contained a shielded crew compartment.

Criticality during flight first occurred on September 5, 1955. The NTA containing the ASTR made 47 test flights and 215 hours of flight time (during 89 hours of which the reactor was operated) between July 1955 and March 1957.[1] The ASTR was later upgraded to 10 MW thermal and used exclusively for ground testing. Figure 1 shows the NB-36H in flight with its B-50 chase plane. Figure 2 shows the ASTR being lifted into the bomb bay of the NB-36H on a hydraulic cradle. Figure 3 shows the NB-36H shielded crew compartment.

[1] Some references say that the NTA made 17 flights.

Figure 1. Air-to-Air View of Convair NB-36H and Boeing B-50 Chase Plane

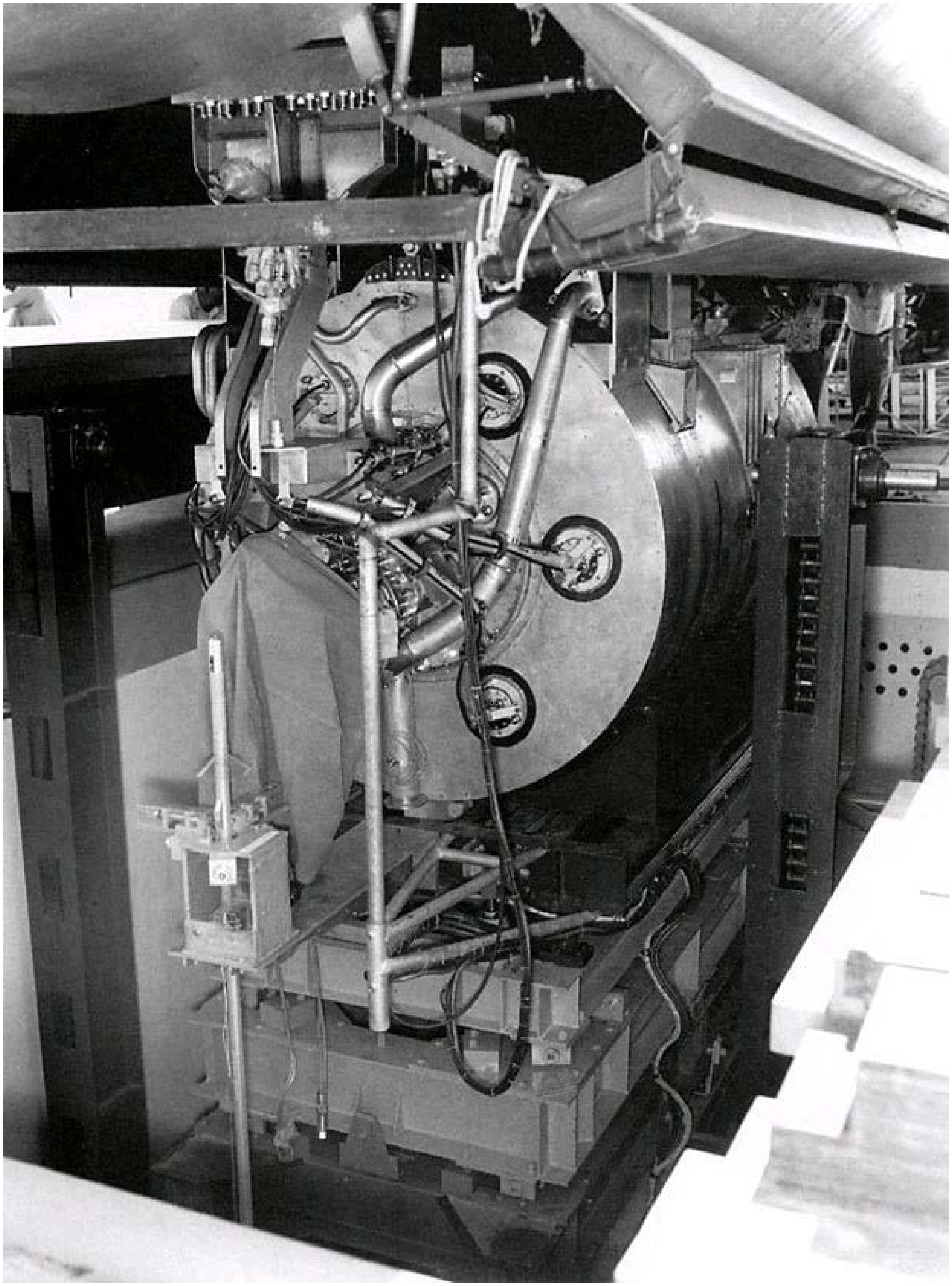


Figure 2. Aircraft Shield Test Reactor on Hydraulic Cradle Being Lifted Up into the Convair NB-36H

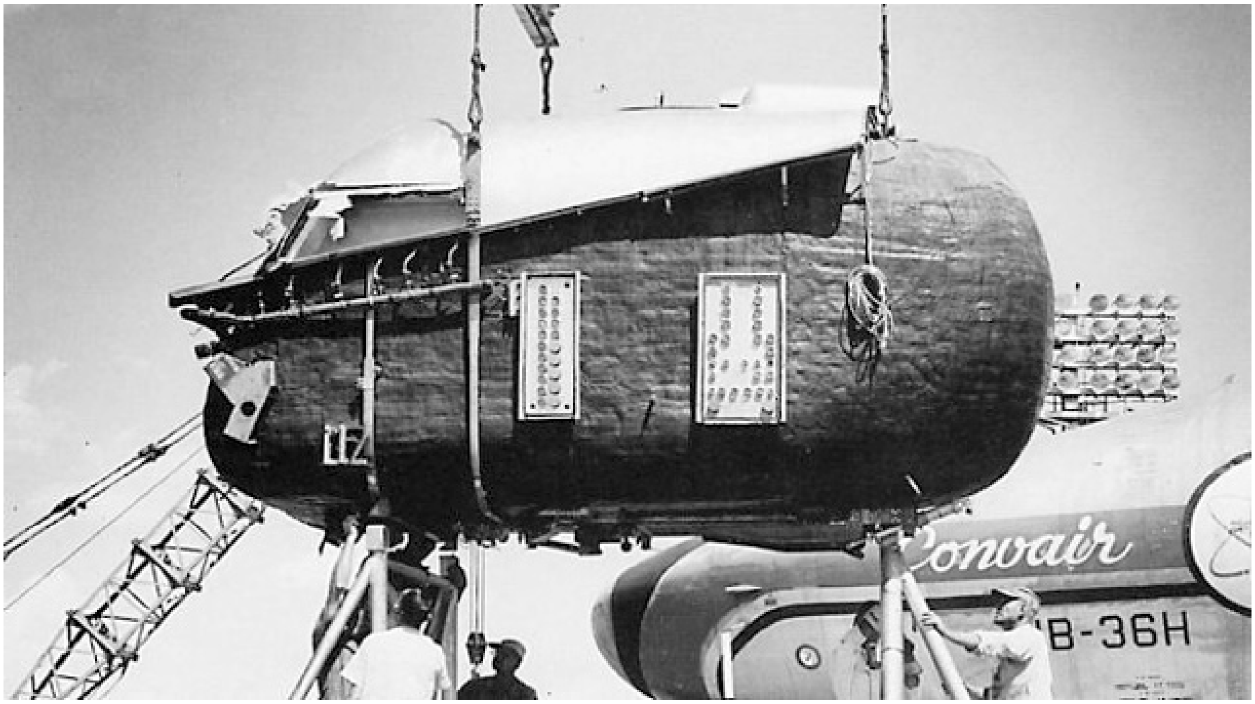



Figure 3. Convair NB-36H Shielded Crew Compartment

## 2.3 ML-1 Reactor Transportability Studies

The ML-1 nuclear power plant was a 3.3 MW thermal gas-cooled reactor that consisted of 61 pin-type fuel elements containing 49 kg of highly enriched uranium and used water as a moderator and nitrogen as a coolant. The ML-1 operated at the National Reactor Testing Station (later INL) from 1961-1965. In addition to operating the ML-1, tests were performed to determine the transportability of the ML-1 nuclear power plant (Aerojet-General Nucleonics 1960).

The ML-1 plant consisted of 1) the nuclear reactor package, 2) the power conversion package, 3) the control cab, and 4) the auxiliary package. The nuclear reactor package was 111 x 108 x 93 inches and weighed 30,000 lb. The power conversion package was 168 x 113 x 93 inches and also weighed 30,000 lb.

To assess transportability, full-scale mockups of the reactor and power conversion packages were fabricated that duplicated the overall dimensions, the weight, and center-of-gravity of the ML-1 packages. Mockups were not constructed of the control cab or of the auxiliary package, because the weights and sizes of these units permitted handling by conventional techniques. The mockups duplicated the skid-mounting concept and the shock mounts, consisting of silicone rubber cores bonded to aluminum supports, planned for the ML-1. The shock mounts, in conjunction with nylon rope tie-downs, were designed to attenuate shock loads encountered during transport and to reduce these loads to values less than the maximum allowable. Figure 4 shows the full-scale mockup of the truck-mounted ML-1 nuclear power plant.


Figure 4. Full-Scale Mockup of the ML-1 Nuclear Power Plant

The primary means of transporting the ML-1 was to be the U.S. Army M-172, or M-172-A-1, low-bed semitrailer. It was further specified that the control cab be transported by an M-35 2.5-ton cargo truck; and that auxiliary equipment be transported either on the M-35 or on M-55 5-ton trucks. Because mobility and rapid deployment were among the prime requisites of the ML-1, it was also capable of being transported by aircraft. U.S. Air Force C-124, C-130, and C-133 aircraft were the specified carriers. In the case of the C-124 and the C-130, three separate air lifts were required to transport the ML-1. (One aircraft carries the reactor; a second, the power conversion equipment; and a third, the seven-man crew, the control cab, and the power plant auxiliaries.) The C-133 has the capacity to transport the entire power plant, including its crew, control cab, and auxiliaries; in one flight. A third transport method specified for the ML-1 was by standard railroad flatcar. When positioned on a flatcar, the ML-1 must satisfy the clearance requirements of United States and European main lines.

Trailer transport tests were performed with the mockup packages near the Aerojet General Corporation plant at San Ramon, California, in September 1959. The U.S. Army supplied the M-172 trailer, M-52 tractor, and a 3-man crew for the tests.

The purposes of the tests were to determine that: 1) the ML-1 packages could be loaded by standard techniques, and 2) the experimental shock mounts were satisfactory both during loading and while in transit. The tests, augmented by time and motion studies, also provided data for the development of loading procedures.

The tests showed that the ML-1 power plant could be loaded in the field by conventional methods and transported by the M-172 trailer. The ML-1 could also be satisfactorily transported cross country by the M-172 trailer and M-52 tractor. When the reactor and power conversion packages were coupled and loaded on the M-172 tractor, the resulting tandem axle load exceeded the maximum permitted on most U.S. highways. The tests also showed that overseas military height restrictions could be met with the ML-1 loaded on the M-172 trailer. The height restriction was exceeded with the load on an M-172-A-1 trailer, but the rear wheels could be partially deflated, temporarily, to permit clearing overhead obstructions.

Aircraft loading tests using the C-124, C-130, and C-133 aircraft were conducted during the period September 15-23, 1959. Figure 5 shows the ML mockups tied down inside a C-133 aircraft. The results of the tests showed that the ML-1 package was able to be loaded aboard the C-124, C-130, and C-133 aircraft with equipment normally available in the field. In the case of the C-133, side clearances were less than the minimum specified for personnel passage. Also, the tie-down system was adequate to protect the ML-1 during aircraft emergency landings.

The railroad tests were conducted on the San Ramon spur line of the Southern Pacific Railroad Company, during the last two weeks of October 1959. Figure 6 shows the ML mockups tied down on a railroad flatcar. The tests were performed for two purposes: 1) to determine the effectiveness of the tie-down system for shock reduction under severe railroad switching and humping operations; and 2) to simulate an aircraft emergency landing and establish the effectiveness of the tie-downs during such a landing.

The railroad tests showed that when loaded and tied down on railroad flatcars, the ML-1 met all clearance limitations specified for both United States and European main lines. The tie-downs and shock mounts were found to isolate all shocks sufficiently to eliminate any danger of damage to the ML-1 during railroad switching and humping operations.

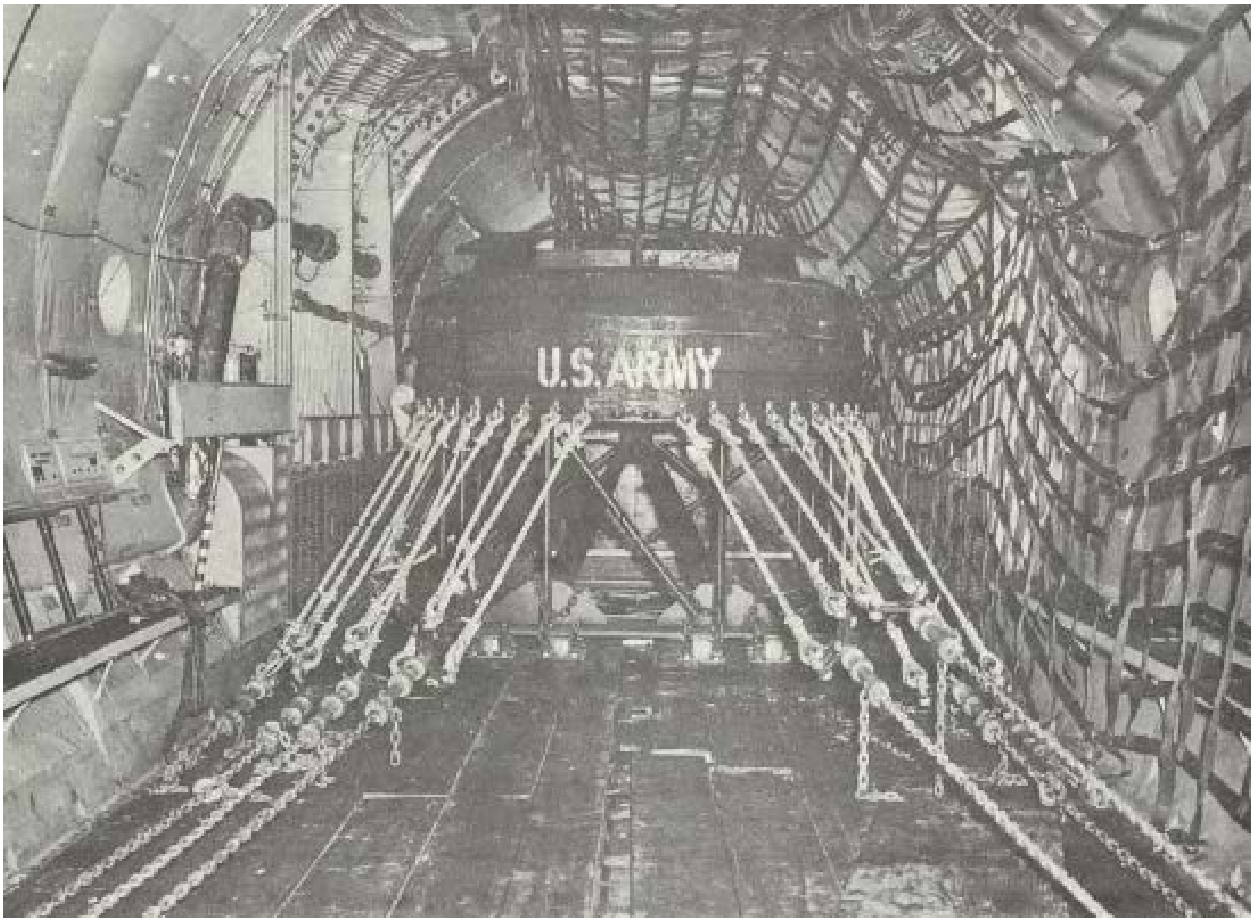



Figure 5. ML-1 Mockups Tied Down Inside a C-133

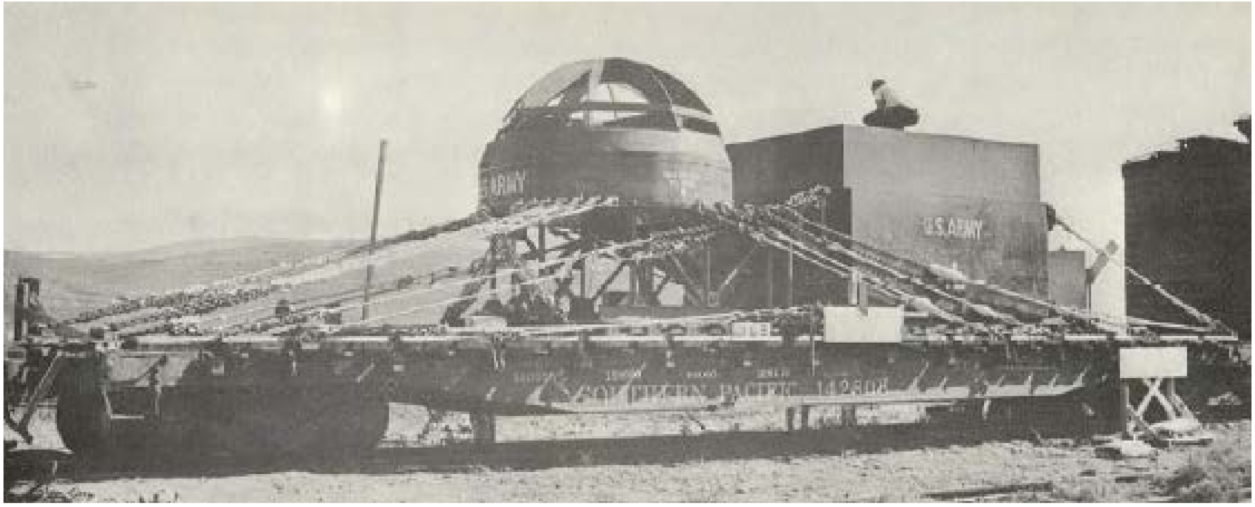



Figure 6. ML-1 Mockups Tied Down on a Railroad Flatcar

# 3.0 Microreactor Transportation Options

In contrast to large LWRs or small modular reactors, one of the unique attributes of microreactors is their ability to be transported. This section discusses microreactor transportation options, which include transport by highway, rail, barge or ship, and air. Included in this section are discussions of cargo containers and tie-downs.

There are four possible transportation scenarios that could be used to support a microreactor demonstration at the INL.

In the first scenario, the microreactor and its unirradiated fuel would be transported separately to the INL and assembled onsite for the demonstration. In this scenario, hazardous material regulations would not apply to shipping the unoperated reactor without fuel. However, the microreactor may require special permitting as an overdimension or overweight load. The unirradiated fuel, likely to be comprised of HALEU, would require application of schedules featured in Sections 4.1, 4.2, and 4.4 for transport. It is assumed that the HALEU is not contaminated with plutonium, so that application of the Type B package schedule in Section 4.3 is not necessary.

In the second scenario, the microreactor and its unirradiated fuel would be transported together to the INL for the demonstration. The microreactor and its unirradiated fuel would require application of schedules in Sections 4.1, 4.2, and 4.4. It is assumed that the HALEU is not contaminated with plutonium so that application of the Type B package schedule in Section 4.3 is not necessary.

In the third scenario, the microreactor and its irradiated fuel would be transported separately. The irradiated fuel would require the application of the schedules in Sections 4.1, 4.2, 4.3, and 4.4. After operations, the microreactor would be activated and would require the application of the schedules in Sections 4.1 and 4.4. It is possible that the activated microreactor may contain enough radioactive material to also require the application of the schedules in Section 4.3. It is also possible that the microreactor would be shipped intact or it could be segmented prior to shipping.

In the fourth scenario, the microreactor and its irradiated fuel would be transported together. The microreactor and its irradiated fuel would require the application of the schedules in Sections 4.1, 4.2, 4.3, and 4.4.

For the scenarios involving onsite transport at the INL, such as for onsite storage or demonstration at a second location on INL, DOE Order 460.1D allows for the preparation of a Transportation Safety Document to demonstrate equivalent safety for deviations from DOT hazardous materials transportation requirements. For onsite shipments of materials of national security interest, DOE Order 461.2 also allows the preparation of a Transportation Safety Document. For offsite shipments that do not meet DOT hazardous materials regulations, DOE Order 460.1D requires application to the U.S. Department of Transportation for a Special Permit. For offsite shipments of materials of national security interest, DOE Order 461.1C allows for the preparation of a Transportation Safety Risk Assessment documenting the risk the shipment poses to the health and safety of the worker, public, or environment.

For transport by air by military aircraft, the schedule in Section 4.5 would apply. For international transport by air, the schedule in Section 4.6 would apply.

## 3.1 Cargo Containers

One option for the transport of a microreactor and its components is to place the microreactor and its components in a cargo container. In addition, the ability of a microreactor and its components to fit in a cargo container is listed as an objective in the Project Pele Phase I Request for Solutions.

Cargo containers are transport equipment designed and constructed to facilitate the international and intermodal exchange of goods, and can be used for highway, rail, barge, and air transport. They are designed to be used repeatedly and to provide security during transport. Also, their fittings readily permit handling and transfer from one transport mode to another (TEA 2005).

International Standard ISO 688 (ISO 2020) contains the dimensions and ratings for cargo containers (see Table 1). The 8.5-foot-high by 8-foot-wide by 20-foot-long or 40-foot-long containers are commonly used cargo containers and have a gross weight limit 67,200 lb. The weight of the containers alone is generally less than 6,000 and 9,000 pounds for 20- and 40-foot containers, respectively.

Table 2 lists the minimum internal dimensions and door opening dimensions for ISO 688 cargo containers. The door openings of 8.5-foot-high containers are 90 inches wide and 89 inches high. Interior widths and heights are subject to slight variations but are always larger than the door openings. Items being designed for containerization should be no more than 85 inches wide and no more than 85 inches high. The interior lengths of 20- and 40-foot containers are at least 19-feet 3-inches and 39-feet 4-inches, respectively. However, consideration must also be given to restraining the item in the container.

Table 1. ISO 688 Cargo Container External Dimensions and Gross Weights

| Freight Container Designation | Length (mm) | Width (mm) | Height (mm) | Gross Weight (lb.) |
|---|---|---|---|---|
| 1EE | 13716 | 2438 | 2591 | 67200 |
| 1AA | 12192 | 2438 | 2591 | 67200 |
| 1BB | 9125 | 2438 | 2591 | 67200 |
| 1CC | 6058 | 2438 | 2591 | 67200 |
| Source: ISO (2020) | | | | |

Table 2. ISO 688 Cargo Container Minimum Internal Dimensions and Door Opening Dimensions

| Freight Container Designation | Minimum Internal Dimensions | | | Minimum Door Opening Dimensions | |
|---|---|---|---|---|---|
| | Height (mm) | Width (mm) | Length (mm) | Height (mm) | Width (mm) |
| 1EE | 2350 | 2330 | 13542 | 2261 | 2286 |
| 1AA | 2350 | 2330 | 11998 | 2261 | 2286 |
| 1BB | 2350 | 2330 | 8931 | 2261 | 2286 |
| 1CC | 2350 | 2330 | 5867 | 2261 | 2286 |
| Source: ISO (2020) | | | | | |

## 3.2 Tie-Downs

A microreactor and its components must have adequate lifting and tie-down provisions since these provisions are essential to efficient transport.

MIL-STD-209K (DoD 2005) contains a tie-down design limit load of 4.0 g in the longitudinal direction, 2.0 g in the vertical direction, and 1.5 g in the lateral direction. For rail transport, Rule 88 A.16c(3) in the Field Manual of the Association of American Railroads (AAR) Interchange Rules (AAR 2020) also contains a tie-down requirement of 7.5 g in the longitudinal direction, 2.0 g in the vertical direction, and 2.0 g in the lateral direction for SNF transportation casks shipped on flat or gondola railcars. NRC regulation 10 CFR 71.45 contains a tie-down requirement of 10 g in the longitudinal direction, 2.0 g in the vertical direction, and 5.0 g in the lateral direction, but this requirement only applies to a system of tie-down devices that is a structural part of the transportation package.

## 3.3 Highway

One option for the transport of a microreactor and its components is by highway. Highway transport of SNF occurs regularly in the U.S. and according to the NRC, over the period 1979 to 2007, 1285 SNF shipments accounting for 930,000 shipments-miles were made by highway (Garrett et al. 2010).

In the U.S., the federal maximum gross vehicle weight limit for trucks is 80,000 lb. The minimum trailer length is 48 ft. (states may set a longer length standard) and widths are limited to 102 in. There is no federal height standard, but states may set a maximum height. Figure 7 summarizes these standards. State laws and regulations set varying size and weight limits and permitting requirements for vehicles that exceed these limits and that operate on highways and bridges. For example, states' length standards vary between the minimum federal standard of 48 feet and 65 feet for a semitrailer. Vehicles that exceed these dimensions and weights are known as oversize or overdimension (see Figure 8) (GAO 2015).

49 CFR 385, Subpart E contains requirements for hazardous materials safety permits. A highway route controlled quantity truck shipment requires a hazardous materials safety permit [49 CFR 385.403(a)]. Operational requirements associated with this permit include a written route plan and a pre-trip Commercial Vehicle Safety Alliance (CVSA) Level VI inspection.

49 CFR 397, Subpart D contains requirements for the routing of Class 7 (radioactive) materials, including requirements for motor carriers and drivers (49 CFR 397.101) and requirements for state routing designations (49 CFR 397.103). 49 CFR 397.101(a) contains requirements for the routing of placarded shipments and 49 CFR 397.101(b) contains requirements for highway route controlled quantity shipments.

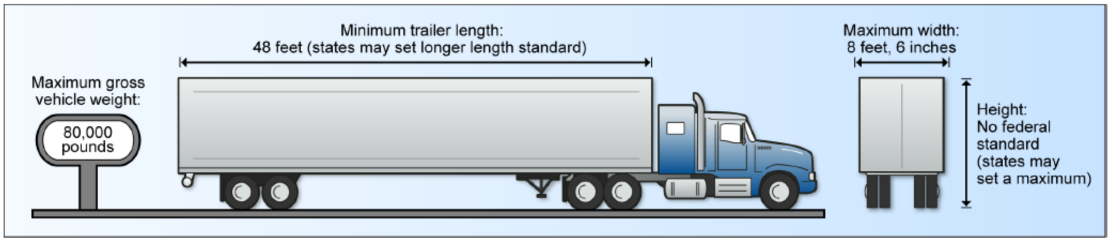



Figure 7. Federal Size and Weight Standards (GAO 2015)

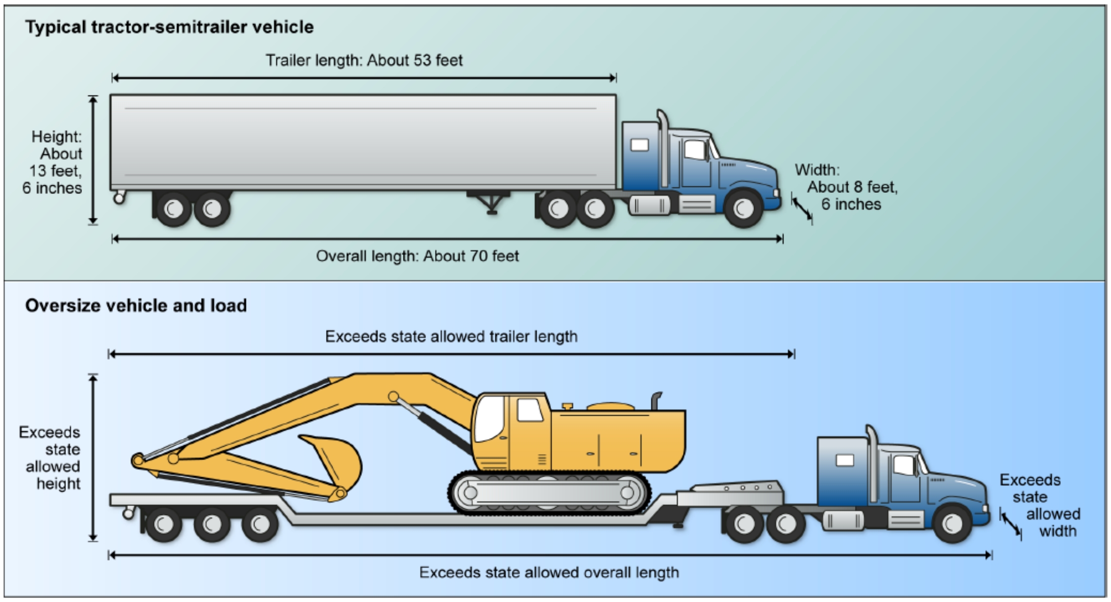



Figure 8. Typical and Oversize Vehicles and Loads (GAO 2015)

For oversize and overdimension vehicles, states issue and enforce permits, and practices vary by state. Table 3 summarizes the permitting practices for oversize and overweight vehicles. Vehicles that are extremely heavy, long, wide, or tall are known as “superloads” (see Table 4) and are typically subject to additional permitting requirements.

Table 3. Summary of Permit Processes for Oversize and Overweight Vehicles in the 50 States and District of Columbia

| Permit Processes | Description |
|---|---|
| Permit issuing agency | • 32 issue permits from Departments of Transportation.<br>• In other states, Departments of Motor Vehicles, Departments of Revenue, or others issue permits. |
| Permit system | • 45 offer online permit applications. |
| Automated routing system | • 23 offer automated truck routing. |
| Escort vehicles | • 44 may require escort vehicles above a certain height.<br>• 51 may require escort vehicles beyond a certain width. |
| Certification of escort drivers | • 38 do not require certification for escort drivers. |
| Source: GAO (2015) | |

Table 4. State Superload Width, Height, Length, and Weight Requirements for the 50 States and District of Columbia

| State | Superload Width Requirement | Superload Height Requirement | Superload Length Requirement | Superload Weight Requirement (lb.) |
|---|---|---|---|---|
| Alabama | 16 feet 0 inches | 16 feet 0 inches | 150 feet 0 inches | 250,000 |
| Alaska | 18 feet 0 inches | 18 feet 0 inches | 150 feet 0 inches | 250,000 |
| Arizona | 14 feet 0 inches | 16 feet 0 inches | 120 feet 0 inches | 250,000 |
| Arkansas | 18 feet 0 inches | 17 feet 0 inches | 100 feet 0 inches | 180,000 |
| California | 15 feet 0 inches | 17 feet 0 inches | 135 feet 0 inches | None specified |
| Colorado | 17 feet 0 inches | 16 feet 0 inches | 130 feet 0 inches | 500,000 |
| Connecticut | 16 feet 0 inches | 15 feet 4 inches | 150 feet 0 inches | 200,000 |
| Delaware | 15 feet 0 inches | 15 feet 0 inches | 120 feet 0 inches | 120,000 |
| District of Columbia | Varies | Varies | Varies | Varies |
| Florida | 16 feet 0 inches | 16 feet 0 inches | 150 feet 0 inches | 199,000 |
| Georgia | 16 feet 0 inches | 18 feet 0 inches | None specified | 150,000 |
| Hawaii | None specified | None specified | None specified | None specified |
| Idaho | 16 feet 0 inches | 16 feet 0 inches | 120 feet 0 inches | Varies |
| Illinois | 14 feet 6 inches | 14 feet 6 inches | 145 feet 0 inches | 120,000 |
| Indiana | 16 feet 0 inches | 15 feet 0 inches | 110 feet 0 inches | 120,000 |
| Iowa | 18 feet 0 inches | 18 feet 0 inches | 120 feet 0 inches | 156,000 |
| Kansas | None specified | None specified | None specified | 150,000 |
| Kentucky | 16 feet 0 inches | 15 feet 6 inches | 125 feet 0 inches | 250,000 |
| Louisiana | Varies | Varies | Varies | 232,000 |

| State | Superload Width Requirement | Superload Height Requirement | Superload Length Requirement | Superload Weight Requirement (lb.) |
|---|---|---|---|---|
| Maine | 16 feet 0 inches | 16 feet 0 inches | 125 feet 0 inches | 130,000 |
| Maryland | 16 feet 0 inches | 16 feet 0 inches | 100 feet 0 inches | 120,000 |
| Massachusetts | 14 feet 0 inches | Varies | 120 feet 0 inches | 130,000 |
| Michigan | 16 feet 0 inches | 15 feet 0 inches | 150 feet 0 inches | None specified |
| Minnesota | 16 feet 0 inches | 15 feet 6 inches | 150 feet 0 inches | 155,000 |
| Mississippi | 20 feet 0 inches | 17 feet 0 inches | 120 feet 0 inches | 190,000 |
| Missouri | 16 feet 0 inches | 16 feet 0 inches | 150 feet 0 inches | 160,000 |
| Montana | 18 feet 0 inches | 17 feet 0 inches | 150 feet 0 inches | None specified |
| Nebraska | 16 feet 0 inches | 16 feet 0 inches | 100 feet 0 inches | 160,000 |
| Nevada | 17 feet 0 inches | 18 feet 0 inches | 200 feet 0 inches | 500,000 |
| New Hampshire | 15 feet 0 inches | 13 feet 6 inches | 110 feet 0 inches | 149,999 |
| New Jersey | None specified | None specified | None specified | None specified |
| New Mexico | None specified | None specified | None specified | None specified |
| New York | 16 feet 0 inches | 16 feet 0 inches | 160 feet 0 inches | 199,999 |
| North Carolina | 15 feet 0 inches | None specified | None specified | 132,000 |
| North Dakota | 18 feet 0 inches | 18 feet 0 inches | 120 feet 0 inches | 150,000 |
| Ohio | 14 feet 0 inches | 14 feet 6 inches | None specified | 120,000 |
| Oklahoma | 16 feet 0 inches | 15 feet 0 inches | 110 feet 0 inches | 202,000 |
| Oregon | 16 feet 0 inches | 17 feet 0 inches | 150 feet 0 inches | None specified |
| Pennsylvania | 16 feet 0 inches | None specified | 160 feet 0 inches | 201,000 |
| Rhode Island | 14 feet 0 inches | 13 feet 6 inches | 90 feet 0 inches | 120,000 |
| South Carolina | 16 feet 0 inches | 16 feet 0 inches | None specified | 130,000 |
| South Dakota | None specified | None specified | None specified | None specified |
| Tennessee | 16 feet 0 inches | 15 feet 0 inches | 120 feet 0 inches | 100,000 |
| Texas | None specified | None specified | None specified | 254,300 |
| Utah | 17 feet 0 inches | 17 feet 6 inches | 175 feet 0 inches | 125,000 |
| Vermont | 15 feet 0 inches | 14 feet 0 inches | 100 feet 0 inches | 150,000 |
| Virginia | 15 feet 0 inches | 15 feet 0 inches | 150 feet 0 inches | 115,000 |
| Washington | 16 feet 0 inches | 16 feet 0 inches | 125 feet 0 inches | 200,000 |
| West Virginia | 16 feet 0 inches | None specified | None specified | 120,000 |
| Wisconsin | 16 feet 0 inches | None specified | 160 feet 0 inches | 100,000 |
| Wyoming | 18 feet 0 inches | 17 feet 0 inches | 120 feet 0 inches | 160,000 |
| Source: GAO (2015) | | | | |

## 3.4 Rail

A second option for the transport of a microreactor and its components is by rail. Rail transport of SNF has occurred in the U.S. and according to the NRC, over the period 1979 to 2007, 269 SNF shipments accounting for 74,000 shipments-miles were made by rail (Garrett et al. 2010).

In the U.S., typical 4-axle freight railcars have a gross rail limit of 286,000 lb. and a nominal capacity of about 110 tons. Figure 9 illustrates an example of a typical 4-axle freight railcar manufactured by Kasgro Rail Corporation. Freight railcars that are acceptable for unrestricted interchange must meet the dimensional requirements contained in AAR Standard S-2056, Plate B (see Figure 10) (AAR 2017a), which limit the width of the railcar and its cargo to 10 ft. 8 in. If the microreactor and its components were shipped in an intermodal container (i.e., an ISO container), then a specialized intermodal railcar could be used.

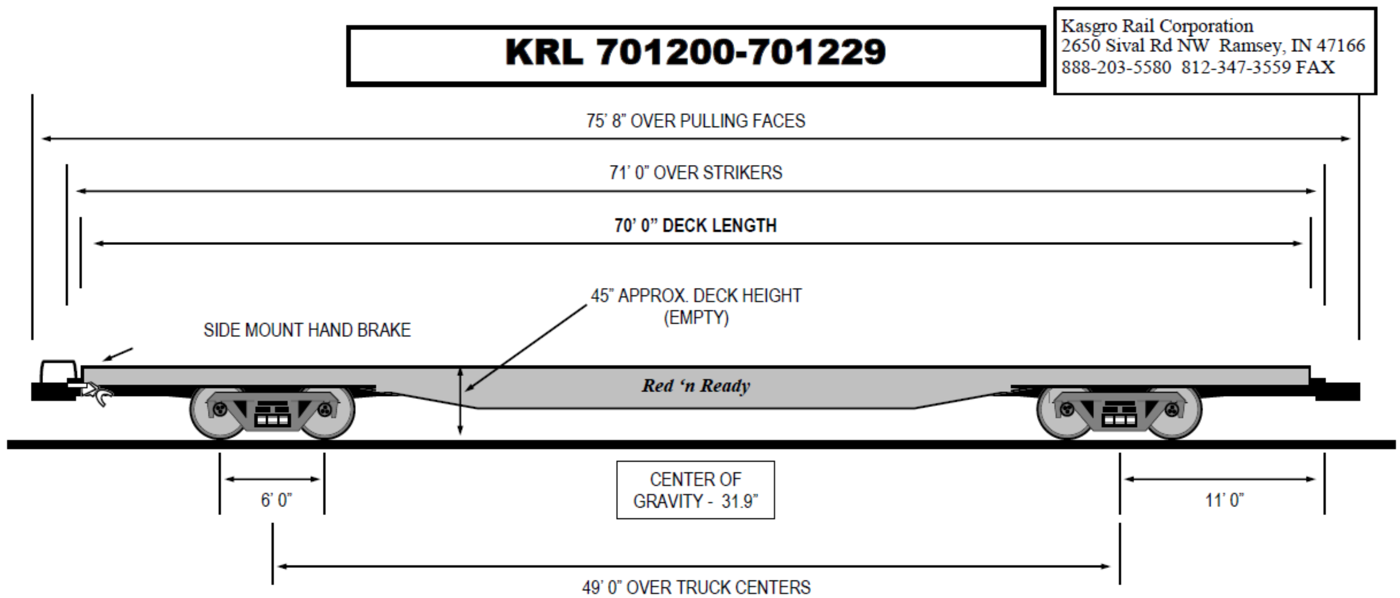
AAR Standard S-2043 (AAR 2017b) establishes performance guidelines for trains carrying SNF and/or high-level radioactive waste (HLRW).[1] This standard applies to transportation in cask-carrying railcars, buffer cars, and railcars containing security escorts (known as a rail escort vehicle or REV). While the use of railcars that comply with AAR Standard S-2043 is not a regulatory requirement imposed by the Federal Railroad Administration, it is the expectation by the railroads that SNF or HLRW shipped to a repository or interim storage site would be moved using railcars that comply with AAR Standard S-2043. The DoD and DOE have also signed settlement agreements with three of the Class 1 railroads (Union Pacific, Norfolk Southern, and the BNSF) that require the use of AAR approved equipment to take advantage of the rates in the settlement agreements.

U.S. Navy shipments of SNF are currently being made using cask-carrying railcars that meet AAR Standard S-2043 and the U.S. Navy is currently developing a REV that meets AAR Standard S-2043. The DOE is also developing the 12-axle Atlas railcar, a buffer railcar, and an 8-axle railcar to meet AAR Standard S-2043. Figure 11, Figure 12, and Figure 13 show the Atlas railcar, the buffer railcar, and the REV, respectively.

Cask-carrying railcars that meet AAR Standard S-2043 are tested with specific minimum and maximum loads. The minimum load that the Atlas railcar is being tested with is about 195,000 lb., substantially greater than a potential microreactor and its components.

AAR Circular OT-55 (AAR 2018) would define a train carrying a microreactor and its irradiated fuel as a key train. OT-55 contains recommended operating practices for key trains. For example, OT-55 limits the speed of key trains to 50 mph. OT-55 also prohibits the operation of a train carrying SNF or HLRW in a single bore double track tunnel at the same time as another train carrying loaded tank cars of flammable gas, flammable liquids or combustible liquids.

[1] In AAR Standard S-2043, SNF and HLRW are collectively referred to as high-level radioactive material.




| LENGTH OF LADING (ft) | LOAD LIMITS (lbs) | CAR NUMBERS | LOAD LIMITS (lbs) | LIGHT WEIGHTS (lbs) | MAXIMUM GROSS (lbs) | SPRING TRAVEL (in) | DECK LENGTH (ft-in) | DECK HEIGHT (ft-in) | JOURNAL SIZE BEARING TYPE |
|---|---|---|---|---|---|---|---|---|---|
| 2<br>6<br>10<br>14<br>18 & OVER | 187,500<br>195,650<br>204,550<br>214,290<br>LOAD LIMIT | **701200 - 701229** | 224,000 | 62,000 | 286,000 | 3 11/16" | 70' 0" | 3' 9" | 6 1/2" X 9" ROLLER |
| | | | | | | WHEEL DIAMETER (in) | DECK WIDTH (ft-in) | DRAFT GEAR | |
| | | | | | | 36" | 10' 0" | 15" EOC | |

**KRL 701200-701229**
**112 Ton - 70' Flat Deck Car**
**Drawing No. A19643, Rev. B**

*Figure courtesy of Kasgro Rail Corporation*

Figure 9. Typical 4-Axle Freight Railcar

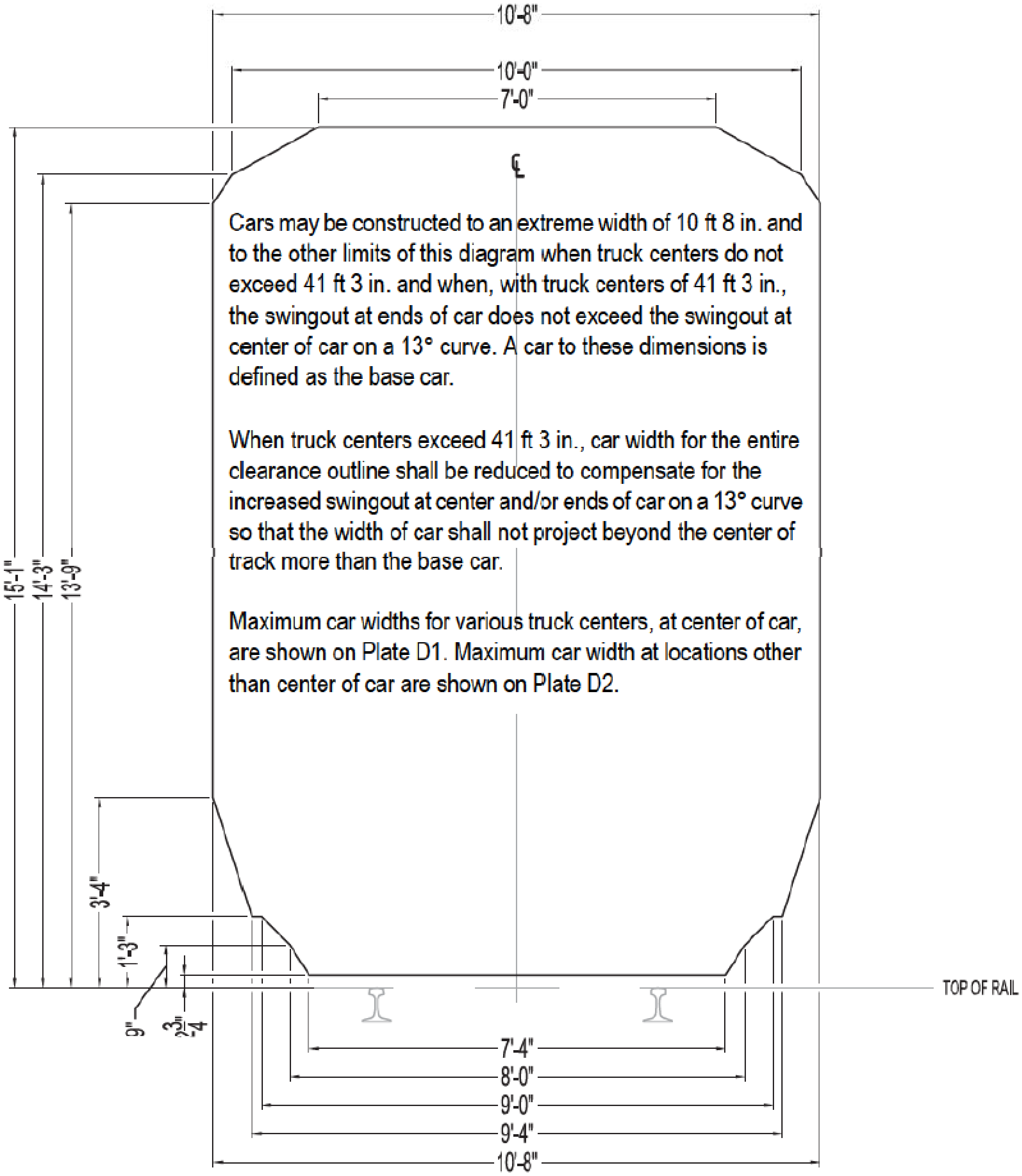



Figure 10. Plate B Equipment Diagram for Unrestricted Interchange Service


Figure 11. Atlas Railcar with Test Weights

Figure 12. Buffer Railcar


Figure 13. Rail Escort Vehicle

## 3.5 Barge or Ship

A third option for the transport of a microreactor and its components is by barge or ship. Transport of SNF by barge or ship has occurred in the U.S. For example, lightly irradiated fuel has been shipped from the Shoreham nuclear power plant site to the Limerick nuclear power plant site using barge. In addition, foreign research reactor SNF is routinely shipped to the U.S. by ship. Transport of large components such as reactor pressure vessels, steam generators, and pressurizers by barge to and from nuclear power plant sites is also routinely done in the U.S.

The U.S. Coast Guard (USCG) has published Navigation and Vessel Inspection Circular No. 2-87, Domestic Barge Transportation of Radioactive Materials/Nuclear Waste (USCG 1987). This circular references American National Standards Institute (ANSI) Standard N14.24-1985,[1] Highway Route Controlled Quantities of Radioactive Materials – Domestic Barge Transport, which identifies the organizations, equipment, operations, and documentation

[1] ANSI N14.24-1985 has been withdrawn because it has not been revised or reaffirmed in over 10 years.

involved in barge shipments of radioactive materials between U.S. ports by inland waterways and in coastwise and ocean service. The standard includes requirements pertaining to:

- Selection of the cask, barge, and towing vessel
- Certification and documentation
- Radiological and non-radiological operations
- Insurance
- Emergency planning
- Physical protection and security of the shipment.

It should be noted that a Coast Guard–issued Certificate of Inspection (COI) is required to move hazardous materials by barge including Class 7 Radioactive Material, and 90 percent of barges do not have a COI (Feldman et al. 2019).

## 3.6 Air

A fourth option for the transport of a microreactor and its components is by air. In addition, the Project Pele Phase I Request for Solutions specified that the mobile nuclear reactor developed under Project Pele be transportable in a single C-17 aircraft. Table 5 lists the design limits for equipment to be transportable in the C-17.

Table 5. C-17 Transportability Design Limits

| | |
|---|---|
| Height | 142 inches |
| Width | 196 inches<br>204 inches if the height is less than 136 inches |
| Length | 784 inches (cargo deck)<br>238 inches (ramp) |
| Maximum payload | 167,400 lb.<br>130,000 lb. (for a range of 3200 nautical miles) |
| Source: TEA (2005) | |

# 4.0 Transportation Regulations Relevant to Microreactor Transportation Options

The transportation regulations relevant to microreactor transportation options are presented in the form of schedules. The schedules presented in this section contain specific regulatory requirements for the transport of fissile material packages and Type B packages. Schedules for common provisions of transportation regulations, radioactive material package design and testing, military air shipment of fissile material and Type B packages, and Type C fissile material packages are also presented.

The schedules do not include the requirements for LSA shipments, SCO shipments, uranium hexafluoride shipments, import and export shipments, shipments by passenger aircraft, or special form shipments (i.e., shipments were assumed to be normal form) because these types of shipments are unlikely to be relevant to microreactor shipments. In addition, requirements for Industrial Packages (IP) (i.e., IP-1, IP-2, and IP-3) or empty packages are not listed because these packages are not likely to be relevant to microreactor shipments. The NRC physical protection requirements specified in 10 CFR Part 37 are also not listed because these requirements are unlikely to be relevant to microreactor shipments containing irradiated fuel. However, this assumption will be revaluated when more detailed information is available on the activation of the microreactor structural material for the case where the microreactor is defueled and the irradiated fuel and the microreactor are shipped separately.

The schedules are patterned after similar schedules presented in Cook et al. (1999) and IAEA (2015) and presented in a two-column format. The right column is the regulatory requirement and the left column is the citation of the regulation in which the requirement is found. In some cases, the regulatory requirement may be paraphrased from the actual regulations for simplicity and conciseness. In general, the schedules are organized into sections on materials, packaging/package, radiation, contamination, decontamination, mixed content, loading and segregation, marking and labeling, placarding, transport documents, storage and dispatch, carriage, and other provisions.

## 4.1 Common Provisions for Fissile Material and Radioactive Material in Type B Packages

This section contains the schedule for the common provisions for transporting fissile material and Type B packages. Typical identification numbers associated with fissile packages include UN 3327, UN 3328, UN 3329, and UN 3331. Typical identification numbers associated with Type B packages include UN 3328 and UN 3329.

| Citation | Requirement |
|---|---|
| | **1. MATERIALS** |
| 49 CFR 173.403 | (a) Radioactive material means any material containing radionuclides where both the activity concentration and the total activity in the consignment exceed the values specified in the table in 49 CFR 173.436 or values derived according to the |

| Citation | Requirement |
|---|---|
| | instructions in 49 CFR 173.433. Non-fixed contamination levels that exceed 0.4 Bq/cm 2 for beta and gamma emitters and low toxicity alpha emitters or 0.04 Bq/cm 2 for all other alpha emitters could also result in an object being Class 7 (radioactive) material. |
| 49 CFR 173.403 | (b) Type A quantity means a quantity of Class 7 (radioactive) material, the aggregate radioactivity which does not exceed $A_1$ for special form Class 7 (radioactive) material of $A_2$ for normal form Class 7 (radioactive) material, where $A_1$ and $A_2$ values are given in 49 CFR 173.435 or are determined in accordance with 49 CFR 173.433. |
| 49 CFR 173.403 | (c) Type B quantity means a quantity of material greater than a Type A quantity. |
| 49 CFR 173.403 | (d) $A_1$ means the maximum activity of special form Class 7 (radioactive) material permitted in a Type A package. This value is either listed in 49 CFR 173.435 or may be derived in accordance with the procedures prescribed in 49 CFR 173.433. |
| 49 CFR 173.403 | (e) $A_2$ means the maximum activity of Class 7 (radioactive) material, other than special form material, LSA material, and SCO, permitted in a Type A package. This value is either listed in 49 CFR 173.435 or may be derived in accordance with the procedures prescribed in 49 CFR 173.433. |
| 49 CFR 173.435<br>10 CFR 71, Appendix A<br>49 CFR 173.433(b)<br>10 CFR 71, Appendix A(II) | (f) $A_1$ and $A_2$ values for radionuclides are listed in 49 CFR 173.435 and 10 CFR 71 Appendix A, Table A-1. For unlisted radionuclides, the values in 49 CFR 173.433, Table 7 may be used. Alternatively, other values may be approved by the DOT, PHMSA, Associate Administrator for Hazardous Materials Safety, or NRC. |
| 49 CFR 173.403 | (g) Fissile material means plutonium-239, plutonium-241, uranium-233, uranium-235, or any combination of these radionuclides. Fissile material means the fissile nuclides themselves, not material containing fissile nuclides, but does not include: Unirradiated natural uranium or depleted uranium; and natural uranium or depleted uranium that has been irradiated in thermal reactors only. Certain exceptions for fissile materials are provided in 49 CFR 173.453. |
| 49 CFR 173.403 | (h) Normal form Class 7 (radioactive) material means Class 7 (radioactive) which has not been demonstrated to qualify as ‘‘special form Class 7 (radioactive) material.’’ |
| 49 CFR 173.403 | (i) Special form Class 7 (radioactive) material means either an indispersible solid radioactive material or a sealed capsule containing radioactive material which satisfies the following conditions:<br>(1) It is either a single solid piece or a sealed capsule containing radioactive material that can be opened only by destroying the capsule;<br>(2) The piece or capsule has at least one dimension not less than 5 mm (0.2 in); and<br>(3) It satisfies the test requirements of 49 CFR 173.469. |

| Citation | Requirement |
|---|---|
| 49 CFR 173.403 | (j) Natural thorium means thorium with the naturally occurring distribution of thorium isotopes (essentially 100 percent by weight of thorium-232). |
| 49 CFR 173.403 | (k) Unirradiated thorium means thorium containing not more than $10^{-7}$ grams uranium-233 per gram of thorium-232. |
| 49 CFR 173.403 | (l) Unirradiated uranium means uranium containing not more than $2 \times 10^3$ Bq of plutonium per gram of uranium-235, not more than $9 \times 10^6$ Bq of fission products per gram of uranium-235 and not more than $5 \times 10^{-3}$ g of uranium-236 per gram of uranium-235. |
| 49 CFR 173.403 | (m) Uranium—natural, depleted, or enriched means the following:<br>(1)(i) ''Natural uranium'' means uranium (which may be chemically separated) containing the naturally occurring distribution of uranium isotopes (approximately 99.28% uranium-238 and 0.72% uranium-235 by mass).<br>(ii) ''Depleted uranium'' means uranium containing a lesser mass percentage of uranium-235 than in natural uranium.<br>(iii) ''Enriched uranium'' means uranium containing a greater mass percentage of uranium-235 than 0.72%.<br>(2) For each of these definitions, a very small mass percentage of uranium-234 may be present. |
| 49 CFR 173.476 | (n) Each offeror of special form material must retain the safety analysis, including test documentation for at least two years after the latest shipment. An IAEA Competent Authority Certificate of Approval may be used to meet this requirement. |
| 49 CFR 173.461 | (o) Required material characteristics (e.g., special form) may be demonstrated using the methods prescribed in 49 CFR 173.461. |
| 49 CFR 173.403 | (p) Highway route controlled quantity means a quantity within a single package which exceeds:<br>(1) 3,000 times the $A_1$ value of the radionuclides as specified in 49 CFR 173.435 for special form Class 7 (radioactive) material;<br>(2) 3,000 times the $A_2$ value of the radionuclides as specified in 49 CFR 173.435 for normal form Class 7 (radioactive) material; or<br>(3) 1,000 TBq (27,000 Ci), whichever is least. |
| | **2. PACKAGING/PACKAGE** |
| 49 CFR 173.403 | (a) Packaging means, for Class 7 (radioactive) materials, the assembly of components necessary to ensure compliance with the packaging requirements of this subpart. It may consist of one or more receptacles, absorbent materials, spacing structures, thermal insulation, radiation shielding, service equipment for filling, emptying, venting and pressure relief, and devices for cooling or absorbing mechanical shocks. The conveyance, tie-down system, and auxiliary equipment may sometimes be designated as part of the packaging. |
| 49 CFR 173.403 | (b) ''Type A package'' means a packaging that, together with its radioactive contents limited to $A_1$ or $A_2$ as appropriate, meets the requirements of 49 CFR 173.410 and 49 CFR 173.412 and is designed to retain the integrity of containment and shielding required by this part under NCT as demonstrated by the tests set forth |

| Citation | Requirement |
| --- | --- |
| | in 49 CFR 173.465 or 49 CFR 173.466, as appropriate. A Type A package does not require Competent Authority approval. |
| 49 CFR 173.403 | (c) ‘‘Type B package’’ means a packaging designed to transport greater than an $A_1$ or $A_2$ quantity of radioactive material that, together with its radioactive contents, is designed to retain the integrity of containment and shielding required by this part when subjected to the NCT and hypothetical accident test conditions set forth in 10 CFR Part 71. |
| 49 CFR 173.403 | (d) ‘‘Type B(U) package’’ means a Type B packaging that, together with its radioactive contents, for international shipments requires unilateral approval only of the package design and of any stowage provisions that may be necessary for heat dissipation. |
| 49 CFR 173.403 | (e) ‘‘Type B(M) package’’ means a Type B packaging, together with its radioactive contents, that for international shipments requires multilateral approval of the package design and may require approval of the conditions of shipment. Type B(M) packages are those Type B package designs which have a maximum normal operating pressure of more than 700 kPa/cm$^2$ (100 lb/in$^2$) gauge or a relief device which would allow the release of Class 7 (radioactive) material to the environment under the HAC specified in 10 CFR Part 71. |
| 10 CFR 71.4 | (f) Type B package means a Type B packaging together with its radioactive contents. On approval, a Type B package design is designated by NRC as B(U) unless the package has a maximum normal operating pressure of more than 700 kPa (100 lb/in$^2$) gauge or a pressure relief device that would allow the release of radioactive material to the environment under the tests specified in 10 CFR 71.73 (hypothetical accident conditions), in which case it will receive a designation B(M). B(U) refers to the need for unilateral approval of international shipments; B(M) refers to the need for multilateral approval of international shipments. There is no distinction made in how packages with these designations may be used in domestic transportation. To determine their distinction for international transportation, see DOT regulations in 49 CFR Part 173. A Type B package approved before September 6, 1983, was designated only as Type B. Limitations on its use are specified in 10 CFR 71.19. |
| 49 CFR 173.403 | (g) ‘‘Fissile material package’’ means a packaging, together with its fissile material contents, which meets the requirements for fissile material packages described in 10 CFR 71, Subpart E. A fissile material package may be a Type AF package, a Type B(U)F package, or a Type B(M)F package. |
| 49 CFR 173.442 | (h) Thermal Limitations.<br>A package of Class 7 (radioactive) material must be designed, constructed, and loaded so that—<br>(a) The heat generated within the package by the radioactive contents will not, during conditions normally incident to transport, affect the integrity of the package; and<br>(b) The temperature of the accessible external surfaces of the loaded package will not, assuming still air in the shade at an ambient temperature of 38 °C (100 °F), exceed either—<br>(1) 50 °C (122 °F) in other than an exclusive use shipment; or<br>(2) 85 °C (185 °F) in an exclusive use shipment. |

| Citation | Requirement |
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| | **3. RADIATION** |
| 49 CFR 173.441 | (a) The maximum allowed radiation levels are shown in the table below. |
| 49 CFR 173.441 | (b) Packages exceeding a surface radiation level of 2 mSv/hr or a Transport Index of 10 may not be transported by aircraft except under special circumstances approved by DOT. |

| Type of Shipment | Radiation Level Limit | | | | |
|---|---|---|---|---|---|
| | Transport Index | Package Surface | Vehicle Outer Surface (including top and bottom)[1] | 2 m from Vehicle Outer Surface (excluding top and bottom)[2] | Normally Occupied Space |
| Non-Exclusive Use | 10 | 2 mSv/hr (200 mrem/hr) | – | – | – |
| Exclusive Use | – | 2 mSv/hr (200 mrem/hr)[3] | 2 mSv/hr (200 mrem/hr) | 0.1 mSv/hr (10 mrem/hr) | 0.02 mSv/hr 2 mrem/hr)[4] |

Notes:
(1) On flat-bed type of vehicles, on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load or enclosure if used, and on the vehicle underside.
(2) On a flat-bed type of vehicle, a point 2 m (6.6') from the vertical planes projected by the outer edges of the vehicle.
(3) 10 mSv/h (1000 mrem/h) if the following conditions are met: the shipment is made in a closed transport type of vehicle; the package is secured within the vehicle so that its position remains fixed during transportation; and there are no loading or unloading operations between the beginning and end of operation.
(4) This provision does not apply to private carriers if exposed personnel under their control wear radiation dosimetry devices as part of a radiation protection program.

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| | **4. CONTAMINATION** |
| 49 CFR 173.443(a) | (a) Non-fixed contamination on the external surfaces of packages must be kept as low as reasonably achievable and the wipe limits given below must not be exceeded (49 CFR 173.443, Table 9). Specific methods of performing the wipe are prescribed. |
| 49 CFR 173.443(b) | (b) For packages transported as exclusive use shipments by rail or public highway only, the non-fixed (removable) radioactive contamination on any package at any time during transport may not exceed ten times the levels prescribed above. The levels at the beginning of transport may not exceed the values given in the table below. |

| Contaminant | Maximum Permissible Limits | | |
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| | Bq/cm$^2$ | µCi/cm$^2$ | dpm/cm$^2$ |
| Beta and gamma emitters and low toxicity alpha emitters | 4 | $10^{-4}$ | 240 |
| All other alpha emitting radionuclides | 0.4 | $10^{-5}$ | 24 |

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| | **5. DECONTAMINATION** |
| | **Decontamination: General** |
| 49 CFR 173.443(c) | (a) Each transport vehicle which exceeds the contamination limits above must be surveyed with appropriate radiation detection instruments after each use. A vehicle may not be returned to service until the radiation dose rate at each accessible surface is 0.005 mSv/h (0.5 mrem/h) or less, and there is no significant non-fixed (removable) radioactive surface contamination. |
| 49 CFR 174.715<br>49 CFR 177.843 | (b) A closed transport vehicle used solely for exclusive use transportation by highway or rail of Class 7 material packages may be returned to service if:<br>(1) A survey of the interior surfaces of the empty vehicle shows that the radiation dose rate at any point does not exceed 0.1 mSv/h (10 mrem/h) at the surface or 0.02 mSv/h (2 mrem/h) at 1 meter (3.3 feet) from the surface;<br>(2) Each vehicle is stenciled with the words "For Radioactive Materials Use Only" in letters at least 76 millimeters (3 in) high in a conspicuous place on both sides of the exterior of the vehicle; and<br>(3) Each vehicle is kept closed except for loading or unloading. |
| | **Decontamination: Aircraft** |
| 49 CFR 175.705 | (a) A carrier shall take care to avoid possible inhalation, ingestion, or contact by any person with Class 7 (radioactive) materials that may have been released from their packagings.<br><br>(b) When contamination is present or suspected, the package containing a Class 7 material, any loose Class 7 material, associated packaging material, and any other materials that have been contaminated must be segregated as far as practicable from personnel contact until radiological advice or assistance is obtained from the DOE or appropriate state or local radiological authorities.<br><br>(c) An aircraft in which Class 7 (radioactive) material has been released must be taken out of service and may not be returned to service or routinely occupied until the aircraft is checked for radioactive substances and it is determined that any radioactive substances present do not meet the definition of radioactive material, as defined in 49 CFR 173.403 of this subchapter, and it is determined in accordance with 49 CFR 173.443 of this subchapter that the dose rate at every accessible surface must not exceed 0.005 mSv per hour (0.5 mrem per hour) and there is no significant removable surface contamination. |

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| | (d) Each aircraft used routinely for transporting Class 7 materials shall be periodically checked for radioactive contamination, and an aircraft must be taken out of service if contamination exceeds the level specified in 49 CFR 175.705(c). The frequency of these checks shall be related to the likelihood of contamination and the extent to which Class 7 materials are transported.<br><br>(e) In addition to the reporting requirements of (49 CFR 171.15 and 49 CFR 171.16) of this subchapter and 49 CFR 175.31 of this part, an aircraft operator shall notify the offeror at the earliest practicable moment following any incident in which there has been breakage, spillage, or suspected radioactive contamination involving Class 7 (radioactive) materials shipments. |
| | **6. MIXED CONTENTS** |
| 49 CFR 173.2<br>49 CFR 173.2a | (a) In general, radioactive materials that exceed the activity limits in 173.421 or 173.424, and that satisfy more than one hazard classification or division must be classified as Class 7 (radioactive materials). 49 CFR 173.2a provides several exceptions. |
| | **7. LOADING AND SEGREGATION** |
| | **Loading and Segregation: General** |
| 49 CFR 173.448(a) | (a) Each shipment of Class 7 materials must be secured to prevent shifting during normal transportation conditions. |
| 49 CFR 173.448(b) | (b) Except for the specific segregation requirements for rail, vessel, and highway (described later), or as otherwise required by the Competent Authority in the applicable certificate, a package of Class 7 materials may be carried among packaged general cargo without special stowage provisions, if:<br>(1) The heat output in watts does not exceed 0.1 times the minimum package dimension in centimeters; or<br>(2) The average surface heat flux of the package does not exceed 15 W/m$^2$ and the immediately surrounding cargo is not in sacks or bags or otherwise in a form that would seriously impede air circulation for heat removal. |
| 49 CFR 173.448(c) | (c) Packages or overpacks bearing labels prescribed in 49 CFR 172.403 (RADIOACTIVE WHITE-I, RADIOACTIVE YELLOW-II, or RADIOACTIVE YELLOW-III) may not be carried in compartments occupied by passengers, except in those compartments exclusively reserved for couriers accompanying those packages. |
| 49 CFR 173.448(d) | (d) Mixing of different kinds of packages that include fissile packages is authorized only in accordance with 49 CFR 173.459. |
| 49 CFR 173.448(g) | (e) If an overpack is used to consolidate individual packages or to enclose a single package of Class 7 (radioactive) materials, the package(s) must comply with the packaging, marking, and labeling requirements of this subchapter, and:<br>(1) The overpack must be labeled as prescribed in 49 CFR 172.403(h) of this subchapter;<br>(2) The overpack must be marked as prescribed in 49 CFR 172, Subpart D and 49 CFR 173.25(a); and<br>(3) The transport index of the overpack may not exceed 3.0 for passenger carrying aircraft shipments, or 10.0 for cargo aircraft shipments. |

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| 49 CFR 173.442 | (f) Packages must be loaded so that:<br>(a) The heat generated within the package by the radioactive contents will not, during conditions normally incident to transport, affect the integrity of the package; and<br>(b) The temperature of the accessible external surfaces of the loaded package will not, assuming still air in the shade at an ambient temperature of 38°C (100°F), exceed either:<br>(1) 50°C (122°F) in other than an exclusive use shipment; or<br>(2) 85°C (185°F) in an exclusive use shipment. |
| | **Loading and Segregation: Aircraft** |
| 49 CFR 175.702 | (a) Specific separation distance requirements for packages containing Class 7 (radioactive) materials in cargo aircraft are listed in 49 CFR 175.702 |
| | **Loading and Segregation: Plutonium by Aircraft** |
| 49 CFR 175.705 | (a) Shipments of plutonium which are subject to 10 CFR 71.88(a)(4) must comply with the following:<br>(a) Each package containing plutonium must be secured and restrained to prevent shifting under normal conditions.<br>(b) A package of plutonium having a gross mass less than 40 kg (88 pounds) and both its height and diameter less than 50 cm (19.7 inches)—<br>(1) May not be transported aboard an aircraft carrying other cargo required to bear a Division 1.1 label; and<br>(2) Must be stowed aboard the aircraft on the main deck or the lower cargo compartment in the aft-most location that is possible for cargo of its size and weight, and no other cargo may be stowed aft of packages containing plutonium.<br>(c) A package of plutonium exceeding the size and weight limitations in paragraph (b) of this section—<br>(1) May not be transported aboard an aircraft carrying other cargo required to bear any of the following labels: Class 1 (all Divisions), Class 2 (all Divisions), Class 3, Class 4 (all Divisions), Class 5 (all Divisions), or Class 8; and<br>(2) Must be securely cradled and tied down to the main deck of the aircraft in a manner that restrains the package against the following internal forces acting separately relative to the deck of the aircraft; Upward, 2g; Forward, 9g; Sideward, 1.5g; Downward, 4.5g. |
| | **Loading and Segregation: Railroad** |
| 49 CFR 174.700(b) | (a) The number of packages of Class 7 materials that may be transported by rail or stored at any single location is limited to a total transport index number of not more than 50. This provision does not apply to exclusive use shipments. |
| 49 CFR 174.700(c) | (b) Each package of Class 7 material bearing RADIOACTIVE YELLOW-II or RADIOACTIVE YELLOW-III labels may not be placed closer than 0.9 meter (3 feet) to an area (or dividing partition between areas) which may be continuously occupied by any passenger, rail employee, or shipment of one or more animals, nor closer than 4.5 meters (15 feet) to any package containing undeveloped film (if so marked). If more than one package of Class 7 materials is present, the distance must be computed from the table contained in 49 CFR 174.700(c). |
| 49 CFR 174.700(f) | (c) A person shall not remain unnecessarily in, on, or near a transport vehicle containing Class 7 materials. |

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| | **Loading and Segregation: Vessel** |
| 49 CFR 176.704(a) | (a) The sum of the transport indexes for all packages of radioactive materials on board a vessel may not exceed the limits in the table contained Table IIIA in 49 CFR 176.704. |
| 49 CFR 176.704(d) | (b) The sum of the criticality safety indices for all packages and overpacks of fissile Class 7 (radioactive) materials on board a vessel may not exceed the limits contained in Table IIIB in 49 CFR 176.704. |
| 49 CFR 176.83 | (c) General segregation requirements are given in Table 176.83(b). |
| 49 CFR 176.708 | (d) The segregation distances which apply to the stowage of packages of Class 7 materials on board a vessel are contained in Table IV in 49 CFR 176.708. |
| | **Loading and Segregation: Highway** |
| 49 CFR 177.842(a) | (a) The number of packages of Class 7 materials in any transport vehicle or storage location must be limited so that the total transport index number does not exceed 50. The total transport index of a group of packages and overpacks is determined by adding together the transport index number on the labels on the individual packages and overpacks in the group. This provision does not apply to exclusive use shipments. |
| 49 CFR 177.842(b) | (b) Packages of Class 7 material bearing RADIOACTIVE YELLOW-II or RADIOACTIVE YELLOW-III labels may not be placed in a transport vehicle, storage location or in any other place closer than the distances shown in the table contained in 49 CFR 177.842 to any area which may be continuously occupied by any passenger, employee, or animal, nor closer than the distances shown in the table contained in 49 CFR 177.842 to any package containing undeveloped film (if so marked), and must conform to the following conditions:<br>(1) If more than one of these packages is present, the distance must be computed from the following table on the basis of the total transport index number determined by adding together the transport index number on the labels on the individual packages and overpacks in the vehicle or store room.<br>(2) Where more than one group of packages is present in any single storage location, a single group may not have a total transport index greater than 50. Each group of packages must be handled and stowed not closer than 6 meters (20 feet) (measured edge to edge) to any other group. |
| 49 CFR 177.842(d) | (c) Packages must be so blocked and braced that they cannot change position during conditions normally incident to transportation. |
| 49 CFR 177.842(e) | (d) Persons should not remain unnecessarily in a vehicle containing Class 7 materials. |
| | **8. MARKING AND LABELING** |
| | **Marking and Labeling: General** |
| 49 CFR 172.310 | (a) Class 7 (radioactive) material package marking requirements are contained in 49 CFR 172.310. |

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| 49 CFR 173.471 | (b) Marking requirements for NRC packages are contained in 49 CFR 173.471(b) and (c). |
| 49 CFR 172.401(a) | (c) No package bearing a hazard label may be transported unless:<br>(1) The package contains a material that is a hazardous material, and<br>(2) The label represents a hazard of the hazardous material in the package. |
| 49 CFR 172.401(b) | (d) No person may offer for transportation and no carrier may transport a package bearing any marking or label which by its color, design, or shape could be confused with or conflict with a label prescribed in 49 CFR 172. |
| 49 CFR 172.402 | (e) Additional labeling requirements are contained in 49 CFR 172.402, including requirements for subsidiary hazard labels, display of hazard class on labels, cargo aircraft only label, and Class 7 (radioactive) material labels. |
| | **Marking and Labeling: Radioactive Labels** |
| 49 CFR 172.436 | (a) Description of RADIOACTIVE WHITE-I label |
| 49 CFR 172.438 | (b) Description of RADIOACTIVE YELLOW-II label |
| 49 CFR 172.440 | (c) Description of RADIOACTIVE YELLOW-III label |
| 49 CFR 172.441 | (d) Description of FISSILE label |
| 49 CFR 172.450 | (e) Description of EMPTY label |
| 49 CFR 172.403(b)<br>49 CFR 172.403(c) | (f) The proper label to affix to a package of Class 7 material is based on the radiation level at the surface of the package and the transport index. The label to be applied must be the highest category required for any of the two determining conditions for the package as shown in the table contained in 49 CFR 172.403. RADIOACTIVE WHITE-I is the lowest category and RADIOACTIVE YELLOW-III is the highest. For example, a package with a transport index of 0.8 and a maximum surface radiation level of 0.6 mSv/h (60 mrem/h) must bear a RADIOACTIVE YELLOW-III label. |
| 49 CFR 172.403(f)<br>49 CFR 172.406(a)<br>49 CFR 172.406(e)(5) | (g) Each package labeled with a RADIOACTIVE label must have two of these labels, affixed to opposite sides (not the bottom) of the package, and near the proper shipping name marking if package dimensions are adequate. For freight containers, one of each required label must be displayed on or near the closure. |
| 49 CFR 172.403(g) | (h) The following must be entered in the blank spaces on the RADIOACTIVE label:<br>(1) Contents: The name of the radionuclides as taken from the listing of radionuclides in 49 CFR 173.435. For mixtures of radionuclides, use the guidance in 49 CFR 173.433(g)<br>(2) Activity: Activity units must be expressed in appropriate SI units [e.g., Becquerels (Bq), Terabecquerels (TBq), etc.] or in both appropriate SI units and |

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| | appropriate customary units [Curies (Ci), milliCuries (mCi), microcuries (uCi), etc.]. Abbreviations are authorized.<br>(3) Transport index: If the measured transport index (TI) is not greater than 0.05, the value may be considered to be zero. |
| | **Marking and Labeling: Overpacks** |
| 49 CFR 172.403(h) | (a) If an overpack is used to consolidate individual packages of Class 7 materials, the packages must comply with the packaging, marking, and labeling requirements, and the overpack must be labeled RADIOACTIVE WHITE-I, RADIOACTIVE YELLOW-II, or RADIOACTIVE YELLOW-III, except as follows:<br>(1) The "contents" entry on the label may state "mixed" unless each inside package contains the same radionuclide(s);<br>(2) The "activity" entry on the label must be determined by adding together the number of Becquerels (curies) of the Class 7 materials packages contained therein;<br>(3) For a non-rigid overpack, the required label together with required package markings must be affixed to the overpack by means of a securely attached, durable tag. The TI must be determined by adding together the TIs of the Class 7 materials packages contained therein; and<br>(4) For a rigid overpack, the TI may be alternatively be determined by direct measurement taken by the person initially offering the packages contained within the overpack for shipment;<br>(5) The category of the Class 7 label is based on the table contained in 49 CFR 172.403 and the maximum radiation level on the surface of the overpack.<br>(6) For fissile material, the criticality safety index which must be entered on the overpack FISSILE label is the sum of the criticality safety indices of the individual packages in the overpack, as stated in the certificate of approval for the package design issued by the NRC or the U.S. Competent Authority. |
| 49 CFR 173.25(a)(2)<br>49 CFR 172.404(b) | (b) The overpack must be marked with the proper shipping name and identification number and labeled as required for each hazardous material contained therein unless markings and labels representative of each hazardous material in the overpack are visible. |
| 49 CFR 173.25(a)(3)<br>49 CFR 172.312 | (c) Each package subject to the orientation marking requirements must be marked with package orientation marking arrows on two opposite vertical sides of the overpack with the arrows pointing in the correct direction. |
| 49 CFR 172.25(a)(4) | (d) The overpack is marked with a statement indicating that the inside (inner) packages comply with the prescribed specifications when specification packagings are required, unless specification markings on the inside packages are visible. |
| 49 CFR 172.404 | (e) When authorized hazardous materials having different hazard classes are packed within the same packaging, or within the same outside container or overpack, the packaging, outside container or overpack must be labeled for each class of hazard contained therein. |
| 49 CFR 172.301(a) | (f) Each non-bulk package must be marked with the proper shipping name and identification number (preceded by "UN", "NA", or “ID” as appropriate) for the material as shown in the hazardous material table (49 CFR 172.101). |

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| 49 CFR 172.301(b) | (g) Each non-bulk packaging containing hazardous materials must be marked with its technical name in parentheses in association with the proper shipping name. |
| 49 CFR 172.301(d) | (h) Consignee's or consignor's name and address. Each non-bulk package must be marked with the name and address of the consignor or consignee. |
| 49 CFR 172.324 | (i) For each non-bulk package that contains a hazardous substance, the letters "RQ" must be marked on the package in association with the proper shipping name. |
| | **9. PLACARDING** |
| 49 CFR 172.556 | (a) Description of radioactive placard |
| 49 CFR 172.504(a) | (b) With few exceptions, each bulk packaging, freight container, unit load device, transport vehicle or rail car containing any RADIOACTIVE YELLOW-III labeled packages must be placarded on each side and each end with RADIOACTIVE placards. |
| 49 CFR 172.507<br>49 CFR 172.527<br>49 CFR 173.403 | (c) Each motor vehicle used to transport a package of highway route controlled quantity of radioactive material, must have the required RADIOACTIVE warning placard on a white square background surrounded by a black border. |
| 49 CFR 172.505(d) | (d) Radioactive materials possessing secondary hazards may exhibit subsidiary placards. This may be done even when not required elsewhere in the regulations. |
| 49 CFR 172.506 | (e) Each person offering radioactive material for transportation by highway must provide the motor carrier with the required placards for that shipment, prior to or at the time the material is offered for transport. However, if the carrier's motor vehicle is already appropriately placarded, no action is needed. |
| 49 CFR 172.508 | (f) Each person offering radioactive material for transportation by rail must affix the required placards to the rail car containing the material. Placards which are on motor vehicles, transport containers or portable tanks may be used in satisfying this requirement. |
| 49 CFR 172.516(a) | (g) Each placard on a motor vehicle or rail car must be readily visible from the direction it faces. However, placards are not required to be visible from the direction of another motor vehicle or rail car to which it is coupled. |
| 49 CFR 172.516(b) | (h) The required placarding of the front of a motor vehicle may be on the front of a truck tractor instead of, or in addition to, the placarding on the front of the cargo body to which the truck tractor is attached. |
| 49 CFR 172.516(c) | (i) Placards must be securely attached and be maintained readily readable and visible. |
| 49 CFR 172.516(d) | (j) Specifications for a placard holder are contained in 49 CFR 172, Appendix C. |

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| 49 CFR 172.516(e) | (k) A placard or placard holder may be hinged provided the required format, color, and legibility of the placard are maintained. |
| | **10. TRANSPORT DOCUMENTS** |
| | **Transport Documents: Shipping Papers** |
| 49 CFR 172.200 | Requirement for description of hazardous material. |
| 49 CFR 172.201 | Requirements for preparation and retention of shipping papers. |
| 49 CFR 172.202 | Requirements for description of hazardous material on shipping papers. |
| 49 CFR 172.203 | Requirements for additional descriptions on shipping papers. |
| 49 CFR 172.203(d) | Detailed requirements for description of radioactive material on shipping papers. |
| 49 CFR 172.204 | Requirements for shipper's certification. |
| | **Transport Documents: Emergency Response Information** |
| 49 CFR 172.600 | Applicability and general requirements |
| 49 CFR 172.602 | Requirements for emergency response information. |
| 49 CFR 172.604 | Requirements for emergency response phone number. |
| 49 CFR 172.606 | Each carrier who transports or accepts for transportation a hazardous material for which a shipping paper is required shall instruct the operator of a motor vehicle, train, aircraft, or vessel to contact the carrier (e.g., by telephone or mobile radio) in the event of an incident involving the hazardous material. |
| | **11. STORAGE AND DISPATCH** |
| | No specific provisions. |
| | **12. CARRIAGE** |
| 49 CFR 177.816(a) | (a) In addition to hazmat employee training, no carrier may transport a hazardous material by highway unless each hazmat employee who will operate a motor vehicle has received further training on the procedures necessary for the safe operation of that motor vehicle. |

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| 49 CFR 177.817(e) | (b) A driver of a motor vehicle containing hazardous material must ensure that the shipping papers are readily available and recognizable by authorities in the event of an accident or inspection. |
| 49 CFR 397.101(a) | (c) Except as provided in paragraph (b) of this section or in circumstances when there is only one practicable highway route available, considering operating necessity and safety, a carrier or any person operating a motor vehicle that contains a Class 7 (radioactive) material, as defined in 49 CFR 172.403, for which placarding is required under 49 CFR part 172 shall:<br>(1) Ensure that the motor vehicle is operated on routes that minimize radiological risk;<br>(2) Consider available information on accident rates, transit time, population density and activities, and the time of day and the day of week during which transportation will occur to determine the level of radiological risk; and<br>(3) Tell the driver which route to take and that the motor vehicle contains Class 7 (radioactive) materials. |
| 49 CFR 397.101(b) | (d) Except as otherwise permitted in this paragraph and in paragraph (f) of this section, a carrier or any person operating a motor vehicle containing a highway route controlled quantity of Class 7 (radioactive) materials, as defined in 49 CFR 173.403, shall operate the motor vehicle only over preferred routes.<br>(1) For purposes of this subpart, a preferred route is an Interstate System highway for which an alternative route is not designated by a state routing agency; a state-designated route selected by a state routing agency pursuant to 49 CFR 397.103; or both of the above.<br>(2) The motor carrier or the person operating a motor vehicle containing a highway route controlled quantity of Class 7 (radioactive) materials, as defined in 49 CFR 173.403, shall select routes to reduce time in transit over the preferred route segment of the trip. An Interstate System bypass or Interstate System beltway around a city, when available, shall be used in place of a preferred route through a city, unless a state routing agency has designated an alternative route. |
| 49 CFR 397.101(c) | (e) A motor vehicle may be operated over a route, other than a preferred route, only under the following conditions:<br>(1) The deviation from the preferred route is necessary to pick up or deliver a highway route controlled quantity of Class 7 (radioactive) materials, to make necessary rest, fuel or motor vehicle repair stops, or because emergency conditions make continued use of the preferred route unsafe or impossible;<br>(2) For pickup and delivery not over preferred routes, the route selected must be the shortest-distance route from the pickup location to the nearest preferred route entry location, and the shortest-distance route to the delivery location from the nearest preferred route exit location. Deviation from the shortest-distance pickup or delivery route is authorized if such deviation:<br>(i) Is based upon the criteria in paragraph (a) of this section to minimize the radiological risk; and<br>(ii) Does not exceed the shortest-distance pickup or delivery route by more than 25 miles and does not exceed 5 times the length of the shortest-distance pickup or delivery route.<br>(iii) Deviations from preferred routes, or pickup or delivery routes other than preferred routes, which are necessary for rest, fuel, or motor vehicle repair stops or because of emergency conditions, shall be made in accordance with the criteria in paragraph (a) of this section to minimize radiological risk, unless due to emergency conditions, time does not permit use of those criteria. |

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| 49 CFR 397.101(d) | (f) A carrier (or a designated agent) who operates a motor vehicle which contains a package of highway route controlled quantity of Class 7 (radioactive) materials, as defined in 49 CFR 173.403, shall prepare a written route plan and supply a copy before departure to the motor vehicle driver and a copy to the shipper (before departure for exclusive use shipments, as defined in 49 CFR 173.403, or within 15 working days following departure for all other shipments). Any variation between the route plan and routes actually used, and the reason for it, shall be reported in an amendment to the route plan delivered to the shipper as soon as practicable but within 30 days following the deviation. The route plan shall contain:<br>(1) A statement of the origin and destination points, a route selected in compliance with this section, all planned stops, and estimated departure and arrival times; and<br>(2) Telephone numbers which will access emergency assistance in each state to be entered. |
| 49 CFR 397.101(e) | (g) No person may transport a package of highway route controlled quantity of Class 7 (radioactive) materials on a public highway unless:<br>(1) The driver has received within the two preceding years, written training on:<br>(i) Requirements in 49 CFR Parts 172, 173, and 177 pertaining to the Class 7 (radioactive) materials transported;<br>(ii) The properties and hazards of the Class 7 (radioactive) materials being transported; and<br>(iii) Procedures to be followed in case of an accident or other emergency.<br>(2) The driver has in his or her immediate possession a certificate of training as evidence of training required by this section, and a copy is placed in his or her qualification file (see 49 CFR 391.51), showing:<br>(i) The driver's name and operator's license number;<br>(ii) The dates training was provided;<br>(iii) The name and address of the person providing the training;<br>(iv) That the driver has been trained in the hazards and characteristics of highway route controlled quantity of Class 7 (radioactive) materials; and<br>(v) A statement by the person providing the training that information on the certificate is accurate.<br>(3) The driver has in his or her immediate possession the route plan required by paragraph (d) of this section and operates the motor vehicle in accordance with the route plan. |
| 49 CFR 397.101(f) | (h) A person may transport irradiated reactor fuel only in compliance with a plan if required under 49 CFR 173.22(c) that will ensure the physical security of the material. Variation for security purposes from the requirements of this section is permitted so far as necessary to meet the requirements imposed under such a plan, or otherwise imposed by the NRC in 10 CFR Part 73. |
| 49 CFR 107.601-107.620 | (i) There are also registration requirements associated with highway route controlled shipments. |
| | **13. OTHER PROVISIONS** |
| | **Training** |

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| 49 CFR 172.700-172.704 | 49 CFR 172.700-172.704 contain training requirements for hazmat employees. |
| | **Safety and Security Plans** |
| 49 CFR 172.800-172.822 | 49 CFR 172.800-172.822 contain requirements for safety and security plans. |
| 49 CFR 172.820 | 49 CFR 172.820 contains additional planning requirements for transportation by rail. These requirements are applicable to a highway route controlled quantity of Class 7 (radioactive) material and include a requirement to analyze the safety and security risks for rail transportation routes. Each calendar year, the safety and security risks present must be analyzed for the route and railroad facilities along the route. For purposes of this section, railroad facilities are railroad property including, but not limited to, classification and switching yards, storage facilities, and non-private sidings. The route analysis must be in writing and include the factors contained in 49 CFR 172, Appendix D. In performing the analysis, the rail carrier must seek relevant information from state, local, and tribal officials, as appropriate, regarding security risks to high-consequence targets along or in proximity to the route(s) utilized. The rail carrier must identify practicable alternative routes and analyze these routes if they exist. The written alternative route analysis must also consider: (i) safety and security risks presented by use of the alternative route(s); (ii) comparison of the safety and security risks of the alternative(s) to the primary rail transportation route, including the risk of a catastrophic release from a shipment traveling along each route; (iii) any remediation or mitigation measures implemented on the primary or alternative route(s); and (iv) potential economic effects of using the alternative route(s), including but not limited to the economics of the commodity, route, and customer relationship. In performing the analysis, the rail carrier should seek relevant information from state, local, and tribal officials, as appropriate, regarding security risks to high-consequence targets along or in proximity to the alternative routes. If a rail carrier determines that it is not appropriate to seek such relevant information, then it must explain its reasoning for that determination in its analysis. |
| 49 CFR 172, Appendix D | 49 CFR 172, Appendix D contains rail risk analysis factors to be used by rail carriers in determining these routes. |
| 49 CFR 172.822 | 49 CFR 172.822 limits actions by states, local governments, and Tribes to prohibit use of a rail line for transportation of hazardous materials. |
| | **Hazardous Materials Safety Permits** |
| 49 CFR 385.401-385.423 | 49 CFR 385.401-385.423 contains requirements for hazardous materials safety permits. |
| 49 CFR 385.403(a) | A highway route controlled quantity truck shipment requires a hazardous materials safety permit. Operational requirements associated with this permit include a written route plan and a pre-trip CVSA Level VI inspection. |
| | **Licensing** |

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| 10 CFR 30.41(a) | (a) Generally, radioactive material may only be transferred to those authorized to possess it and such authorization (or exemption) must be confirmed before transfer. |
| 10 CFR 30.41(b) | Specifically, byproduct material may only be transferred by NRC (or Agreement State) licensees to:<br>(1) The DOE;<br>(2) The agency in an Agreement State which regulates radioactive material;<br>(3) Anyone exempt for the licensing requirements of the AEA or the Agreement State;<br>(4) Any person authorized to receive such byproduct material under the terms of a specific or general license issued by the NRC or Agreement State.<br>(5) A person abroad in accordance with an NRC general export license;<br>(6) Anyone else specifically authorized by the NRC in writing. |
| 10 CFR 30.41(c), 30.41(d) | The licensee transferring the radioactive material must verify that the transferee's license authorizes the receipt of the type, form, and quantity of the byproduct material transferred. Several methods are allowed, the simplest is to have and read a current copy of the transferee's license. |
| | **Quality Assurance** |
| 49 CFR 173.474 | Prior to the first use of any packaging for the shipment of Class 7 material, the offeror must determine that:<br>(1) The packaging meets the quality of design and construction requirements as specified; and<br>(2) The effectiveness of the shielding, containment and, when required, the heat transfer characteristics of the package, are within the limits specified for the package design. |
| | Before each shipment of any radioactive materials package the offeror must ensure that: |
| 49 CFR 173.475(a) | The packaging is proper for the contents to be shipped; |
| 49 CFR 173.475(b) | The packaging is in unimpaired physical condition, except for superficial marks; |
| 49 CFR 173.475(c) | Each closure device is properly installed, secured and free of defects; |
| 49 CFR 173.475(d) | For fissile material, each moderator and neutron absorber, if required to be present is present and in proper condition; |
| 49 CFR 173.475(e) | Each special instruction for filling, closing and preparation has been followed; |
| 49 CFR 173.475(f) | Each closure, valve or other opening is properly closed and sealed; |
| 49 CFR 173.475(g) | Each packaging containing liquid in excess of an $A_2$ quantity and intended for air shipment has been tested to show that it will not leak under an ambient atmospheric pressure of not more than 25 kPa absolute. |

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| 49 CFR 173.475(h) | The internal pressure of the containment system will not exceed the design pressure during transportation. |
| 49 CFR 173.475(i) | External radiation and contamination levels are within the allowable limits specified. |
| 10 CFR 71.101-71.137 | Each licensee involved with designing, purchasing, fabricating, handling, shipping, storing, cleaning, assembling, inspecting, operating, maintaining, repairing or modifying an NRC approved packaging must establish, maintain and execute a QA program meeting the requirements described in 10 CFR 71 Subpart H. |
| | **Advance Notification** |
| 10 CFR 71.97 | 10 CFR 71.97 contains requirements for advance notification of shipments of irradiated reactor fuel and nuclear waste. |
| | **Physical Protection** |
| 10 CFR 73.37 | 10 CFR 73.37 contains the requirements for physical protection of irradiated reactor fuel in transit. This applies to shipments of greater than 100 grams of irradiated reactor fuel with a dose rate in excess of 1 Gy (100 rad) per hour at a distance of 1 meter from any accessible surface without intervening shielding. See also *Physical Protection of Shipments of Irradiated Nuclear Fuel*, NUREG-0561, Revision 2 (2013). |
| 10 CFR 73.35 | 10 CFR 73.35 contains the requirements for physical protection of irradiated reactor fuel in transit. This applies to shipments of less than 100 grams of irradiated reactor fuel with a dose rate in excess of 1 Gy (100 rad) per hour at a distance of 1 meter from any accessible surface without intervening shielding. |
| 10 CFR 73.20, 73.25, 73.26, and 73.27 | If the dose rate is less than 1 Gy (100 rad) per hour at a distance of 1 meter from any accessible surface without intervening shielding and the mass of U-233, U-235, and plutonium exceeds a formula quantity (see definition in 10 CFR 73.2) is exceeded, then the requirements of 10 CFR 73.20, 73.25, 73.26, and 73.27 apply. |
| 10 CFR 73.67 | Lesser physical protection requirements apply to special nuclear material of moderate strategic significance (Category II, see definition in 10 CFR 73.2) and of low strategic significance (Category III, see definition in 10 CFR 73.2). |
| 10 CFR 73.72 | Contains requirements for advance notice of shipment of formula quantities of strategic special nuclear material, special nuclear material of moderate strategic significance, or irradiated reactor fuel. |
| 33 CFR 6 | Contains USCG requirements for the protection and security of vessels, harbors, and waterfront facilities. |
| 33 CFR 165 | 33 CFR 165 allows the USCG to establish RNAs and Limited Access Areas. RNAs are water areas within a defined boundary for which regulations for vessels navigating within the area have been established. RNAs usually prescribe what type or size of vessels may enter an area or in what manner they must navigate. Limited access areas consist of safety zones, security zones, and restricted waterfront areas. The USCG has established safety and/or security zones at many nuclear power plants. |

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| 33 CFR 101, 103-106 | 33 CFR Parts 101 and 103-106 also contain detailed maritime security requirements. |

## 4.2 Fissile Material Packages

This section contains the schedule for transporting fissile material packages.

| Citation | Requirement |
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| | **1. MATERIALS** |
| 49 CFR 173.401<br>10 CFR 71.4 | (a) Fissile material means plutonium-239, plutonium-241, uranium-233, uranium-235, or any combination of these radionuclides. Fissile material means the fissile nuclides themselves, not material containing fissile nuclides, but does not include: Unirradiated natural uranium or depleted uranium; and natural uranium or depleted uranium that has been irradiated in thermal reactors only. Certain exceptions for fissile materials are provided in 49 CFR 173.453 and 10 CFR 71.15 |
| 49 CFR 173.453<br>10 CFR 71.15 | (b) Fissile material exceptions. This section lists 6 exceptions for small amounts (< 15 g), low concentrations, or low enrichments of fissile material. |
| | **2. PACKAGING/PACKAGE** |
| 49 CFR 173.403<br>10 CFR 71.4 | (a) ‘‘Fissile material package’’ means a packaging, together with its fissile material contents, which meets the requirements for fissile material packages described in subpart E of 10 CFR 71. A fissile material package may be a Type AF package, a Type B(U)F package, or a Type B(M)F package. |
| 49 CFR 173.403<br>10 CFR 71.4 | (b) Criticality Safety Index (CSI) means a number (rounded up to the next tenth) which is used to provide control over the accumulation of packages, overpacks or freight containers containing fissile material. The CSI for a package containing fissile material is determined in accordance with the instructions provided in 10 CFR 71.22, 71.23, and 71.59. The CSI for an overpack, freight container, consignment or conveyance containing fissile material packages is the arithmetic sum of the CSIs of all the fissile material packages contained within the overpack, freight container, consignment or conveyance. |
| 49 CFR 173.403 | (c) Transport index (TI) means the dimensionless number (rounded up to the next tenth) placed on the label of a package, to designate the degree of control to be exercised by the carrier during transportation. The TI is determined by multiplying the maximum radiation level in millisieverts (mSv) per hour at 1 m (3.3 ft) from the external surface of the package by 100 (equivalent to the maximum radiation level in millirem per hour at 1 m (3.3 ft)). |
| 49 CFR 173.417 | (d) Authorized fissile materials packages.<br>(a) Except as provided in 49 CFR 173.453, fissile materials containing not more than $A_1$ or $A_2$ as appropriate, must be packaged in one of the following |

| Citation | Requirement |
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| | packagings:<br>(1)(i) Any packaging listed in 49 CFR 173.415, limited to the Class 7 (radioactive) materials specified in 10 CFR 71, subpart C;<br>(ii) Any Type AF, Type B(U)F, or Type B(M)F packaging that meets the applicable standards for fissile material packages in 10 CFR 71; or<br><br>(b) Fissile Class 7 (radioactive) materials with radioactive content exceeding $A_1$ or $A_2$ must be packaged in one of the following packagings:<br>(1) Type B(U), or Type B(M) packaging that meets the standards for packaging of fissile materials in 10 CFR 71, and is approved by the NRC and used in accordance with 49 CFR 173.471;<br><br>(c) A package approved by the NRC under a special package authorization granted in accordance with 10 CFR 71.41(d) provided it is offered only for domestic transportation in accordance with the requirements in 49 CFR 173.471(b) and (c). |
| 49 CFR 173.467 | (e) Tests for demonstrating the ability of Type B and fissile materials packagings to withstand accident conditions in transportation.<br>Each Type B packaging or packaging for fissile material must meet the test requirements prescribed in 10 CFR Part 71 for ability to withstand accident conditions in transportation. |
| 49 CFR 173.471 | (f) Requirements for U.S. Nuclear Regulatory Commission approved packages.<br>In addition to the applicable requirements of the NRC and other requirements of this subchapter, any offeror of a Type B(U), Type B(M), or fissile material package that has been approved by the NRC in accordance with 10 CFR Part 71 must also comply with the following requirements:<br>(a) The offeror shall be registered with the USNRC as a party to the packaging approval, and make the shipment in compliance with the terms of the packaging approval;<br>(b) The outside of each package must be durably and legibly marked with the package identification marking indicated in the USNRC packaging approval;<br>(c) Each shipping paper related to the shipment of the package must bear the package identification marking indicated in the USNRC packaging approval. |
| 10 CFR 71.17 | (g) For a Type B or fissile material package, the design of which was approved by NRC before April 1, 1996, the general license is subject to the additional restrictions of 10 CFR 71.19. |
| 10 CFR 71.19 | (h) 10 CFR 71.19 lists the conditions under which a previously approved Type B(U), Type B(M) or fissile material package without and without the "-85" designation may be used. |
| 10 CFR 71.22 | (i) 10 CFR 71.22 lists the conditions under which a general license is issued to transport fissile material. The fissile material need not be contained in a package which meets the standards in 10 CFR 71, Subpart E and F; however, the material must be contained in a Type A package. The Type A package must also meet the DOT requirements of 49 CFR 173.417(a). |
| 10 CFR 71.35(b) and (c) | (j) (b) For a fissile material package, the allowable number of packages that may be transported in the same vehicle in accordance with 10 CFR 71.59; and (c) For a fissile material shipment, any proposed special controls and precautions for |

| Citation | Requirement |
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| | transport, loading, unloading, and handling and any proposed special controls in case of an accident or delay. |
| | **3. MAXIMUM RADIATION LEVELS** |
| | See Common Provisions. |
| | **4. CONTAMINATION** |
| | See Common Provisions. |
| | **5. DECONTAMINATION** |
| | See Common Provisions. |
| | **6. MIXED CONTENTS** |
| | See Common Provisions. |
| | **7. LOADING AND SEGREGATION** |
| | (a) See Common Provisions. |
| | **Loading and Segregation: General** |
| 49 CFR 173.459 | (b) Mixing of fissile material packages with non-fissile or fissile-excepted material packages.<br>Mixing of fissile material packages with other types of Class 7 (radioactive) materials in any conveyance or storage location is authorized only if the TI of any single package does not exceed 10, the CSI of any single package does not exceed 50, and the provisions of 49 CFR 173.441 and 49 CFR 173.457 are satisfied. |
| 49 CFR 173.457 | (c) Transportation of fissile material packages—specific requirements.<br>(a) Packages containing fissile radioactive material which are not excepted under 49 CFR.453 must be assigned by the offeror, in accordance with their definitions in 49 CFR 173.403, a CSI and a TI.<br>(b) Fissile material packages and conveyances transporting fissile material packages must satisfy the radiation level restrictions of 49 CFR 173.441.<br>(c) Except for consignments under exclusive use, the CSI of any package or overpack may not exceed 50. A fissile material package with CSI greater than 50 must be transported by exclusive use.<br>(d) For non-exclusive use shipments of fissile material packages, except on vessels, the total sum of CSI's in a freight container or on a conveyance may not exceed 50.<br>(e) For exclusive use shipments of fissile material packages, except on vessels, the total sum of CSI's in a freight container or on a conveyance may not exceed 100.<br>(f) Exclusive use shipments of fissile material packages must satisfy the radiation level and administrative requirements of 49 CFR 173.441(b).<br>(g) The number of packages, overpacks and freight containers containing fissile material stored in transit in any one storage area must be so limited that the total sum of the CSI's in any group of packages, overpacks or freight containers does |

| Citation | Requirement |
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| | not exceed 50. Groups of packages shall be stored so as to maintain a spacing of a least 6 m (20 ft) between the closest surfaces of any two groups.<br>(h) Provisions for shipment by vessel of Class 7 (radioactive) material packages, including fissile material packages by vessel are described in 49 CFR 176.700-176.720. |
| | **Loading and Segregation: Railroad** |
| 49 CFR 174.700(b) | (a) The number of packages of Class 7 (radioactive) materials that may be transported by rail car or stored at any single location is limited to a total TI and a total CSI (as defined in 49 CFR 173.403) of not more than 50 each. This provision does not apply to exclusive use shipments as described in 49 CFR 173.403, 173.427, 173.441, and 173.457. |
| 49 CFR 174.700(d) | (b) Each shipment of fissile material packages must conform to requirements of 49 CFR 173.457 and 173.459. |
| | **Loading and Segregation: Highway** |
| 49 CFR 177.842(f) | (a) The number of packages of fissile Class 7 (radioactive) material in any non-exclusive use transport vehicle must be limited so that the sum of the CSIs does not exceed 50. In loading and storage areas, fissile material packages must be grouped so that the sum of CSIs in any one group is not greater than 50; there may be more than one group of fissile material packages in a loading or storage area, so long as each group is at least 6 m (20 feet) away from all other such groups. All pertinent requirements of 49 CFR 173.457 and 173.459 apply. |
| 49 CFR 177.842(g) | (b) The sum of CSIs for packages containing fissile material may not exceed 100 in an exclusive use vehicle. |
| | **Loading and Segregation: Aircraft** |
| 49 CFR 175.700 (a) | (a) A vented Type B(M) package or liquid pyrophoric Class 7 (radioactive) material may not be carried aboard any aircraft. |
| 49 CFR 175.700 (b) | (b) Limits for TI and CSI. A person may carry the following Class 7 (radioactive) materials aboard an aircraft only when—<br>(2) On a cargo aircraft—<br>(i) Each single package on the aircraft has a TI no greater than 10.0.<br>(ii) The combined TI of all the packages on the aircraft is no greater than 200, and the combined criticality index of all the packages on the aircraft is no greater than—<br>(A) 50 on a non-exclusive use cargo aircraft, or<br>(B) 100 on an aircraft assigned for the exclusive use of the shipper [offeror] for the specific shipment of fissile Class 7 material. Instructions for the exclusive use must be developed by the shipper [offeror] and carrier, and the instructions must accompany the shipping papers.<br>(3) The combined TI and combined criticality index are determined by adding together the TI and criticality index numbers, respectively, shown on the labels of the individual packages. |
| 49 CFR 175.702(b) | (c) In addition to the limits on combined CSIs stated in 49 CFR 175.700(b),<br>(1) The CSI of any single group of packages must not exceed 50.0 (as used in |

| Citation | Requirement |
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| | this section, the term ‘‘group of packages’’ means packages that are separated from each other in an aircraft by a distance of 6 m (20 feet) or less); and<br>(2) Each group of packages must be separated from every other group in the aircraft by not less than 6 m (20 feet), measured from the outer surface of each group. |
| 49 CFR 175.703(b) | (d) Each shipment of fissile material packages must conform to the requirements of 49 CFR 173.457 and 173.459. |
| 49 CFR 175.704 | (e) Plutonium shipments. Shipments of plutonium which are subject to 10 CFR 71.88(a)(4) must comply with the following:<br>(a) Each package containing plutonium must be secured and restrained to prevent shifting under normal conditions.<br>(b) A package of plutonium having a gross mass less than 40 kg (88 pounds) and both its height and diameter less than 50 cm (19.7 inches)—<br>(1) May not be transported aboard an aircraft carrying other cargo required to bear a Division 1.1 label; and<br>(2) Must be stowed aboard the aircraft on the main deck or the lower cargo compartment in the aft-most location that is possible for cargo of its size and weight, and no other cargo may be stowed aft of packages containing plutonium.<br>(c) A package of plutonium exceeding the size and weight limitations in paragraph (b) of this section—<br>(1) May not be transported aboard an aircraft carrying other cargo required to bear any of the following labels: Class 1 (all Divisions), Class 2 (all Divisions), Class 3, Class 4 (all Divisions), Class 5 (all Divisions), or Class 8; and<br>(2) Must be securely cradled and tied down to the main deck of the aircraft in a manner that restrains the package against the following internal forces acting separately relative to the deck of the aircraft; Upward, 2g; Forward, 9g; Sideward, 1.5g; Downward, 4.5g. |
| | **Loading and Segregation: Water Vessel** |
| 49 CFR 176.704(d) | (a) The sum of the CSI’s for all packages and overpacks of fissile Class 7 (radioactive) materials on board a vessel may not exceed the limits specified in Table IIIB of 49 CFR 176.704. |
| 49 CFR 176.704(e) | (b) Each group of fissile Class 7 (radioactive) material packages and overpacks, containing a sum of CSIs no greater than 50 for a non-exclusive use shipment, or no greater than 100 for an exclusive use shipment, must be separated from all other groups containing fissile material packages and overpacks by a distance of at least 6 m (20 ft) at all times. |
| 49 CFR 176.704(f) | (c) The limitations specified in paragraphs (a) through (c) of 49 CFR 176.704 do not apply when the entire vessel is reserved or chartered for use by a single offeror under exclusive use conditions if—<br>(1) The number of packages of fissile Class 7 (radioactive) material satisfies the individual package CSI limits of 49 CFR 173.457, except that the total sums of CSI’s in the last column of Table IIIB of 49 CFR 176.704, including table note (d) apply;<br>(2) A radiation protection program for the shipment has been established and approved by the Competent Authority of the flag state of the vessel and, when requested, by the Competent Authority at each port of call;<br>(3) Stowage arrangements have been predetermined for the whole voyage, |

| Citation | Requirement |
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| | including any consignments to be loaded at ports of call;<br>(4) The loading, transport and unloading are to be supervised by persons qualified in the transport of radioactive material; and<br>(5) The entire shipment operation is approved by the Associate Administrator in advance. |

| Table IIIB—CSI Limits for Freight Contains and Conveyances | | |
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| Type of freight container or conveyance | Limit on total sum of CSI in a single freight container or aboard a conveyance | |
| | Not under exclusive use | Under exclusive use |
| I. Freight container—small | 50 | NA |
| II. Freight container—large | 50 | 100 |
| III. Vessel | | |
| 1. Hold, compartment or defined deck areas | | |
| Packages, overpack, small freight containers | 50 | 100 |
| Large freight containers | 50 | 100 |
| 2. Total vessel | | |
| Packages, overpack, small freight containers | 200 | 200 |
| Large freight containers | No limit | No limit |

NOTES:
a For vessels, the requirements in both 1 and 2 must be fulfilled.
b Packages or overpacks transported in or on a vehicle which are offered for transport in accordance with the provisions of 49 CFR 173.441(b) may be transported by vessels provided that they are not removed from the vehicle at any time while on board the vessel. In that case, the entries under the heading ‘‘under exclusive use’’ apply.
c The consignment must be handled and stowed such that the total sum of CSIs in any group does not exceed 50, and such that each group is handled and stowed so that the groups are separated from each other by at least 6 m (20 ft).
d The consignment must be handled and stowed such that the total sum of CSIs in any group does not exceed 100, and such that each group is handled and stowed so that the groups are separated from each other by at least 6 m (20 ft). The intervening space between groups may be occupied by other cargo.

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| | **8. MARKING AND LABELING** |
| | (a) See Common Provisions. |
| 49 CFR 172.203<br>49 CFR 172.403 | (b) Except for plutonium-239 and plutonium-241, the weight in grams or kilograms of fissile radionuclides (or the mass of each fissile nuclide for mixtures when appropriate) may be inserted instead of activity units. For plutonium-239 and plutonium-241, the weight in grams of fissile radionuclides (or the mass of each fissile nuclide for mixtures when appropriate) may be inserted in addition to the activity units. |
| 49 CFR 172.203 | (c) For a package containing fissile Class 7 (radioactive) material:<br>(i) The words ‘‘Fissile Excepted’’ if the package is excepted pursuant to 49 CFR |

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| | 173.453; or otherwise<br>(ii) The CSI for that package. |
| 49 CFR 172.402 | (d) Each package or overpack containing fissile material, other than fissile-excepted material (see 49 CFR 173.453) must bear two FISSILE labels, affixed to opposite sides of the package or overpack, which conforms to the figure shown in 49 CFR 172.441; such labels, where applicable, must be affixed adjacent to the labels for radioactive materials. |
| 49 CFR 172.403 | (e) FISSILE label. For packages required in 49 CFR 172.402 to bear a FISSILE label, each such label must be completed with the CSI assigned in the NRC or DOE package design approval, or in the certificate of approval for special arrangement or the certificate of approval for the package design issued by the Competent Authority for import and export shipments. For overpacks and freight containers required in 49 CFR 172.402 to bear a FISSILE label, the CSI on the label must be the sum of the CSIs for all of the packages contained in the overpack or freight container. |
| 49 CFR 172.403 | (f) For fissile material, the CSI which must be entered on the overpack FISSILE label is the sum of the CSI of the individual packages in the overpack, as stated in the certificate of approval for the package design issued by the NRC or the U.S. Competent Authority. |
| 49 CFR 172.441 | (g) Provides specification for FISSILE label. |
| | **9. PLACARDING** |
| | See Common Provisions. |
| | **10. TRANSPORT DOCUMENTS** |
| | See Common Provisions. |
| | **11. STORAGE AND DISPATCH** |
| | No specific provisions. |
| | **12. CARRIAGE** |
| | See Common Provisions. |
| | **13. OTHER PROVISIONS** |
| | See Common Provisions. |

## 4.3 Type B Packages

This section contains the schedule for transporting Type B packages.

| Citation | Requirement |
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| | **a. MATERIALS** |
| | (a) See Common Provisions. |
| 173.431(b) | (b) The limits on activity contained in a Type B(U) or Type B(M) package are specified in the package's approval certificate or special package authorization. |
| | **b. PACKAGING/PACKAGE** |
| 49 CFR 173.413 | (a) Requirements for Type B packages.<br>Except as provided in 49 CFR 173.416, each Type B(U) or Type B(M) package must be designed and constructed to meet the applicable requirements specified in 10 CFR Part 71. |
| 49 CFR 173.416 | (b) Authorized Type B packages. Each of the following packages is authorized for shipment of quantities exceeding $A_1$ or $A_2$, as appropriate:<br>(a) Any Type B(U) or Type B(M) packaging that meets the applicable requirements of 10 CFR Part 71 and that has been approved by the NRC may be shipped pursuant to 49 CFR 173.471.<br>(b) Any Type B(U) or B(M) packaging that meets the applicable requirements in "IAEA Regulations for the Safe Transport of Radioactive Material, SSR–6" (IBR, see 49 CFR 171.7 of this subchapter) and for which the foreign Competent Authority Certificate has been revalidated by DOT pursuant to 49 CFR 173.473. These packagings are authorized only for export and import shipments.<br>(c) A package approved by the NRC under a special package authorization granted in accordance with 10 CFR 71.41(d) provided it is offered only for domestic transportation in accordance with the requirements in 49 CFR 173.471(b) and (c). |
| 49 CFR 173.467 | (c) Tests for demonstrating the ability of Type B and fissile materials packagings to withstand accident conditions in transportation.<br>Each Type B packaging or packaging for fissile material must meet the test requirements prescribed in 10 CFR Part 71 for ability to withstand accident conditions in transportation. |
| 49 CFR 173.471 | (d) Requirements for NRC approved packages.<br>In addition to the applicable requirements of the NRC and other requirements of this subchapter, any offeror of a Type B(U), Type B(M), or fissile material package that has been approved by the NRC in accordance with 10 CFR Part 71 must also comply with the following requirements:<br>(a) The offeror shall be registered with the NRC as a party to the packaging approval, and make the shipment in compliance with the terms of the packaging approval;<br>(b) The outside of each package must be durably and legibly marked with the package identification marking indicated in the NRC packaging approval;<br>(c) Each shipping paper related to the shipment of the package must bear the package identification marking indicated in the NRC packaging approval. |
| 10 CFR 71.17 | (e) For a Type B or fissile material package, the design of which was approved by NRC before April 1, 1996, the general license is subject to the additional restrictions of 10 CFR 71.19. |

| Citation | Requirement |
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| 10 CFR 71.19 | (f) 10 CFR 71.19 lists the conditions under which a previously approved Type B(U), Type B(M) or fissile material package without and without the "-85" designation may be used. |
| | **c. MAXIMUM RADIATION LEVELS** |
| | See Common Provisions. |
| | **d. CONTAMINATION** |
| | See Common Provisions. |
| | **e. DECONTAMINATION** |
| | See Common Provisions. |
| | **f. MIXED CONTENTS** |
| | See Common Provisions. |
| | **g. LOADING AND SEGREGATION** |
| | See Common Provisions. |
| | **h. MARKING AND LABELING** |
| | (a) See Common Provisions. |
| 49 CFR 172.310(d)<br>49 CFR 172, Appendix B | (b) Each Type B, Type B(U) or Type B(M) packaging must be marked on the outside of the package with the radiation trefoil symbol. |
| 49 CFR 172.310(b) | (c) Each packaging must be marked on the outside of the package, in letters at least 12 mm (0.47 inch) high, with the words "TYPE B(U) or Type B(M)" as appropriate. A packaging which does not conform to Type B(U) or Type B(M) requirements may not be so marked. |
| | **i. PLACARDING** |
| | See Common Provisions. |
| | **j. TRANSPORT DOCUMENTS** |
| | See Common Provisions |
| | **k. STORAGE AND DISPATCH** |
| | See Common Provisions. |
| | **l. CARRIAGE** |

| Citation | Requirement |
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| | (a) See Common Provisions. |
| 49 CFR 175.700(a) | (b) Type B(M) packages may not be used on passenger carrying aircraft. Vented Type B(M) packages may not be carried aboard any aircraft. |
| | **m. OTHER PROVISIONS** |
| | See Common Provisions. |

## 4.4 Radioactive Material Package Design and Testing

This section contains the schedule for radioactive material package design and testing.

| Citation | Requirement |
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| 49 CFR 173.410 | General design requirements. In addition to the requirements of 49 CFR 173 Subparts A and B, each package used for the shipment of Class 7 (radioactive) materials must be designed so that— |
| 49 CFR 173.410(a) | The package can be easily handled and properly secured in or on a conveyance during transport. |
| 49 CFR 173.410(b) | Each lifting attachment that is a structural part of the package must be designed with a minimum safety factor of three against yielding when used to lift the package in the intended manner, and it must be designed so that failure of any lifting attachment under excessive load would not impair the ability of the package to meet other requirements of this subpart. Any other structural part of the package which could be used to lift the package must be capable of being rendered inoperable for lifting the package during transport or must be designed with strength equivalent to that required for lifting attachments. |
| 49 CFR 173.410(c) | The external surface, as far as practicable, will be free from protruding features and will be easily decontaminated. |
| 49 CFR 173.410(d) | The outer layer of packaging will avoid, as far as practicable, pockets or crevices where water might collect. |
| 49 CFR 173.410(e) | Each feature that is added to the package will not reduce the safety of the package. |
| 49 CFR 173.410(f) | The package will be capable of withstanding the effects of any acceleration, vibration or vibration resonance that may arise under NCT without any deterioration in the effectiveness of the closing devices on the various receptacles or in the integrity of the package as a whole and without loosening or unintentionally releasing the nuts, bolts, or other securing devices even after repeated use (see 49 CFR 173.24, 173.24a, and 173.24b). |

| Citation | Requirement |
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| 49 CFR 173.410(g) | The materials of construction of the packaging and any components or structure will be physically and chemically compatible with each other and with the package contents. The behavior of the packaging and the package contents under irradiation will be taken into account. |
| 49 CFR 173.410(h) | All valves through which the package contents could escape will be protected against unauthorized operation. |
| 49 CFR 173.410(i) | For transport by air—<br>(1) The temperature of the accessible surfaces of the package will not exceed 50 °C (122 °F) at an ambient temperature of 38 °C (100 °F) with no account taken for insulation;<br>(2) The integrity of containment will not be impaired if the package is exposed to ambient temperatures ranging from -40 °C (-40 °F) to + 55 °C (131 °F); and<br>(3) A package containing liquid contents must be capable of withstanding, without leakage, an internal pressure that produces a pressure differential of not less than the maximum normal operating pressure plus 95 kPa (13.8 psi). |
| 49 CFR 173.412 | Additional Design Requirements for Type A Packages. In addition to meeting the general design requirements prescribed in 49 CFR 173.410, each Type A packaging must be designed so that— |
| 49 CFR 173.412(a) | The outside of the packaging incorporates a feature, such as a seal, that is not readily breakable, and that, while intact, is evidence that the package has not been opened. In the case of packages shipped in closed transport vehicles in exclusive use, the cargo compartment, instead of the individual packages, may be sealed. |
| 49 CFR 173.412(b) | The smallest external dimension of the package is not less than 10 cm (4 inches). |
| 49 CFR 173.412(c) | Containment and shielding is maintained during transportation and storage in a temperature range of -40 °C (-40 °F) to 70 °C (158 °F). Special attention shall be given to liquid contents and to the potential degradation of the packaging materials within the temperature range. |
| 49 CFR 173.412(d) | The packaging must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by pressure that may arise within the package during normal transport. Special form Class 7 (radioactive) material, as demonstrated in accordance with 49 CFR 173.469, may be considered as a component of the containment system. If the containment system forms a separate unit of the package, it must be securely closed by a positive fastening device that is independent of any other part of the package. |
| 49 CFR 173.412(e) | For each component of the containment system account is taken, where applicable, of radiolytic decomposition of materials and the generation of gas by chemical reaction and radiolysis. |
| 49 CFR 173.412(f) | The containment system will retain its radioactive contents under the reduction of ambient pressure to 60 kPa (8.7 psia). |
| 49 CFR 173.412(g) | Each valve, other than a pressure relief device, is provided with an enclosure to retain any leakage. |

| Citation | Requirement |
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| 49 CFR 173.412(h) | Any radiation shield that encloses a component of the packaging specified as part of the containment system will prevent the unintentional escape of that component from the shield. |
| 49 CFR 173.412(i) | Failure of any tie-down attachment that is a structural part of the packaging, under both normal and accident conditions, must not impair the ability of the package to meet other requirements of this subpart. |
| 49 CFR 173.412(j) | When evaluated against the performance requirements of this section and the tests specified in 49 CFR 173.465 or using any of the methods authorized 49 CFR 173.461(a), the packaging will prevent—<br>(1) Loss or dispersal of the radioactive contents; and<br>(2) A significant increase in the radiation levels recorded or calculated at the external surfaces for the condition before the test. |
| 49 CFR 173.412(k) | Each packaging designed for liquids will—<br>(1) Be designed to provide for ullage to accommodate variations in temperature of the contents, dynamic effects and filling dynamics;<br>(2) Meet the conditions prescribed in paragraph (j) of this section when subjected to the tests specified in 49 CFR 173.466 or evaluated against these tests by any of the methods authorized by 49 CFR 173.461(a); and<br>(3) Either—<br>(i) Have sufficient suitable absorbent material to absorb twice the volume of the liquid contents. The absorbent material must be compatible with the package contents and suitably positioned to contact the liquid in the event of leakage; or<br>(ii) Have a containment system composed of primary inner and secondary outer containment components designed to enclose the liquid contents completely and ensure retention of the liquid within the secondary outer component in the event that the primary inner component leaks. |
| 49 CFR 173.412(l) | Each package designed for gases, other than tritium not exceeding 40 TBq (1080 Ci) or noble gases not exceeding the $A_2$ value appropriate for the noble gas, will be able to prevent loss or dispersal of contents when the package is subjected to the tests prescribed in 49 CFR 173.466 or evaluated against these tests by any of the methods authorized by 49 CFR 173.461(a). |
| 49 CFR 173.415 | Authorized Type A Packages. The following packages are authorized for shipment if they do not contain quantities exceeding $A_1$ or $A_2$ as appropriate: |
| 49 CFR 173.415(a) | DOT Specification 7A (see 49 CFR 178.350) Type A general packaging. Until January 1, 2017 each offeror of a Specification 7A package must maintain on file for at least one year after the latest shipment, and shall provide to DOT on request, complete documentation of tests and an engineering evaluation or comparative data showing that the construction methods, packaging design, and materials of construction comply with that specification. After January 1, 2017 each offeror of a Specification 7A package must maintain on file for at least two years after the offeror's latest shipment, and shall provide to DOT on request, one of the following:<br>(1) A description of the package showing materials of construction, dimensions, weight, closure and closure materials (including gaskets, tape, etc.) of each item of the containment system, shielding and packing materials used in normal transportation, and the following:<br>(i) If the packaging is subjected to the physical tests of 49 CFR 173.465, and if |

| Citation | Requirement |
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| | applicable, 49 CFR 173.466, documentation of testing, including date, place of test, signature of testers, a detailed description of each test performed including equipment used, and the damage to each item of the containment system resulting from the tests, or<br>(ii) For any other demonstration of compliance with tests authorized in 49 CFR 173.461, a detailed analysis which shows that, for the contents being shipped, the package meets the pertinent design and performance requirements for a DOT 7A Type A specification package.<br>(2) If the offeror has obtained the packaging from another person who meets the definition of ''packaging manufacturer'' in 49 CFR 178.350(c) of this subchapter, a certification from the packaging manufacturer that the package meets all the requirements of 49 CFR 178.350 for the radioactive contents presented for transport and a copy of documents maintained by the packaging manufacturer that meet the requirements of paragraph (a)(1) of this section. |
| 49 CFR 173.415(b) | Any other Type A packaging that also meets the applicable standards for fissile materials in 10 CFR Part 71 and is used in accordance with 49 CFR 173.471. |
| 49 CFR 173.415(c) | Any Type B(U) or Type B(M) packaging authorized pursuant to 49 CFR 173.416. |
| 49 CFR 173.415(d) | Any foreign-made packaging that meets the standards in the "IAEA Regulations for the Safe Transport of Radioactive Material, SSR–6" (IBR, see 49 CFR 171.7) and bears the marking ''Type A''. Such packagings may be used for domestic and export shipments of Class 7 (radioactive) materials provided the offeror obtains the applicable documentation of tests and engineering evaluations and maintains the documentation on file in accordance with paragraph (a) of this section. These packagings must conform with requirements of the country of origin (as indicated by the packaging marking) and the IAEA regulations applicable to Type A packagings. |
| 49 CFR 173.418 | Authorized Packages— Pyrophoric Class 7 (Radioactive) Materials. Pyrophoric Class 7 (radioactive) materials, as referenced in the 49 CFR 172.101 table of this subchapter, in quantities not exceeding $A_2$ per package must be transported in DOT Specification 7A packagings constructed of materials that will not react with, nor be decomposed by, the contents. Contents of the package must be— |
| 49 CFR 173.418(a) | In solid form and must not be fissile unless excepted by 49 CFR 173.453; |
| 49 CFR 173.418(b) | Contained in sealed and corrosion resistant receptacles with positive closures (friction or slip-fit covers or stoppers are not authorized); |
| 49 CFR 173.418(c) | Free of water and contaminants that would increase the reactivity of the material; and |
| 49 CFR 173.418(d) | Made Inert to prevent self-ignition during transport by either—<br>(1) Mixing with large volumes of inert materials, such as graphite, dry sand, or other suitable inert material, or blended into a matrix of hardened concrete; or<br>(2) Filling the innermost receptacle with an appropriate inert gas or liquid. |
| 49 CFR 173.418(e) | Pyrophoric Class 7 (radioactive) materials transported by aircraft must be packaged in Type B packages. |

| Citation | Requirement |
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| 49 CFR 173.419 | Authorized Packages—Oxidizing Class 7 (Radioactive) Materials |
| 49 CFR 173.419(a) | An oxidizing Class 7 (radioactive) material, as referenced in the 49 CFR 172.101 table of this subchapter, is authorized in quantities not exceeding an $A_2$ per package, in a DOT Specification 7A package provided that—<br>(1) The contents are:<br>(i) Not fissile;<br>(ii) Packed in inside packagings of glass, metal or compatible plastic; and<br>(iii) Cushioned with a material that will not react with the contents; and<br>(2) The outside packaging is made of wood, metal, or plastic. |
| 49 CFR 173.419(b) | The package must be capable of meeting the applicable test requirements of 49 CFR 173.465 without leakage of contents. |
| 49 CFR 173.419(c) | For shipment by air, the maximum quantity in any package may not exceed 11.3 kg (25 pounds). |
| | Demonstration of compliance |
| 10 CFR 71.41(a) | The effects on a package of the tests specified in 10 CFR 71.71 (“Normal conditions of transport”), and the tests specified in 10 CFR 71.73 (“Hypothetical accident conditions”), and 10 CFR 71.61 (“Special requirements for Type B packages containing more than 105 $A_2$”), must be evaluated by subjecting a specimen or scale model to a specific test, or by another method of demonstration acceptable to the Commission, as appropriate for the particular feature being considered. |
| 10 CFR 71.41(b) | Considering the type of vehicle, the method of securing or attaching the package, and the controls to be exercised by the shipper, the Commission may permit the shipment to be evaluated together with the transporting vehicle. |
| 10 CFR 71.41(c) | Environmental and test conditions different from those specified in 10 CFR 71.71 and 10 CFR 71.73 may be approved by the Commission if the controls proposed to be exercised by the shipper are demonstrated to be adequate to provide equivalent safety of the shipment. |
| 10 CFR 71.41(d) | Packages for which compliance with the other provisions of these regulations is impracticable shall not be transported except under special package authorization. Provided the applicant demonstrates that compliance with the other provisions of the regulations is impracticable and that the requisite standards of safety established by these regulations have been demonstrated through means alternative to the other provisions, a special package authorization may be approved for one-time shipments. The applicant shall demonstrate that the overall level of safety in transport for these shipments is at least equivalent to that which would be provided if all the applicable requirements had been met. |
| | General standards for all packages |
| 10 CFR 71.43(a) | The smallest overall dimension of a package may not be less than 4 in. |

| Citation | Requirement |
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| 10 CFR 71.43(b) | The outside of a package must incorporate a feature, such as a seal, that is not readily breakable and that, while intact, would be evidence that the package has not been opened by unauthorized persons. |
| 10 CFR 71.43(c) | Each package must include a containment system securely closed by a positive fastening device that cannot be opened unintentionally or by a pressure that may arise within the package. |
| 10 CFR 71.43(d) | A package must be made of materials and construction that assure that there will be no significant chemical, galvanic, or other reaction among the packaging components, among package contents, or between the packaging components and the package contents, including possible reaction resulting from in-leakage of water, to the maximum credible extent. Account must be taken of the behavior of materials under irradiation. |
| 10 CFR 71.43(e) | A package valve or other device, the failure of which would allow radioactive contents to escape, must be protected against unauthorized operation and, except for a pressure relief device, must be provided with an enclosure to retain any leakage. |
| 10 CFR 71.43(f) | A package must be designed, constructed, and prepared for shipment so that under the tests specified in 10 CFR 71.71 there would be no loss or dispersal of radioactive contents, no significant increase in external surface radiation levels, and no substantial reduction in the effectiveness of the packaging. |
| 10 CFR 71.43(g) | A package must be designed, constructed, and prepared for transport so that in still air at 100 °F and in the shade, no accessible surface of a package would have a temperature exceeding 122 °F in a non-exclusive use shipment, or 185 °F in an exclusive use shipment. |
| 10 CFR 71.43(h) | A package may not incorporate a feature intended to allow continuous venting during transport. |
| | Normal conditions of transport. |
| 71.71(a) | Evaluation. Separate packages may be used for the free drop test, compression test, and penetration test, if each package is subjected to the water spray test before being subjected to any of the other tests. |
| 10 CFR 71.71(b) | Initial conditions. Based on ambient temperature preceding and following the tests remaining constant at that value between -20 °F and 100 °F which is most unfavorable for the feature under consideration. Initial internal pressure within the containment system must be considered to be the maximum normal operating pressure, unless a lower internal pressure consistent with the ambient temperature considered to precede and follow the tests is more unfavorable. |
| 10 CFR 71.71(c) | Conditions and tests. |
| 10 CFR 71.71(c)(1) | Heat. Ambient temperature of 100 °F in still air and insolation. |

| Citation | Requirement |
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| 10 CFR 71.71(c)(2) | Cold. Ambient temperature of -40 °F in still air and shade. |
| 10 CFR 71.71(c)(3) | Reduced external pressure. An external pressure of 3.5 lbf/in$^2$ absolute. |
| 10 CFR 71.71(c)(4) | Increased external pressure. An external pressure of 20 lbf/in$^2$ absolute. |
| 10 CFR 71.71 (c)(5) | Vibration. Vibration normally incident to transport. |
| 10 CFR 71.71(c)(6) | Water spray. A water spray that simulates exposure to rainfall of approximately 2 in. per hour for at least 1 hour. |
| 10 CFR 71.71(c)(7) | Free drop. Between 1.5 and 2.5 hours after the conclusion of the water spray test, a free drop onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. Note the distance of the drop is a function of weight. |
| 10 CFR 71.71(c)(8) | Corner drop. A free drop onto each corner of the package in succession from a height of 1 ft onto a flat, essentially unyielding, horizontal surface. Note that for a cylindrical package, the free drop would be onto each quarter of each rim.<br><br>Note this test only applies to fiberboard, wood, or fissile material rectangular packages not exceeding 110 lb. and fiberboard, wood, or fissile material cylindrical packages not exceeding 220 lb. |
| 10 CFR 71.71(c)(9) | Compression. The package is subjected for a period of 24 hours to a compressive load applied uniformly to the top and bottom of the package in the position the package would normally be transported. The compressive load is the greater of five times the weight of the package or the equivalent of 2 lbf/in$^2$ multiplied by the vertically projected area of the package.<br><br>Note this test is applicable for packages weighing up to 11,000 lb. |
| 10 CFR 71.71(c)(10) | Penetration. Impact of the hemispherical end of a vertical steel cylinder of 1.25 in. diameter and 13 lb mass dropped from a height of 40 in. onto the surface of the package that is expected to be the most vulnerable to puncture. |
| | Hypothetical accident conditions. |
| 10 CFR 71.73(a) | Test procedures. Based on sequential application of the tests, in the order indicated, to determine their cumulative effect on a package or array of packages. An undamaged specimen may be used for the water immersion tests specified in 10 CFR 71.73(c)(6). |
| 10 CFR 71.73(b) | Test conditions. Initial conditions for the tests, except for the water immersion tests, the ambient air temperature before and after the tests must remain constant at that value between -20 °F and 100 °F which is most unfavorable for the features under consideration. Initial internal pressure within the containment system must be the maximum normal operating pressure, unless a lower internal pressure, consistent |

| Citation | Requirement |
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| | with the ambient temperature considered to precede and follow the tests, is more unfavorable. |
| 10 CFR 71.3(c) | Tests. |
| 10 CFR 71.73(c)(1) | Free drop. A free drop of a package through a distance of 30 ft onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. |
| 10 CFR 71.73(c)(2) | Crush. A crush test on a flat, essentially unyielding horizontal surface so as to suffer maximum damage by the drop of a 1100 lb mass from 30 ft onto the package. The mass must consist of a solid mild steel plate 40 in. by 40 in. and must fall in a horizontal attitude.<br><br>• The crush test is only required when the package has a mass not greater than 1100 lb, an overall density not greater than 62.4 lb/ft$^3$ based on external dimension, and radioactive contents greater than 1000 $A_2$ not as special form radioactive material.<br><br>Note for packages containing fissile material, the radioactive contents greater than 1000 $A_2$ criterion does not apply. |
| 10 CFR 71.73(c)(3) | Puncture. A free drop of the package through a distance of 40 in. in the position for which maximum damaged is expected onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted onto an essentially unyielding, horizontal surface. The bar must be 6 in. in diameter and have a length as to cause maximum damage to the package, but not less than 8 in. long. |
| 10 CFR 71.73(c)(4) | Thermal. Exposure of the package fully engulfed in a hydrocarbon fuel/air fire with an average flame temperature of at least 1475 °F for a period of 30 minutes. |
| 10 CFR 71.73(c)(5) | Immersion – fissile material. For fissile material subject to 10 CFR 71.55, in cases where water in-leakage has not been assumed for criticality analyses, immersion under a head of water of at least 3 ft in the attitude for which maximum leakage is expected. |
| 10 CFR 71.73(c)(6) | Immersion – all packages. A separate, undamaged package subjected to water pressure equivalent to immersion under a head of water of at least 50 ft. |
| | Additional requirements for Type B packages |
| 10 CFR 71.51(a)(1) | There would be no loss or dispersal of radioactive contents--as demonstrated to a sensitivity of $10^{-6}$ $A_2$ per hour and no substantial reduction in the effectiveness of the packaging under the 10 CFR 71.71 NCT tests |
| 10 CFR 71.51(a)(2) | There would be no escape of krypton-85 exceeding 10 $A_2$ in 1 week and no escape of other radioactive material exceeding a total amount $A_2$ in 1 week under the 10 CFR 71.73 HAC tests |
| | Special requirements for Type B packages containing more than $10^5 A_2$ |

| Citation | Requirement |
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| 10 CFR 71.61 | A Type B package containing more than $10^5$ $A_2$ must be designed so that its undamaged containment system can withstand an external water pressure of 2 MPa (290 psi) for a period of not less than 1 hour without collapse, buckling, or in-leakage of water. |
| | External radiation standards for all packages |
| 10 CFR 71.47(a) | Except as provided in paragraph (b) of this section, each package of radioactive materials offered for transportation must be designed and prepared for shipment so that under conditions normally incident to transportation the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package, and the TI does not exceed 10. |
| 10 CFR 71.47(b) | A package that exceeds the radiation level limits specified in paragraph (a) of this section must be transported by exclusive use shipment only, and the radiation levels for such shipment must not exceed the following during transportation:<br><br>(1) 2 mSv/h (200 mrem/h) on the external surface of the package, unless the following conditions are met, in which case the limit is 10 mSv/h (1000 mrem/h):<br><br>(i) The shipment is made in a closed transport vehicle;<br><br>(ii) The package is secured within the vehicle so that its position remains fixed during transportation; and<br><br>(iii) There are no loading or unloading operations between the beginning and end of the transportation;<br><br>(2) 2 mSv/h (200 mrem/h) at any point on the outer surface of the vehicle, including the top and underside of the vehicle; or in the case of a flat-bed style vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load or enclosure, if used, and on the lower external surface of the vehicle; and<br><br>(3) 0.1 mSv/h (10 mrem/h) at any point 2 meters (80 in) from the outer lateral surfaces of the vehicle (excluding the top and underside of the vehicle); or in the case of a flat-bed style vehicle, at any point 2 meters (6.6 feet) from the vertical planes projected by the outer edges of the vehicle (excluding the top and underside of the vehicle); and<br><br>(4) 0.02 mSv/h (2 mrem/h) in any normally occupied space, except that this provision does not apply to private carriers, if exposed personnel under their control wear radiation dosimetry devices in conformance with 10 CFR 20.1502. |
| 10 CFR 71.47(c) | For shipments made under the provisions of paragraph (b) of this section, the shipper shall provide specific written instructions to the carrier for maintenance of the exclusive use shipment controls. The instructions must be included with the shipping paper information. |
| 10 CFR 71.47(d) | The written instructions required for exclusive use shipments must be sufficient so that, when followed, they will cause the carrier to avoid actions that will unnecessarily |

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| | delay delivery or unnecessarily result in increased radiation levels or radiation exposures to transport workers or members of the general public. |
| 10 CFR 71.55 | General Requirements for Fissile Material Packages |
| 10 CFR 71.55(b) | Package must remain subcritical if water were to leak into the containment system or liquid contents were to leak out under the following conditions.<br>• 10 CFR 71.55(b)(1) Fissile material in most reactive credible configuration consistent with chemical and physical form of the material;<br>• 10 CFR 71.55(b)(2) Moderation by water to the most reactive credible extent; and<br>• 10 CFR 71.55(b)(3) With close full reflection of the containment system by water on all sides, or such greater reflection of the containment system as may additionally be provided by the surrounding material of the packaging. |
| 10 CFR 71.55(c) | The Commission may approve exceptions to the requirements of 10 CFR 71.55(b) of this section if the package incorporates special design features that ensure that no single packaging error would permit leakage, and if appropriate measures are taken before each shipment to ensure that the containment system does not leak. |
| 10 CFR 71.55(d) | Package must remain subcritical under tests specified in 10 CFR 71.71 (NCT) and must ensure that:<br>• 10 CFR 71.55(d)(2) The geometric form of the package contents would not be substantially altered;<br>• 10 CFR 71.55(d)(3) There would be no leakage of water into the containment; and<br>• 10 CFR 71.55(d)(4) There would be no substantial reduction in the effectiveness of the packaging including:<br>o No more than 5 percent reduction in the total effective volume of the packaging on which nuclear safety is assessed;<br>o No more than 5 percent reduction in the effective spacing between the fissile contents and the outer surface of the packaging; and<br>o No occurrence of an aperture in the outer surface of the packaging large enough to permit the entry of a 10 cm (4 in.) cube. |
| 10 CFR 71.55(e) | Package must remain subcritical under tests specified in 10 CFR 71.73 (HAC)<br>• 10 CFR 71.55(e)(1) The fissile material is in the most reactive credible configuration consistent with the damaged condition of the package and the chemical and physical form of the contents. |

| Citation | Requirement |
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| | • 10 CFR 71.55(e)(2) Water moderation occurs to the most reactive credible extent consistent with the damaged condition of the package and the chemical and physical form of the contents.<br><br>10 CFR 71.55(e)(3) There is full reflection by water on all sides, as close as is consistent with the damaged condition of the package. |
| | Requirements for fissile material packages transported by air |
| 10 CFR 71.55(f)(1) | The package must be designed and constructed, and its contents limited so that it would be subcritical, assuming reflection by 20 cm (7.9 in) of water but no water in-leakage, when subjected to sequential application of:<br><br>• 10 CFR 71.55(f)(1)(i) The free drop test in 10 CFR 71.73(c)(1).<br><br>• 10 CFR 71.55(f)(1)(ii) The crush test in 10 CFR 71.73(c)(2).<br><br>• 10 CFR 71.55(f)(1)(iii) A puncture test (for packages of 250 kg or more).<br><br>• 10 CFR 71.55(f)(1)(iv) The thermal test in 10 CFR 71.73(c)(4), except that the duration of the test must be 60 minutes. |
| 10 CFR 71.55(f)(2) | The package must be designed and constructed, and its contents limited, so that it would be subcritical, assuming reflection by 20 cm (7.9 in) of water but no water in-leakage, when subjected to an impact on an unyielding surface at a velocity of 90 m/s normal to the surface, at such orientation so as to result in maximum damage. A separate, undamaged specimen can be used for this evaluation. |
| | Standards for arrays of fissile material packages |
| 10 CFR 71.59(a) | The package must be controlled during transport to assure that an array of such packages remains subcritical. |
| | Special requirement for plutonium shipments |
| 10 CFR 71.63 | Shipments containing plutonium must be made with the contents in solid form, if the contents contain greater than 0.74 TBq (20 Ci) of plutonium. |
| | Special requirements for plutonium air shipments |
| 10 CFR 71.64(a) | A package for the shipment of plutonium by air, in addition to satisfying the requirements above, must be designed, constructed, and prepared for shipment so that under the tests specified in: |
| 10 CFR 71.64(a)(1) | 10 CFR 71.74, Accident conditions for air transport of plutonium |
| 10 CFR 71.64(a)(1)(i) | The containment vessel would not be ruptured in its post-tested condition, and the package must provide a sufficient degree of containment to restrict accumulated loss of plutonium contents to not more than an $A_2$ quantity in a period of one week. |

| Citation | Requirement |
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| 10 CFR 71.64(a)(1)(ii) | The external radiation level would not exceed 10 mSv/h (1 rem/h) at a distance of 1 m (40 in.) from the surface of the package in its post-tested condition in air. |
| 10 CFR 71.64(a)(1)(iii) | A single package and an array of packages are demonstrated to be subcritical in accordance with this part, except that the damaged condition of the package must be considered to be that which results from the plutonium accident tests in 10 CFR 71.74, rather than the hypothetical accident tests in 10 CFR 71.73. |
| 10 CFR 71.64(a)(2) | After the tests in Section 10 CFR 71.74(c) there would be no detectable leakage of water into the containment vessel of the package. |
| 10 CFR 71.64(b) | With respect to the package requirements of paragraph 10 CFR 71.64(a), there must be a demonstration or analytical assessment showing that— |
| 10 CFR 71.64(b)(1) | The results of the physical testing for package qualification would not be adversely affected to a significant extent by: |
| 10 CFR 71.64(b)(1)(i) | The presence, during the tests, of the actual contents that will be transported in the package; and |
| 10 CFR 71.64(b)(1)(ii) | Ambient water temperatures ranging from 0.6 °C (+ 33 °F) to 38 °C (+ 100 °F) for those qualification tests involving water, and ambient atmospheric temperatures ranging from −40 °C (−40 °F) to + 54 °C (+ 130°F) for the other qualification tests. |
| 10 CFR 71.64(b)(2) | The ability of the package to meet the acceptance standards prescribed for the accident condition sequential tests would not be adversely affected if one or more tests in the sequence were deleted. |
| | Accident conditions for air transport of plutonium. |
| 10 CFR 71.74(a) | Test conditions—Sequence of tests. A package must be physically tested to the following conditions in the order indicated to determine their cumulative effect. |
| 71.74(a)(1) | Impact at a velocity of not less than 129 m/sec (422 ft/sec) at a right angle onto a flat, essentially unyielding, horizontal surface, in the orientation (e.g., side, end, corner) expected to result in maximum damage at the conclusion of the test sequence. |
| 10 CFR 71.74(a)(2) | A static compressive load of 31,800 kg (70,000 lb) applied in the orientation expected to result in maximum damage at the conclusion of the test sequence. The force on the package must be developed between a flat steel surface and a 5 cm (2 in.) wide, straight, solid, steel bar. The length of the bar must be at least as long as the diameter of the package, and the longitudinal axis of the bar must be parallel to the plane of the flat surface. The load must be applied to the bar in a manner that prevents any members or devices used to support the bar from contacting the package. |
| 10 CFR 71.74(a)(3) | Packages weighing less than 227 kg (500 lb) must be placed on a flat, essentially unyielding, horizontal surface, and subjected to a weight of 227 kg (500 lb) falling from a height of 3 m (10 ft) and striking in the position expected to result in maximum damage at the conclusion of the test sequence. The end of the weight contacting the package must be a solid probe made of mild steel. The probe must be the shape of the frustum of a right circular cone, 30 cm (12 in.) long, 20 cm (8 in.) in diameter at |

| Citation | Requirement |
|---|---|
| | the base, and 2.5 cm (1 in.) in diameter at the end. The longitudinal axis of the probe must be perpendicular to the horizontal surface. For packages weighing 227 kg (500 lb) or more, the base of the probe must be placed on a flat, essentially unyielding horizontal surface, and the package dropped from a height of 3 m (10 ft) onto the probe, striking in the position expected to result in maximum damage at the conclusion of the test sequence. |
| 10 CFR 71.74(a)(4) | The package must be firmly restrained and supported such that its longitudinal axis is inclined approximately 45° to the horizontal. The area of the package that made first contact with the impact surface in paragraph (a)(1) of this section must be in the lowermost position. The package must be struck at approximately the center of its vertical projection by the end of a structural steel angle section falling from a height of at least 46 m (150 ft). The angle section must be at least 1.8 m (6 ft) in length with equal legs at least 13 cm (5 in) long and 1.3 cm (0.5 in.) thick. The angle section must be guided in such a way as to fall end-on, without tumbling. The package must be rotated approximately 90° about its longitudinal axis and struck by the steel angle section falling as before. |
| 10 CFR 71.74(a)(5) | The package must be exposed to luminous flames from a pool fire of JP-4 or JP-5 aviation fuel for a period of at least 60 minutes. The luminous flames must extend an average of at least 0.9 m (3 ft) and no more than 3 m (10 ft) beyond the package in all horizontal directions. The position and orientation of the package in relation to the fuel must be that which is expected to result in maximum damage at the conclusion of the test sequence. An alternate method of thermal testing may be substituted for this fire test, provided that the alternate test is not of shorter duration and would not result in a lower heating rate to the package. At the conclusion of the thermal test, the package must be allowed to cool naturally or must be cooled by water sprinkling, whichever is expected to result in maximum damage at the conclusion of the test sequence. |
| 10 CFR 71.74(a)(6) | Immersion under at least 0.9 m (3 ft) of water. |
| 10 CFR 71.74(b) | Individual free-fall impact test |
| 10 CFR 71.74(b)(1) | An undamaged package must be physically subjected to an impact at a velocity not less than the calculated terminal free-fall velocity, at mean sea level, at a right angle onto a flat, essentially unyielding, horizontal surface, in the orientation (e.g., side, end, corner) expected to result in maximum damage. |
| 10 CFR 71.74(b)(2) | This test is not required if the calculated terminal free-fall velocity of the package is less than 129 m/sec (422 ft/sec), or if a velocity not less than either 129 m/sec (422 ft/sec) or the calculated terminal free-fall velocity of the package is used in the sequential test of paragraph (a)(1) of this section. |
| 10 CFR 71.74(c) | Individual deep submersion test |
| 10 CFR 71.74(c) | An undamaged package must be physically submerged and physically subjected to an external water pressure of at least 4 MPa (600 lb/in2). |

## 4.5 Military Air Shipments of Fissile Material and Type B Packages

This section contains the schedule for Class 7 military air shipments of fissile material and for Type B packages derived from USAF (2004).

| Citation | Requirement |
|---|---|
| AFMAN24-204(I), 2.9 | Complying With Special Cargo Requirements.<br><br>Ensure any Inhalation Hazard Zone A material (as identified by Special Provision 1 in Table A4.1., column 7); Class 1, compatibility group K; Fissile Class III Radioactive Materials; infectious substances and biological research materials requiring a technical escort comply with the extensive protective measures outlined in Attachment 24. |
| AFMAN24-204(I), A3.3.7.1 | General Design Requirements.<br><br>Design each package used for shipment of radioactive materials so that:<br><br>A3.3.7.1.1. The package can be easily handled and properly secured during transport.<br><br>A3.3.7.1.2. Each lifting attachment on the package, when used in the intended manner, with a minimum safety factor of three, does not impose an unsafe stress on the structure of the package. In addition, design the lifting attachment so that failure under excessive load does not impair the ability of the package to meet all other requirements of this attachment and Attachment 11. Remove, make inoperable for transport, or design with equivalent strength for lifting each attachment or other feature on the outer surface of the packaging that could be used to lift the package.<br><br>A3.3.7.1.3. The external surface, as far as practical, may be easily decontaminated.<br><br>A3.3.7.1.4. The outer layer of packaging avoids, as far as practicable, pockets or crevices where water might collect.<br><br>A3.3.7.1.5. Each feature that is added to the package at the time of transport, and is not a part of the package, does not reduce the safety of the package.<br><br>A3.3.7.1.6. The package will be capable of withstanding the effects of any acceleration, vibration, or vibration resonance that may occur during transportation without any deterioration in the effectiveness of the of any of the closing devices or in the integrity of the package and without loosening or unintentionally releasing the nuts, bolts, or other securing devices.<br><br>A3.3.7.1.7. The packaging materials and any components will be physically and chemically compatible with each other and the contents.<br><br>A3.3.7.1.8. All valves through which the package contents could escape will be protected against unauthorized operation. |
| AFMAN24-204(I), A3.3.7.2 | Additional Design Requirements for Type A and B Packages |

| Citation | Requirement |
|---|---|
| | A3.3.7.2.1. In addition to meeting the general design requirements each Type A packaging must also meet the design requirements of 49 CFR 173.412 and test requirements of 49 CFR 173.461.<br><br>A3.3.7.2.2. Each type B(U) or type B(M) package must meet the design and test requirements of 10 CFR Part 71. |
| AFMAN24-204(I), A3.3.7.3 | Radiation Level and Thermal Limitations.<br><br>A3.3.7.3.1. Design each package of radioactive materials so that:<br>A3.3.7.3.1.1. The radiation level is not more than 2 mSv/h (200 mrem/h) at any point on the external surface of the package.<br>A3.3.7.3.1.2. The TI is not over 10.<br><br>A3.3.7.3.2. Design, construct, and load each package of radioactive material so that:<br>A3.3.7.3.2.1. The heat generated within the package due to the radioactive contents will not, at any time during transportation, affect the integrity of the package under normal transportation conditions.<br>A3.3.7.3.2.2. The temperature of the accessible external surfaces of the loaded package will not, assuming still air in the shade at an ambient temperature of 38 degrees C (100 degrees F), exceed either a temperature of 50 degrees C (122 degrees F) in other than an exclusive use shipment or 82 degrees C (180 degrees F) in an exclusive use shipment. |
| AFMAN24-204(I), A3.3.7.4 | General Transportation Requirements.<br><br>A3.3.7.4.1. Secure each shipment of radioactive materials to prevent shifting during normal transportation conditions.<br><br>A3.3.7.4.2. Except as specifically required by a CAA, a package of radioactive materials may be carried among packaged general cargo without special stowage provisions, if:<br>A3.3.7.4.2.1. The heat output in watts is not over 0.1 times the minimum package dimension in centimeters.<br>A3.3.7.4.2.2. The average surface heat flux of the package is not over 15 watts per square meter ($W/m^2$) and the immediately surrounding cargo is not in sacks or bags or otherwise in a form that would seriously impede air circulation for heat removal.<br><br>A3.3.7.4.3. Aircraft in which radioactive materials have been spilled may not again be placed in service or routinely occupied until radiation dose rate at any accessible surface is less than 0.005 mSv/h (0.5 mrem/h) and there is no significant removable radioactive surface contamination as determined in A3.3.7.11. When contamination is present or suspected, segregate the package and any other materials it has touched as far as practical from personnel contact until needed radiological advice or assistance is obtained. For personnel safety, take care to avoid possible inhalation, ingestion, or contact with radioactive materials that may have leaked or spilled from its package. Leave any loose radioactive materials and associated packaging materials in a segregated area pending disposal instructions from responsible radiological authorities.<br><br>A3.3.7.4.4. Do not offer for military airlift:<br>A3.3.7.4.4.1. Any type B(U) or type B(M) package with an accessible surface |

| Citation | Requirement |
|---|---|
| | temperature in excess of 50 degrees C (122 degrees F).<br>A3.3.7.4.4.2. Any continuously vented type B(M) packages, which require external cooling by an auxiliary cooling system or packages subject to operational controls during transport.<br>A3.3.7.4.4.3. Any liquid pyrophoric radioactive materials.<br><br>A3.3.7.4.5. Do not transport exclusive use shipments of packages having a surface radiation level in excess of 2 mSv/h (200 mrem/h) except by special arrangement. |
| AFMAN24-204(I), A3.3.7.6 | Stowage on Aircraft or Storage Incident to Transportation.<br><br>A3.3.7.6.1. Do not ship RADIOACTIVE YELLOW-II or RADIOACTIVE YELLOW-III material on the same aircraft or store in any one area, such as a transit area, terminal building, storeroom, or assembly yard, if the sum of the TIs in any individual group of packages exceeds 50.<br><br>A3.3.7.6.2. If the total TI for all packages exceeds 50, separate the packages into groups. Store groups of these packages so as to maintain a spacing of at least 6 meters (20 feet) from other groups of packages containing radioactive materials.<br><br>A3.3.7.6.3. Ensure separation of yellow-II or yellow-III material from packages containing undeveloped film according to the distances shown in 49 CFR 175.703. |
| AFMAN24-204(I), A3.3.7.8 | Specific Requirement for Fissile Shipments.<br><br>A3.3.7.8.1. Packages containing fissile radioactive material which are not excepted according to A3.3.7.9. must be assigned a CSI and a TI.<br><br>A3.3.7.8.2. Fissile material packages and conveyances transporting these packages must satisfy the radiation level restrictions in A3.3.7.3.<br><br>A3.3.7.8.3. Except for consignments under exclusive use, the CSI of any packages or overpack may not exceed 50. A fissile material package with CSI greater than 50 must be transported by exclusive use.<br><br>A3.3.7.8.4. For non-exclusive use shipments of fissile material packages, the total sum of CSIs in a freight container or on a conveyance may not exceed 100.<br><br>A3.3.7.8.5. Exclusive use shipments of fissile material packages must satisfy the radiation level and administrative requirements of 49 CFR 173.441(b).<br><br>A3.3.7.8.6. Mixing fissile material packages with other types of radioactive materials, in any conveyance is authorized only if the TI of any single packages does not exceed 10, the CSI of any single package does not exceed 50 and the requirements in this paragraph and in A3.3.7.3 are met. |
| AFMAN24-204(I), A3.3.7.9 | Fissile Materials–Exceptions.<br><br>A3.3.7.9.1. A package containing less than 2 grams or less of fissile radionuclides.<br><br>A3.3.7.9.2. A package containing 15 grams or less of fissile radionuclides provided the package has at least 200 grams of solid non-fissile material for every gram of fissile material. |

| Citation | Requirement |
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| | A3.3.7.9.3. Low concentrations of solid fissile material commingled with solid non-fissile material where:<br>A3.3.7.9.3.1. There is at least 2000 grams of non-fissile material for every gram of fissile material.<br>A3.3.7.9.3.2. There is no more than 180 grams of fissile material distributed within 360 kg of contiguous non-fissile material.<br><br>A3.3.7.9.4. Uranium enriched in uranium-235 to a maximum of 1 percent by weight, and with a total plutonium and uranium-233 content of up to 1 percent of the mass of uranium-235.<br><br>A3.3.7.9.5. Liquid solutions of uranyl nitrate enriched in uranium-235 to a maximum of 2 percent by weight, with total plutonium and uranium-233 content not exceeding 0.002 percent of the mass of uranium and with minimum nitrogen to uranium atomic ratio of 2. The material must be contained in at least a DOT Type A package.<br><br>A3.3.7.9.6. A package containing individually a total plutonium mass of not more than 1000 grams of which not more than 20 percent by mass may consist of plutonium-239, plutonium-241 or any combination of these radionuclides. |
| AFMAN24-204(I), A3.3.7.10 | Requirements for Foreign-Made Packages.<br><br>In addition to the requirements of Attachment 11, each shipper of a foreign-made type B(U), type B(M), type C, type CF, type H(U), type H(M) or fissile material package for which a Competent Authority Certificate is required by the IAEA "Regulations for the Safe Transport of Radioactive Materials, No. TS-R-1" must meet the requirements of 49 CFR 173.473. |
| AFMAN24-204(I), A3.3.7.11 | Radioactive Contamination.<br><br>A3.3.7.11.1. Contamination Control. Keep the level of non-fixed (removable) radioactive contamination on the external surfaces of each package offered for shipment as low as practical. The level of non-fixed radioactive contamination may be determined by wiping an area of 300 $cm^2$ of the surface concerned with an absorbent material, using moderate pressure, and measuring the activity on the wiping material. Take sufficient measurements in the most appropriate locations to yield a representative assessment of the non-fixed contamination levels. The amount of radioactivity measured on any single wiping material divided by the surface area wiped and divided by the efficiency of the wipe procedure may not exceed the limits set forth in Table A3.3. at any time during transport. Other methods of assessment of equal or greater efficiency may be used.<br><br>A3.3.7.11.2. Inspecting Aircraft for Contamination. Periodically check aircraft used to routinely transport radioactive materials for radioactive contamination. Determine frequency of the checks based on the likelihood of contamination and the extent to which radioactive materials are carried aboard the aircraft. An aircraft must be taken out of service if the radiation dose rate at any accessible surface is 0.005 mSv/h (0.5 mrem/h) or if there is significant removable radioactive surface contamination as outlined above. |

<table>
<tr><th>Citation</th><th>Requirement</th></tr>
<tr><td></td><td>
Table A3.1. Removable External Radioactive Contamination--Wipe Limits.
<table>
<tr><th>Contaminant</th><th colspan="3">Maximum permissible limits</th></tr>
<tr><td></td><td>Bq/cm²</td><td>uCi/cm²</td><td>dpm/cm²</td></tr>
<tr><td>Beta and gamma emitters and low toxicity alpha emitters.</td><td>4</td><td>10⁻⁴</td><td>220</td></tr>
<tr><td>All other alpha emitting radionuclides</td><td>0.4</td><td>10⁻⁵</td><td>2.2</td></tr>
</table>
</td></tr>
<tr><td>AFMAN24-204(I), A4.3.6</td><td>Hazard Classification of Fissile Materials<br><br>Except as provided in A3.3.7.9., classify each package of fissile materials as fissile Class I, II, or III. Determine the numerical values for package assignments as fissile Class I, the TIs for fissile Class II packages, and the conveyance limitations for Fissile Class III shipments according to 10 CFR Part 71.<br><br>A4.3.6.1. Fissile Class I. Packages may be transported in unlimited numbers, and in any arrangement, and require no nuclear criticality safety controls during transportation. A TI is not assigned to fissile Class I packages for the purpose of nuclear criticality safety control, although, the external radiation levels may require a TI number.<br><br>A4.3.6.2. Fissile Class II. Packages may be transported together in any arrangement, but in numbers that are not over an aggregate TI of 50. For the purposes of nuclear criticality safety control, individual packages may have a TI of not less than 0.1 and not more than 10. However, the external radiation levels may require a higher TI number. These shipments require no nuclear criticality safety control by the shipper during transportation.<br><br>A4.3.6.3. Fissile Class III. Shipments of packages of fissile materials that do not meet the requirements of fissile Class I or fissile Class II and are controlled in transit as prescribed in A3.3.7.8. by appropriate arrangements between the shipper and the carrier.</td></tr>
<tr><td>AFMAN24-204(I), A11.7</td><td>Authorized Type B Packages.<br><br>A11.7.1. Any Type B, Type B(U), or Type B(M) packaging that meets the applicable requirements in 10 CFR part 71 and has been approved by the U.S. Nuclear Regulatory Commission may be shipped per 49 CFR 173.471.<br><br>A11.7.2. Any Type B, B(U) or B(M) packaging that meets the applicable requirements of the regulations of the IAEA "Regulations for the Safe Transport of Radioactive Materials, No. TS-R-1" and for which the foreign Competent Authority Certificate has been revalidated by DOT according to 49 CFR 173.473. Authorized only for export and import shipments.</td></tr>
<tr><td>AFMAN24-204(I), A11.8</td><td>Authorized Packaging–Fissile Materials.<br><br>A11.8.1. Except as provided in A3.3.7.8., package fissile materials containing not more than $A_1$ or $A_2$ (as appropriate) in:<br><br>A11.8.1.3. Any packaging listed in A11.6., limited to radioactive materials specified in 10 CFR Part 71, Subpart C.</td></tr>
</table>

| Citation | Requirement |
|---|---|
| | A11.8.1.4. Any other Type AF, Type BF, Type B(U)F, or Type B(M)F packaging for fissile radioactive materials that also meets the applicable standards for fissile materials in 10 CFR Part 71.<br><br>A11.8.1.5. Any other Type AF, Type B(U)F, or Type B(M)F packaging that also meets the applicable requirements for fissile material packaging in section VI of the IAEA "Regulations for the Safe Transport of Radioactive Materials, No. TS-R-1" and for which the foreign Competent Authority Certificate has been revalidated by the DOT according to 49 CFR 173.473. Authorized only for export and import shipments.<br><br>A11.8.2. Fissile Radioactive Materials with Radioactive Content Over $A_1$ or $A_2$. Package in either:<br><br>A11.8.2.3. Type B(U) or B(M) packaging that meets the standards for packaging of fissile materials in 10 CFR Part 71, and is approved by the NRC per 49 CFR 173.471.<br><br>A11.8.2.4. Type B(U) or B(M) packaging that meets the applicable requirements for fissile radioactive materials in section VI of the IAEA "Regulations for the Safe Transport of Radioactive Materials, No. TS-R-1" and for which the foreign Competent Authority Certificate has been revalidated by the DOT according to 49 CFR 173.473. Authorized only for export and import shipments. |
| AFMAN24-204(I), A24.1 | Material Requiring Special Assignment Airlift Mission (SAAM).<br><br>A24.1.3. Fissile Class III Radioactive Material. |
| AFMAN24-204(I), A24.2 | Transportation Requirements.<br><br>A24.2.1. Transport the materials identified in A24.1. by SAAM only. Process SAAM requests, cargo clearance, and appropriate confirmations according to DoD 4500.9R, Defense Transportation Regulation.<br><br>A24.2.3. Fissile Class III shipments must incorporate transportation controls that are performed by the shipper or carrier, as appropriate, to provide nuclear criticality safety, and protect against loading, storing, or transporting that shipment with any other fissile material.<br><br>A24.2.4. Transport Fissile Class III shipments in an aircraft:<br>A24.2.4.1. Assigned to the exclusive use of the shipper with a specific restriction for the exclusive use, to be provided in the appropriate arrangements between shipper and carrier and with instructions to that effect issued with the shipping papers.<br>A24.2.4.2. That does not contain other packages of radioactive material requiring one of the labels prescribed in Attachment 15. |
| AFMAN24-204(I), A24.3 | Technical Escorts.<br><br>Furnish technical escorts when service regulations (or cargo clearance arrangements) require it, or when the shipping activity's medical or flight safety personnel dictate. The shipping activity must initiate action to furnish the qualified personnel, when they are required. They must also furnish technical escorts or other personnel to accompany shipments of infectious substances (etiologic agents) or |

| Citation | Requirement |
|---|---|
| | plant quarantine materials per A10.9. When the shipping activity is required to furnish qualified personnel, it will also initiate action to furnish all required protective clothing and equipment for crew members, in addition to the appropriate decontamination detection and emergency first-aid equipment. The escort has complete jurisdiction over the cargo as it pertains to normal security, safety, protection of personnel, repair, and disposal of containers. However, in the following situations, escort authorities are primarily technical advisors, and are subordinate to:<br><br>A24.3.1. The aircraft commander in matters of flight operations and safety.<br><br>A24.3.2. The base installation commander in matters affecting the safety and mission of the command. |
| AFMAN24-204(I), A24.5 | Aircrew Jettison Criteria.<br><br>For cargo consisting of Class 6.1, PG I, hazard zone A toxic material; Class 2.3, hazard zone A toxic material; infectious substances; biological agents; or radioactive material (other than excepted quantities), the jettison criteria are as follows:<br><br>A24.5.1. Must not be jettisoned over land.<br><br>A24.5.2. May not be jettisoned over water unless the cargo, in addition to size criteria, weighs at least 1.6 g/cm3 (100 lbs./ft3) to ensure sinking. Also, the cargo must be jettisoned at least 19.3 kilometers (12 miles) offshore, and preferably beyond a shelf, in water 100 fathoms (600 ft) or more in depth. The aircraft commander is given a predeparture briefing on acceptable jettisoning locations based on the above criteria. When cargo is jettisoned to decrease weight, jettison all other cargo before hazardous cargo.<br><br>A24.5.3. When cargo is leaking and is beyond control of the escort to repair or neutralize, the escort must inform the aircraft commander. The decision of jettisoning will rest with the aircraft commander. In this instance, the commander may jettison the cargo over water without regard to weight or depth criteria.<br><br>A24.5.4. When the cargo weighs less than 1.6 g/cm3 (100 lb./ft3) or when size of cargo would not permit inflight jettisoning, model of aircraft selected for overwater missions must be based on two-engine performance from equal time point (ETP) to destination. Aircraft performance is based on aircraft remaining airborne when all cargo except the hazardous cargo is jettisoned. |

## 4.6 Type C Fissile Material Packages

This section contains the schedule for a Type C fissile material package from IAEA (2015). The identification number associated with this package would be UN 3330. It should be noted that NRC has not adopted the IAEA Type C package requirements in its regulations.

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| | **1. General Provisions** |
| 110, 507 | Other dangerous properties of contents and transport with other dangerous goods. |
| 301-303 | General provisions for radiation protection. |
| 304, 305, 554(c) | Emergency response. |
| 306 | Management system. |
| 311-315 | Training |
| 431 | Classification in case of international shipment when different approval types apply. |
| 501(a)-(c) | Requirements before the first shipment. |
| 502, 503 | Requirements before each shipment. |
| 561 | Possession of package design approval certificates, and possession of instructions for (a) the proper closing of the package and (b) other preparations for shipment. |
| 602-604 | Design requirements for special form radioactive material. |
| 607-618 | Design requirements for all packagings and packages. |
| 619-621 | Additional design requirements – air transport. |
| 636-647, 648(b) | Additional design requirements for Type A packages. |
| 649 | Additional design requirements for packages containing liquids. |
| 653-657, 661-666 | Additional design requirements for B(U) packages |
| 669 | Design requirements for Type C packages – summary.<br>Type C packages shall be designed to meet the requirements specified in paras 607–621 and 636–649, except as specified in para. 648(a), and the requirements specified in paras 653–657, 661–666 and 670–672. |
| 670–672 | Additional design requirements for Type C packages.<br>670. A package shall be capable of meeting the assessment criteria prescribed for tests in paras 659(b) and 663 after burial in an environment defined by a thermal conductivity of 0.33 W/(m·K) and a temperature of 38°C in the steady state. Initial conditions for the assessment shall assume that any thermal insulation of the package remains intact, the package is at the maximum normal operating pressure and the ambient temperature is 38°C.<br>671. A package shall be so designed that if it were at the maximum normal operating pressure and subjected to:<br>A package shall be so designed that if it were at the maximum normal operating pressure and subjected to:<br>(a) The tests specified in paras 719–724, it would restrict the loss of radioactive contents to not more than $10^{-6}$ $A_2$ per hour.<br>(b) The test sequences in para. 734: |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| | (i) It would retain sufficient shielding to ensure that the dose rate 1 m from the surface of the package would not exceed 10 mSv/h with the maximum radioactive contents that the package is designed to contain.<br>(ii) It would restrict the accumulated loss of radioactive contents in a period of one week to not more than $10A_2$ for krypton-85 and not more than $A_2$ for all other radionuclides.<br>Where mixtures of different radionuclides are present, the provisions of paras 405-407 shall apply, except that for krypton-85 an effective $A_2(i)$ value equal to $10A_2$ may be used. For case (a), the assessment shall take into account the external contamination limits of para. 508.<br>672. A package shall be so designed that there will be no rupture of the containment system following performance of the enhanced water immersion test specified in para. 730. |
| 673–685 | Additional design requirements for packages containing fissile material. |
| 802(a), 808-810, 814-816 | Package design requirements — Competent Authority approval. |
| 823 | Transitional arrangements for special form radioactive material approved under the 1973, 1973 (As Amended), 1985, and 1985 (As Amended 1990) Editions of the Regulations. |
| 824 | Packaging serial numbers — informing the competent authority. |
| | **2. Content Limits for Packages** |
| 432 | The quantity of radioactive material is not allowed to exceed the limits specified in para. 432 of the Regulations. |
| 417 | Fissile material and exceptions. |
| 418 | Fissile material. |
| 504 | A package is not allowed to contain any items other than those that are necessary for the use of the radioactive material. The interaction between these items and the package, under the conditions of transport applicable to the design, is not allowed to reduce the safety of the package. |
| | **3. Contamination** |
| 508, 509 | Non-fixed contamination on the external surfaces of any package and on the external and internal surfaces of overpacks, freight containers, tanks, intermediate bulk containers and conveyances is required to be kept as low as practicable and is not allowed to exceed the following limits, when averaged over any area of 300 $cm^2$ of any part of the surface:<br>(a) Beta, gamma and low toxicity alpha emitters, 4 $Bq/cm^2$;<br>(b) All other alpha emitters, 0.4 $Bq/cm^2$. |
| | **4. Maximum Radiation Levels** |
| 526–528, 575 | (i) The radiation level for a package or overpack is required to be such that the transport index (TI) of the package or overpack does not exceed 10, and the criticality safety index (CSI) is not allowed to exceed 50, except when transported under exclusive use. |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| | (ii) The maximum radiation level at any point on any external surface of the package or overpack is not allowed to exceed 2 mSv/h, except when transported under exclusive use by rail or by road, or under exclusive use by sea.[1]<br>(iii) The maximum radiation level at any point on any external surface of a package or overpack transported under exclusive use is not allowed to exceed 10 mSv/h.<br>[1] Packages or overpacks having a surface radiation level greater than 2 mSv/h carried in or on a vehicle under exclusive use may be transported by vessels in accordance with Table 10 of the Regulations, footnote (a), provided that such packages or overpacks are not removed from the vehicle at any time while on board the vessel. |
| | **5. Categories of Packages and Overpacks** |
| 523, 524 | The TI is required to be derived in accordance with the procedure as stated in paras 523 and 524 of the Regulations. |
| 525, 686 | CSI for packages containing fissile material, and for overpacks and freight containers. |
| 529, Table 8 | Packages and overpacks are required to be assigned to category I-WHITE, Category II-YELLOW or category III-YELLOW. |
| | **6. Marking and Labeling** |
| 507 | Packages, freight containers and overpacks containing materials having other dangerous properties (e.g. corrosiveness) are also required to be marked and labeled as required by the relevant transport regulations. |
| 531 | Each package is required to be marked with an identification of either the consignor or the consignee, or both. |
| 531–533, 535 | All markings are required to be legible and durable, and are required to be on the outside of the packaging. |
| 532, Table 9 | Packages are required to bear the mark "UN 3330" and the proper shipping name "RADIOACTIVE MATERIAL, TYPE C PACKAGE, FISSILE". |
| 533 | Packages with a gross mass exceeding 50 kg are required to be marked with their permissible gross mass on the outside of the packaging. |
| 535 | Each package is required to be marked with:<br>(a) The identification mark allocated to that design by the competent authority;<br>(b) A serial number to uniquely identify each packaging that conforms to that design;<br>(c) "TYPE C". |
| 536, Fig. 1 | The outside of the outermost receptacle that is resistant to the effects of fire and water is required to be plainly marked by embossing, stamping, or other means resistant to the effects of fire and water, with the trefoil symbol shown in Fig. 1 of the Regulations. |
| 538 | Any labels that do not relate to the contents are required to be removed or covered. |
| 538, 541-543, Figs 2-5 | Each package, overpack and freight container is required to bear the appropriate labels. Paragraph 543 of the Regulations sets out alternative provisions for large freight containers and tanks. |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| 539 | The labels are required to be fixed to two opposite sides of the outside of the package or overpack, or on all four sides of a freight container or tank. The labels are not allowed to cover the markings specified in paras 531–536 of the Regulations. |
| 540(a), (b), (d), Table 2 | Each label is required to be marked with the name(s) of the radionuclide(s), the maximum activity of the contents and the TI. Paragraph 540(a) of the Regulations also establishes requirements for labeling mixtures of radionuclides. The mass of fissile material, in grams (g), or multiples of grams, may be used instead of the activity. |
| 540(c) | Except for mixed loads, each label on a freight container or overpack is required to be marked with:<br>(i) The radioactive contents;<br>(ii) The maximum activity of the total radioactive contents during transport.<br>For mixed loads, such entries may read “See Transport Documents”. |
| 545 | It is the consignor’s responsibility to comply with the requirements of marking, labeling and placarding. |
| | **7. Requirements Before Shipping** |
| 501 | Before the first shipment, confirmation is required that the shielding, containment, heat transfer characteristics, confinement system and neutron poisons conform to the approved design. |
| 502, 503 | Before each shipment of any package, the following requirements apply:<br>(a) For any package, it is required to ensure that all the requirements specified in the relevant provisions of the Regulations have been satisfied.<br>(b) It is required to ensure that lifting attachments that do not meet the requirements of para. 608 of the Regulations have been removed or otherwise rendered incapable of being used for lifting the package, in accordance with para. 609 of the Regulations.<br>(c) For each package, it is required to ensure that all the requirements specified in the Competent Authority approval certificates have been satisfied.<br>(d) Each package is required to be held until equilibrium conditions have been approached closely enough to demonstrate compliance with the requirements for temperature and pressure unless an exemption from these requirements has received unilateral approval.<br>(e) For each package, it is required to ensure by inspection and/or appropriate tests that all closures, valves and other openings of the containment system through which the radioactive contents might escape are properly closed and, where appropriate, sealed in the manner for which the demonstrations of compliance with the requirements of paras 659 and 671 of the Regulations were made.<br>(f) For packages containing fissile material, the measurement specified in para. 677(b) of the Regulations and the tests to demonstrate closure of each package as specified in para. 680 of the Regulations are required to be performed where applicable. |
| 546 | Transport documents with each consignment (consignment notes) are required to include all relevant particulars of the consignment. |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| 547–553 | The consignor is required to include a declaration in the transport documents. |
| 554, 555 | The consignor is required to provide a statement regarding actions to be taken by the carrier. |
| 556 | The consignor is required to make competent authority certificates available to the carrier(s) before loading and unloading. |
| 557 | Before the first shipment, the consignor is required to ensure that copies of each Competent Authority Certificate applying to that package design have been submitted to the competent authority of each state through or into which the consignment is to be transported. The consignor is not required to await an acknowledgement from the competent authority, nor is the competent authority required to make an acknowledgement of receiving the certificate. |
| 558(a) | For each shipment containing radioactive material with an activity greater than $3000A_1$ or $3000A_2$, as appropriate, or 1000 TBq, whichever is the lower, the consignor is required to notify the competent authority of each state through or into which the consignment is to be transported. This notification is required to have been received by each competent authority prior to the commencement of the shipment, and preferably at least seven days in advance. See also para. 559 of the Regulations. |
| 559 | The notification referred to in para. 558 of the Regulations is required to include:<br>(a) Clear identification of the package, including all applicable certificate numbers and identification marks;<br>(b) The date of shipment, the expected date of arrival and the proposed routing;<br>(c) The names of the radioactive materials or nuclides;<br>(d) Descriptions of the physical and chemical forms of the radioactive material, or whether it is special form radioactive material or low dispersible radioactive material;<br>The maximum activity of the radioactive contents during transport, expressed in Becquerels (Bq) with the appropriate SI prefix symbol (see Annex II of the Regulations). The mass of fissile material in grams (g), or multiples of grams, may be used in place of activity. |
| 560 | Separate notification is not required if the information has been included in the application for shipment approval (see para. 827 of the Regulations). |
| 825(c) | Shipments — competent authority multilateral approval is required where the CSI is greater than 50. |
| 825(d) | Radiation protection programs for shipments by special use vessels. |
| 826 | Competent authority authorization of transport without shipment approval. |
| 827 | Information to be included in an application for shipment approval. |
| | **8. Provisions Concerning Transport Operations** |
| | **8.1 Modal Requirements** |
| 573(a)–(c) | For transport by rail and by road: for consignments under exclusive use, the radiation level is not allowed to exceed:<br>(a) 10 mSv/h at any point on the external surface of any package or overpack, and may only exceed 2 mSv/h provided that: |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| | (i) The vehicle is equipped with an enclosure that prevents unauthorized access during transport;<br>(ii) The package or overpack is secured to retain its position within the enclosure during routine transport;<br>(iii) There are no loading or unloading operations between the beginning and the end of the shipment.<br>(b) 2 mSv/h at any point on the outer surfaces of the vehicle, including the upper and lower surfaces, or, in the case of an open vehicle, at any point on the vertical planes projected from the outer edges of the vehicle, on the upper surface of the load, and on the lower external surface of the vehicle.<br>(c) 0.1 mSv/h at any point 2 m from the vertical planes represented by the outer lateral surfaces of the vehicle, or, if the load is transported in an open vehicle, at any point 2 m from the vertical planes projected from the outer edges of the vehicle. |
| 574 | For transport by road: no persons other than the driver and assistants are permitted in vehicles carrying packages, overpacks or freight containers bearing Category II-YELLOW or category III-YELLOW labels. |
| 575 | For transport by vessels: packages or overpacks having a surface radiation level greater than 2 mSv/h, unless being carried in or on a vehicle under exclusive use in accordance with Table 10 of the Regulations, footnote (a), are not allowed to be transported. |
| 576 | For transport by vessels: the transport of consignments by means of a special use vessel is excepted from the requirements of para. 566 of the Regulations relating to TI, CSI and radiation level provided that the conditions stated in para. 576 of the Regulations are met. |
| 579 | For transport by air: packages or overpacks having a surface radiation level greater than 2 mSv/h are not allowed to be transported, except under special arrangement. |
| 580, 581 | Transport by post is not permitted. |
| | **8.2 Placarding** |
| 507 | Placards may be required for other dangerous properties of the contents. |
| 543, Fig. 6 | Large freight containers and tanks are required to bear four placards in a vertical orientation on the two external side walls and the two external end walls. |
| 543 | Any placards that do not relate to the contents are required to be removed. |
| 543, Figs 2–6 | As an alternative to the use of placards on large freight containers and tanks, enlarged labels are permitted. |
| 544, Figs 6, 7 | Where an exclusive use consignment in a freight container is UN 3330 Type C packages only, and no other UN number commodities are present, the UN number “UN 3330” is required to be displayed on all four sides of the freight container, in black digits not less than 65 mm high, either in the lower half of the placard shown in Fig. 6 of the Regulations against the white background, or on the placard shown in Fig. 7 of the Regulations. If the placard shown in Fig. 7 of the Regulations is used, it is required to be fixed close to each main placard. |
| 545 | Consignor’s responsibilities. |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| 571, Figs 2–6 | The location of placards and the use of placards with reduced dimensions on a road or rail vehicle are stipulated. |
| 572, Figs 6, 7 | Where an exclusive use consignment in or on a road or rail vehicle is UN 3330 Type C packages only, and no other UN number commodities are present, the UN number “UN 3330” is required to be displayed, in black digits not less than 65 mm high, either in the lower half of the placard shown in Fig. 6 of the Regulations against the white background or on the placard shown in Fig. 7 of the Regulations. If the placard shown in Fig. 7 of the Regulations is used, it is required to be fixed close to each main placard. |
| | **8.3 Stowage during transport, storage in transit and segregation** |
| 562 | Packages, overpacks and freight containers are required to be segregated during transport and during storage in transit. The criteria for segregation are set out in paras 562(a)–(d) and 506 of the Regulations. |
| 562(a) | Criteria for segregation from workers in regularly occupied working areas. |
| 562(b) | Criteria for segregation from members of the public. |
| 562(c) | Criteria for segregation from undeveloped photographic |
| 562(d), 506 | Criteria for segregation from other dangerous goods. |
| 563 | Category II-YELLOW or category III-YELLOW packages or overpacks may be carried in compartments occupied by passengers under specific conditions. |
| 564 | Consignments are required to be securely stowed. |
| 565 | A package or overpack may be carried or stored among packaged general cargo, under certain conditions. |
| 566(a), Table 10 | TI limits for freight containers and conveyances. |
| 566(b) | Limits on the radiation levels from freight containers and conveyances. See para. 573(b) and (c) of the Regulations for exceptions. |
| 566(c), Table 11 | CSI limits for freight containers and conveyances. |
| 567 | Any package or overpack having a TI greater than 10, or any consignment having a CSI greater than 50, is required to be transported only under exclusive use. |
| 568, 569, Table 11 | Segregation of packages during transport and storage in transit. |
| 576 | For a special use vessel, the storage arrangements are excepted from the requirements of para. 566 of the Regulations provided that the conditions stated in para. 576 of the Regulations are met. |
| | **8.4 Damaged or leaking package** |
| 510 | Actions to be taken when a package has been damaged or is leaking, or where it is suspected that the package may have leaked or been damaged. |
| 511 | Movement of packages that are damaged or leaking radioactive contents in excess of allowable limits for normal conditions of transport. |
| | **8.5 Decontamination** |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| 512 | Periodic checking of conveyances and equipment is required to determine the level of contamination. |
| 513 | Decontamination of conveyances, equipment or parts thereof that have become contaminated. |
| | **8.6 Other provisions** |
| 309 | In the event of non-compliance, appropriate actions are required to be taken as soon as possible, including communication and remedy. |
| 582 | Customs operations may be carried out only in a place where adequate means of controlling radiation exposure are provided. |
| 583 | Where a consignment is undeliverable, appropriate actions are required to be taken as soon as possible. |
| | **9. Tests for Type C Packages** |
| 719 | The tests are the water spray test, the free drop test, the stacking test and the penetration test. Specimens of the package shall be subjected to the free drop test, the stacking test and the penetration test, preceded in each case by the water spray test. One specimen may be used for all the tests, provided that the requirements of para. 720 are fulfilled. |
| 720 | The time interval between the conclusion of the water spray test and the succeeding test shall be such that the water has soaked in to the maximum extent, without appreciable drying of the exterior of the specimen. In the absence of any evidence to the contrary, this interval shall be taken to be 2 h if the water spray is applied from four directions simultaneously. No time interval shall elapse, however, if the water spray is applied from each of the four directions consecutively. |
| 721 | Water spray test: The specimen shall be subjected to a water spray test that simulates exposure to rainfall of approximately 5 cm per hour for at least 1 h. |
| 722 | Free drop test: The specimen shall drop onto the target so as to suffer maximum damage in respect of the safety features to be tested:<br>(a) The height of the drop, measured from the lowest point of the specimen to the upper surface of the target, shall be not less than the distance specified in Table 14 for the applicable mass. The target shall be as defined in para. 717.<br>(b) For rectangular fibreboard or wood packages not exceeding a mass of 50 kg, a separate specimen shall be subjected to a free drop onto each corner from a height of 0.3 m.<br>(c) For cylindrical fibreboard packages not exceeding a mass of 100 kg, a separate specimen shall be subjected to a free drop onto each of the quarters of each rim from a height of 0.3 m. |

<table>
<tr><th>SSR-6 Paragraph[a]</th><th>Requirement</th></tr>
<tr><td></td><td>
TABLE 14. FREE DROP DISTANCE FOR TESTING PACKAGES TO NORMAL CONDITIONS OF TRANSPORT
<table>
<tr><th>Package mass (kg)</th><th>Free drop distance (m)</th></tr>
<tr><td>package mass < 5 000</td><td>1.2</td></tr>
<tr><td>5 000 ≤ package mass < 10 000</td><td>0.9</td></tr>
<tr><td>10 000 ≤ package mass < 15 000</td><td>0.6</td></tr>
<tr><td>15 000 ≤ package mass</td><td>0.3</td></tr>
</table>
</td></tr>
<tr><td>723</td><td>Stacking test: Unless the shape of the packaging effectively prevents stacking, the specimen shall be subjected, for a period of 24 h, to a compressive load equal to the greater of the following:<br>(a) The equivalent of five times the maximum weight of the package;<br>(b) The equivalent of 13 kPa multiplied by the vertically projected area of the package.<br>The load shall be applied uniformly to two opposite sides of the specimen, one of which shall be the base on which the package would typically rest.</td></tr>
<tr><td>724</td><td>Penetration test: The specimen shall be placed on a rigid, flat, horizontal surface that will not move significantly while the test is being carried out:<br>(a) A bar, 3.2 cm in diameter with a hemispherical end and a mass of 6 kg, shall be dropped and directed to fall with its longitudinal axis vertical onto the center of the weakest part of the specimen so that if it penetrates sufficiently far it will hit the containment system. The bar shall not be significantly deformed by the test performance.<br>(b) The height of the drop of the bar, measured from its lower end to the intended point of impact on the upper surface of the specimen, shall be 1 m.</td></tr>
<tr><td>730</td><td>Enhanced water immersion test: The specimen shall be immersed under a head of water of at least 200 m for a period of not less than 1 h. For demonstration purposes, an external gauge pressure of at least 2 MPa shall be considered to meet these conditions.</td></tr>
<tr><td>734</td><td>Specimens shall be subjected to the effects of the following test sequences:<br>(a) The tests specified in paras 727(a), 727(c), 735 and 736, in this order;<br>(b) The test specified in para. 737.<br>Separate specimens are allowed to be used for the sequence in (a) and for (b).</td></tr>
<tr><td>727(a), 727(c)</td><td>Mechanical test: The mechanical test consists of three different drop tests. Each specimen shall be subjected to the applicable drops, as specified in para. 659 or para. 685. The order in which the specimen is subjected to the drops shall be such</td></tr>
</table>

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| | that, on completion of the mechanical test, the specimen shall have suffered such damage as will lead to maximum damage in the thermal test that follows:<br><br>(a) For drop I, the specimen shall drop onto the target so as to suffer maximum damage, and the height of the drop, measured from the lowest point of the specimen to the upper surface of the target, shall be 9 m. The target shall be as defined in para. 717.<br><br>(c) For drop III, the specimen shall be subjected to a dynamic crush test by positioning the specimen on the target so as to suffer maximum damage by the drop of a 500 kg mass from 9 m onto the specimen. The mass shall consist of a solid mild steel plate 1 m × 1 m and shall fall in a horizontal attitude. The lower face of the steel plate shall have its edges and corners rounded off to a radius of not more than 6 mm. The height of the drop shall be measured from the underside of the plate to the highest point of the specimen. The target on which the specimen rests shall be as defined in para. 717. |
| 735 | Puncture–tearing test: The specimen shall be subjected to the damaging effects of a vertical solid probe made of mild steel. The orientation of the package specimen and the impact point on the package surface shall be such as to cause maximum damage at the conclusion of the test sequence specified in para. 734(a):<br><br>(a) The specimen, representing a package having a mass of less than 250 kg, shall be placed on a target and subjected to a probe having a mass of 250 kg falling from a height of 3 m above the intended impact point. For this test the probe shall be a 20 cm diameter cylindrical bar with the striking end forming the frustum of a right circular cone with the following dimensions: 30 cm height and 2.5 cm diameter at the top with its edge rounded off to a radius of not more than 6 mm. The target on which the specimen is placed shall be as specified in para. 717.<br><br>(b) For packages having a mass of 250 kg or more, the base of the probe shall be placed on a target and the specimen dropped onto the probe. The height of the drop, measured from the point of impact with the specimen to the upper surface of the probe, shall be 3 m. The probe for this test shall have the same properties and dimensions as specified in (a), except that the length and mass of the probe shall be such as to cause maximum damage to the specimen. The target on which the base of the probe is placed shall be as specified in para. 717. |
| 736 | Enhanced thermal test: The conditions for this test shall be as specified in para. 728, except that the exposure to the thermal environment shall be for a period of 60 min. |
| 728 | Thermal test: The specimen shall be in thermal equilibrium under conditions of an ambient temperature of 38°C, subject to the solar insolation conditions specified in Table 12 and subject to the design maximum rate of internal heat generation within the package from the radioactive contents. Alternatively, any of these parameters are allowed to have different values prior to, and during, the test, provided due account is taken of them in the subsequent assessment of package response. The thermal test shall then consist of (a) followed by (b).<br><br>(a) Exposure of a specimen for a period of 30 min to a thermal environment that provides a heat flux at least equivalent to that of a hydrocarbon fuel–air fire in sufficiently quiescent ambient conditions to give a minimum average flame emissivity coefficient of 0.9 and an average temperature of at least 800°C, fully engulfing the specimen, with a surface absorptivity coefficient of 0.8 or that value that the package may be demonstrated to possess if exposed to the fire specified. |

| SSR-6 Paragraph[a] | Requirement |
|---|---|
| | (b) Exposure of the specimen to an ambient temperature of 38°C, subject to the solar insolation conditions specified in Table 12 and subject to the design maximum rate of internal heat generation within the package by the radioactive contents for a sufficient period to ensure that temperatures in the specimen are decreasing in all parts of the specimen and/or are approaching initial steady state conditions. Alternatively, any of these parameters are allowed to have different values following cessation of heating, provided due account is taken of them in the subsequent assessment of package response. During and following the test, the specimen shall not be artificially cooled and any combustion of materials of the specimen shall be permitted to proceed naturally. |
| 737 | Impact test: The specimen shall be subject to an impact on a target at a velocity of not less than 90 m/s, at such an orientation as to suffer maximum damage. The target shall be as defined in para. 717, except that the target surface may be at any orientation as long as the surface is normal to the specimen path. |
| 717 | The target for the drop test specified in paras 705, 722, 725(a), 727 and 735 shall be a flat, horizontal surface of such a character that any increase in its resistance to displacement or deformation upon impact by the specimen would not significantly increase damage to the specimen. |
| a. Source: IAEA (2018) | |

# 5.0 Onsite Transportation at the Idaho National Laboratory

For onsite transport at DOE sites, DOE Order 460.1D allows for the preparation of a Transportation Safety Document to demonstrate equivalent safety for deviations from hazardous materials transportation requirements.

The INL Transportation Safety Document (INL 2017) describes the INL packaging and transportation program and explains the methodology for complying with the rules, laws, and regulations governing onsite and offsite transportation functions at the INL site. The INL Transportation Safety Document contains the following sections:

1. Purpose, scope and applicability policy, and document control.
2. Definitions and acronyms.
3. Site description.
4. Organizational structure and responsibilities.
5. Transport regulations.
6. Site-specific standards, procedures, and instructions.
7. Safety-assessment methodology.
8. Routine shipments.
9. Nonroutine shipments.
10. Personnel qualification and training.
11. Documentation and recordkeeping.
12. Incident reporting and emergency response.
13. Transport vehicle operation.

Shipments that do not fully comply with DOT hazardous materials regulations are known as nonroutine shipments. Nonroutine shipments require the preparation of a Transport Plan. Cases that require the preparation of a Transport Plan include variations to packaging requirements (such as use of a packaging not authorized by DOT for shipping the material), packaging limits (such as radiation or contamination limits), and any other DOT requirements that cannot be met. The INL Transportation Safety Document requires that Transport Plans identify, as applicable, the specific DOT requirement(s) not met, hazard category, safety analysis, technical safety requirements, administrative controls, hazard controls, engineered barriers, and site-mitigating conditions that ensure a level of safety equivalent to that afforded by DOT requirements for routine shipments. Items that could be included in a Transport Plan include:

1. Scope.
2. Authorized material description.

3. Hazard categorization.

4. DOT requirements not met and proposed alternatives.

5. Projected use of packaging, identification of packaging (such as name, model), and packaging specifications, standards, and tests.

6. Design features (material used, specifications, weight, dimensions, and mechanical features) and general description. Closure devices (bolting, latching, and locking) are to ensure retention of contents under normal transport or accident conditions.

7. Radioactive and fissile-loading considerations, including shielding, heat transfer considerations, maximum load limits, and radiation limits.

8. Nuclear criticality safety analysis, including assignment of a CSI for criticality control.

9. Hazard and accident analysis, primarily based on the capability of the packaging to meet maximum credible accident conditions, and substantiation of accident scenarios.

10. Technical safety requirements (including administrative controls) if the activity is Hazard Category 3 or greater. Examples of technical safety requirements include allowable routes, vehicle speed limits, packaging controls, source term limits, and fissile criticality controls.

11. Restrictions on use and special transport conditions.

12. Additional transportation hazard controls.

13. Lifting devices, rigging devices, tie-down devices, and rigging and tie-down arrangement sketches.

14. Quality assurance, maintenance, and inspection program.

15. Emergency response considerations.

16. ALARA.

17. Transport route including pickup and delivery locations, distances, maps, and overhead clearances.

18. Loading activities at point of origin.

19. Unloading activities at the receiving facility.

Figure 14 and Figure 15 illustrate the process for developing new Transport Plans and revising existing plans. Examples of Transport Plans include:

- *Transport Plan for the High Load Charger Cask* (INL 2018)

- *Transport Plan for the Transfer of EBR-II Driver Fuel Between INTEC and MFC* (INL 2019a)

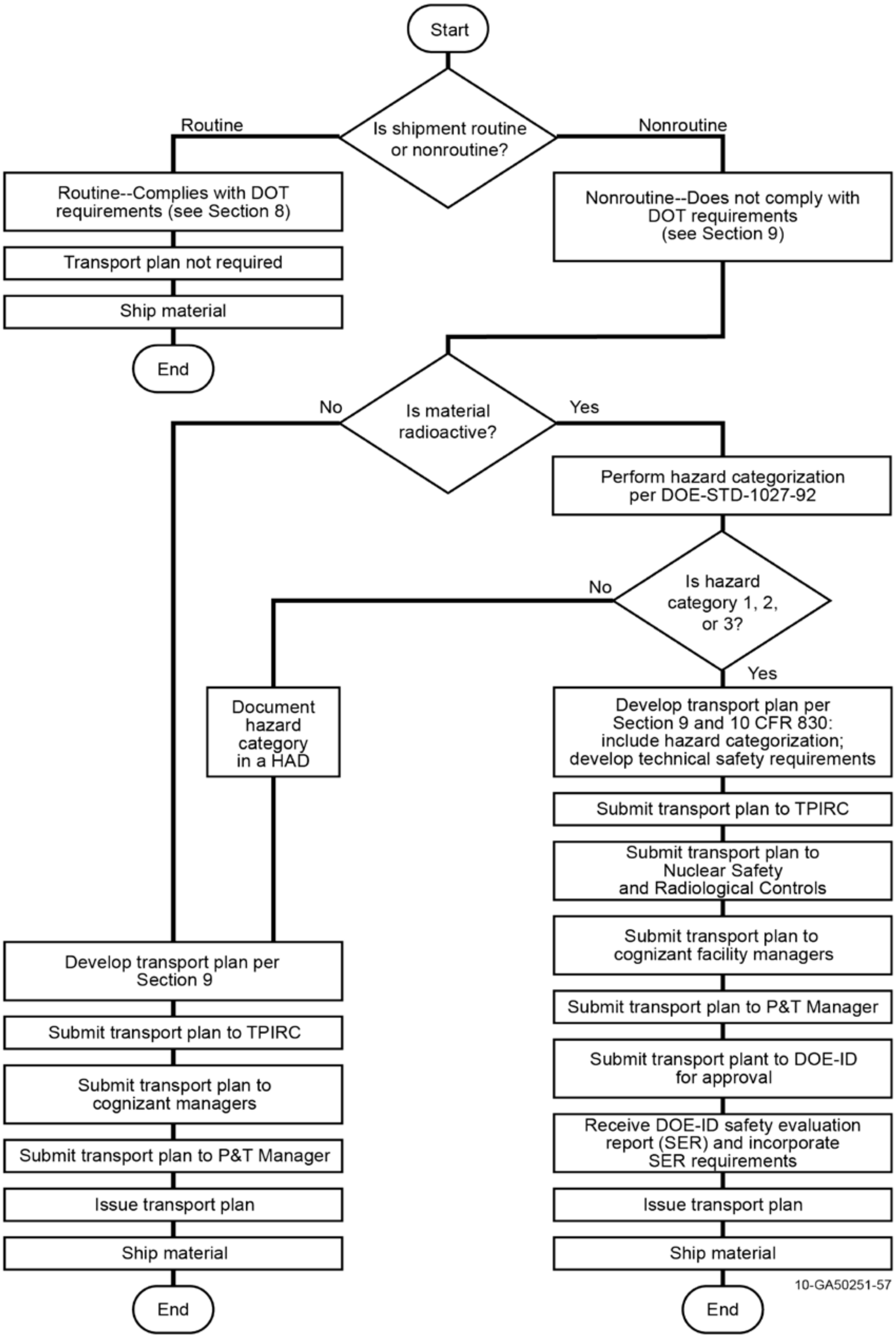


Figure 14. Transport Plan Process Flow for Developing New Plans

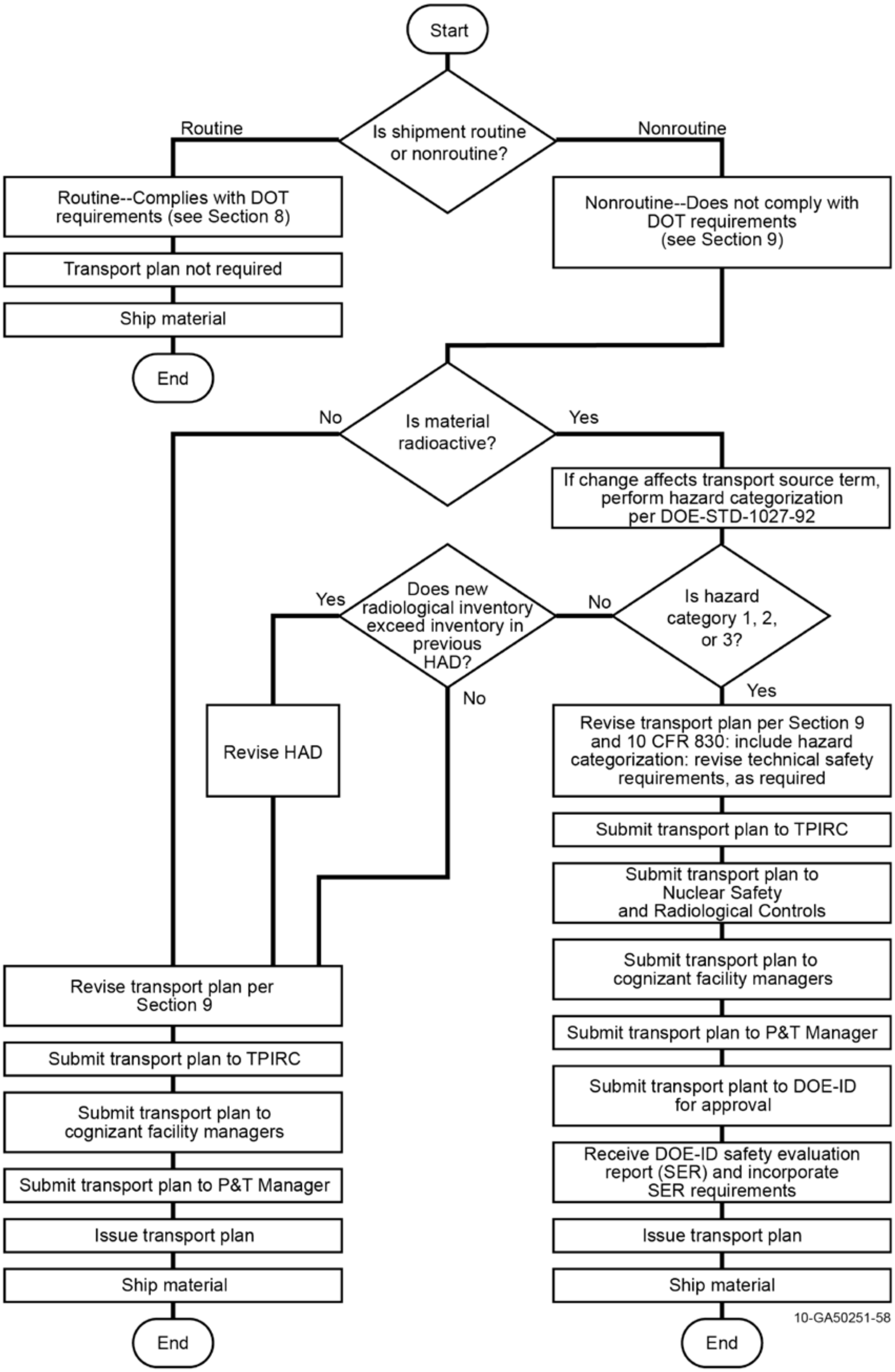


Figure 15. Transport Plan Process Flow for Revising Plans

For nonroutine shipments, INL (2017) allows an alternative to Transport Plan preparation. This alternative consists of preparing a Documented Safety Analysis that includes transportation activities at nonreactor nuclear facilities. If the Documented Safety Analysis addresses all transportation hazards and controls necessary to provide safety equivalent to DOT regulations, then the requirements of DOE Order 460.1D are met and a Transport Plan is not required for the transportation of the material covered by the Documented Safety Analysis. The INL report *Safety Analysis Report for Intra-INL and MFC Inter-Facility Transfers* (INL 2019b) is an example of a Documented Safety Analysis prepared in lieu of a Transport Plan. The technical safety requirements derived from INL (2019b) are contained in the INL report *Technical Safety Requirements for Intra-INL and MFC Inter-Facility Transfers* (INL 2019c). For INL intra-facility transfers between INTEC and MFC, there is one approved container/payload, the NAC-LWT transportation cask containing Materials Test Reactor (MTR) canisters (INL 2019d).

In terms of potential sites at the INL for an advanced reactor or microreactor demonstration, INL has evaluated 32 sites and has identified nine preferred locations on the INL (Connor et al. 2020). These sites include:

- Site #1 – CPP-691 (Fuel Processing Restoration)
- Site #2 – MFC-767 [Experimental Breeder Reactor II (EBR-II)]
- Site #3 – MFC-775/776 (Zero Power Physics Reactor)
- Site #9 – Undeveloped area west of the Materials and Fuels Complex (MFC)
- Site #10 – Undeveloped area north of MFC
- Site #11 – Undeveloped area east of MFC
- Site #6 – Previously developed area west of the Central Facilities Area (CFA)
- Site #32 – Previously developed area east of CFA
- Site #8 – Undeveloped area west of the Advanced Test Reactor (ATR) Complex.

One site is located at the Idaho Nuclear Technology and Engineering Center (INTEC), five of these sites are located at or near MFC, two sites are located in the vicinity of CFA, and one site is located near the ATR Complex, and (see Figure 16). In Figure 16, the preferred sites are denoted with green dots. Figure 17 shows the location of preferred site #1 at INTEC, Figure 18 shows the location of preferred sites #2, 3, 9, 10, and 11 at MFC, Figure 19 shows the location of preferred sites #6 and 32 near CFA, and Figure 20 shows the location of preferred site #8 at ATR.

It should be noted that CFA is connected to the national rail network through the Union Pacific Railroad Mackay Branch Line and the Scoville Spur, located in the southern part of the INL site. A DOE-owned railroad track connects the Scoville Spur to CFA and to INTEC (Griffith and Holland 2015). None of the other locations have rail access. This would make truck a more viable mode of transport between most of the preferred sites identified in Connor et al. (2020).

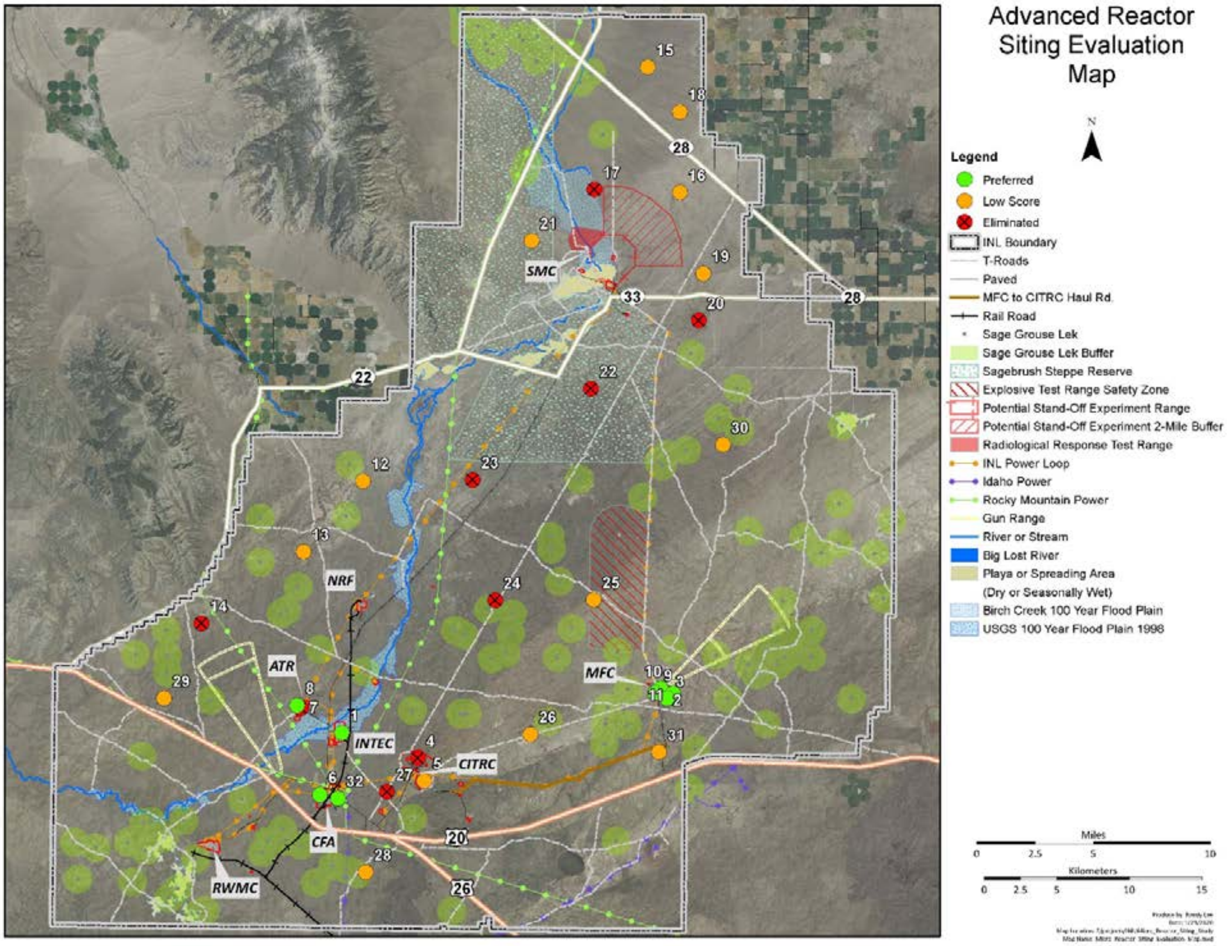


Figure 16. Candidate Advanced Reactor/Microreactor Sites (Connor et al. 2020)

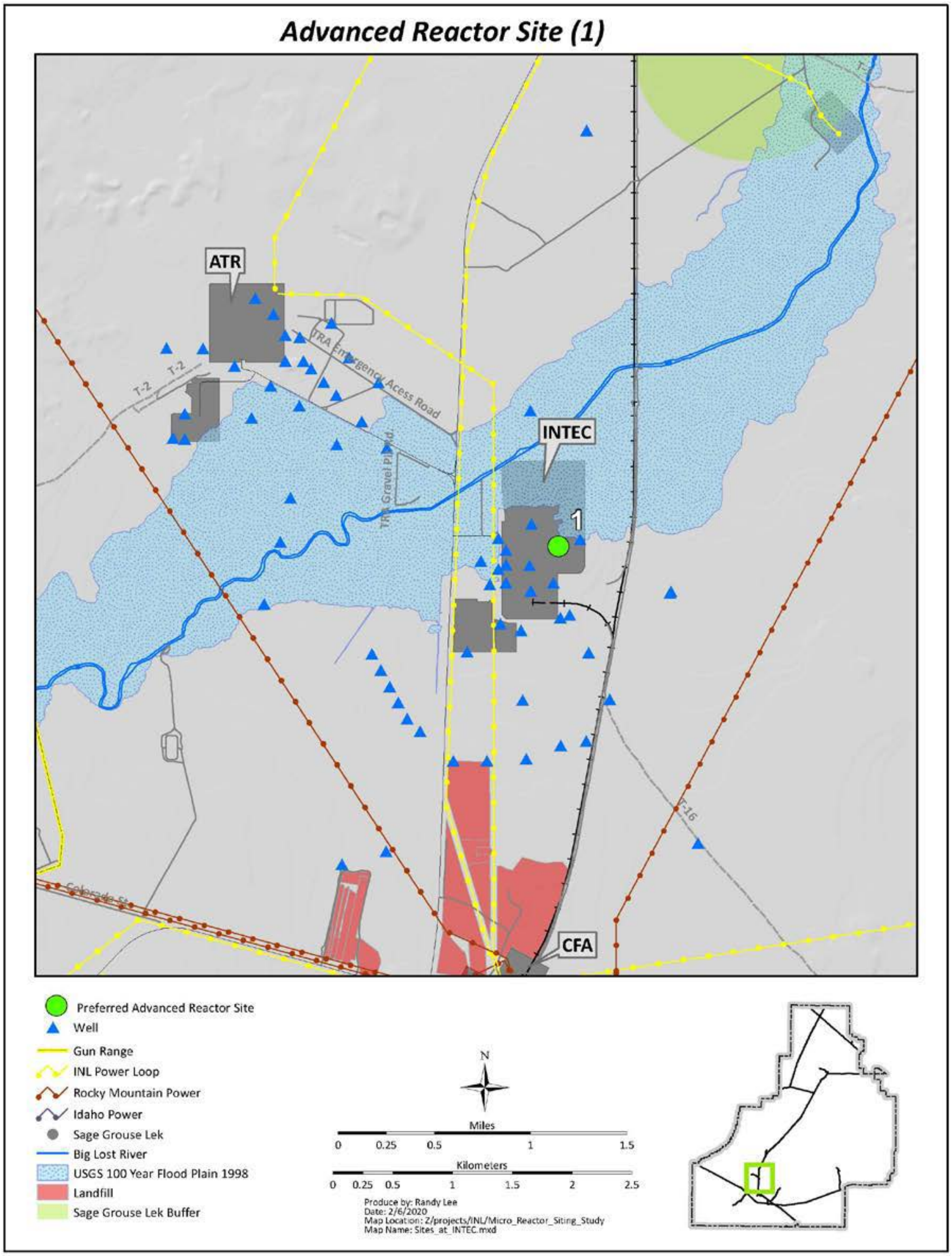


Figure 17. Preferred Site #1 at INTEC (Connor et al. 2020)

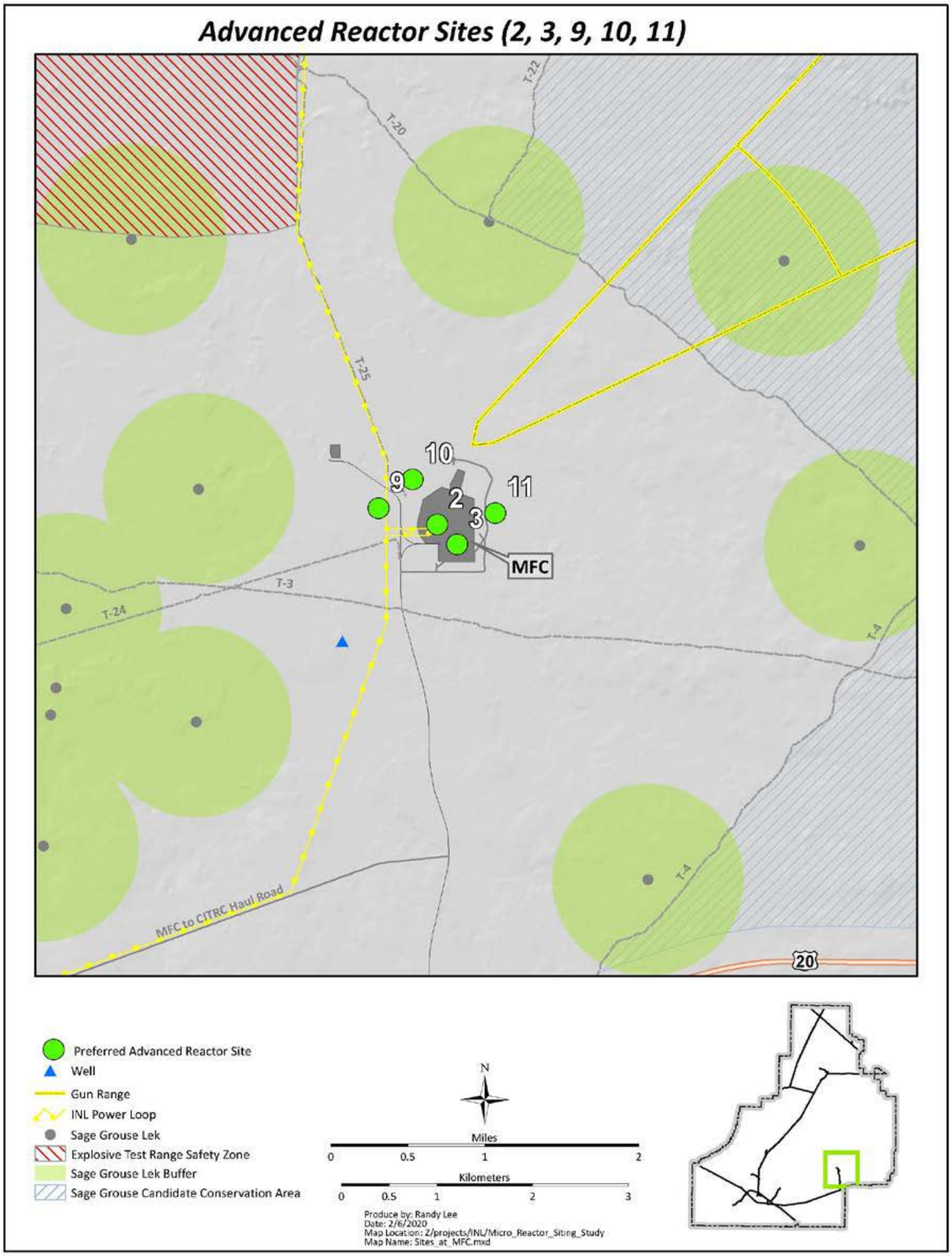


Figure 18. Preferred Sites #2, 3, 9, 10, and 11 at or near MFC (Connor et al. 2020)

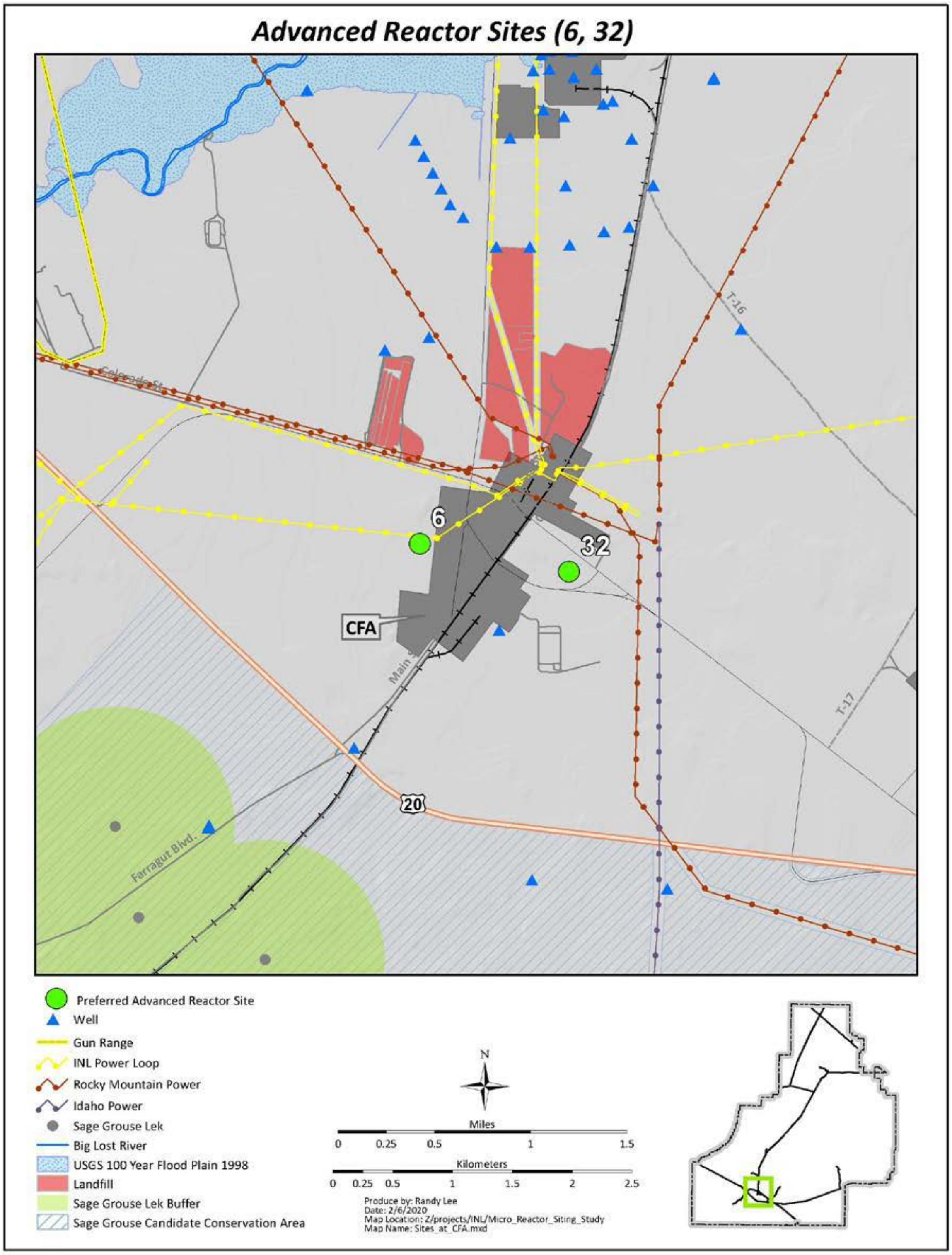


Figure 19. Preferred Sites #6 and 32 near CFA (Connor et al. 2020)

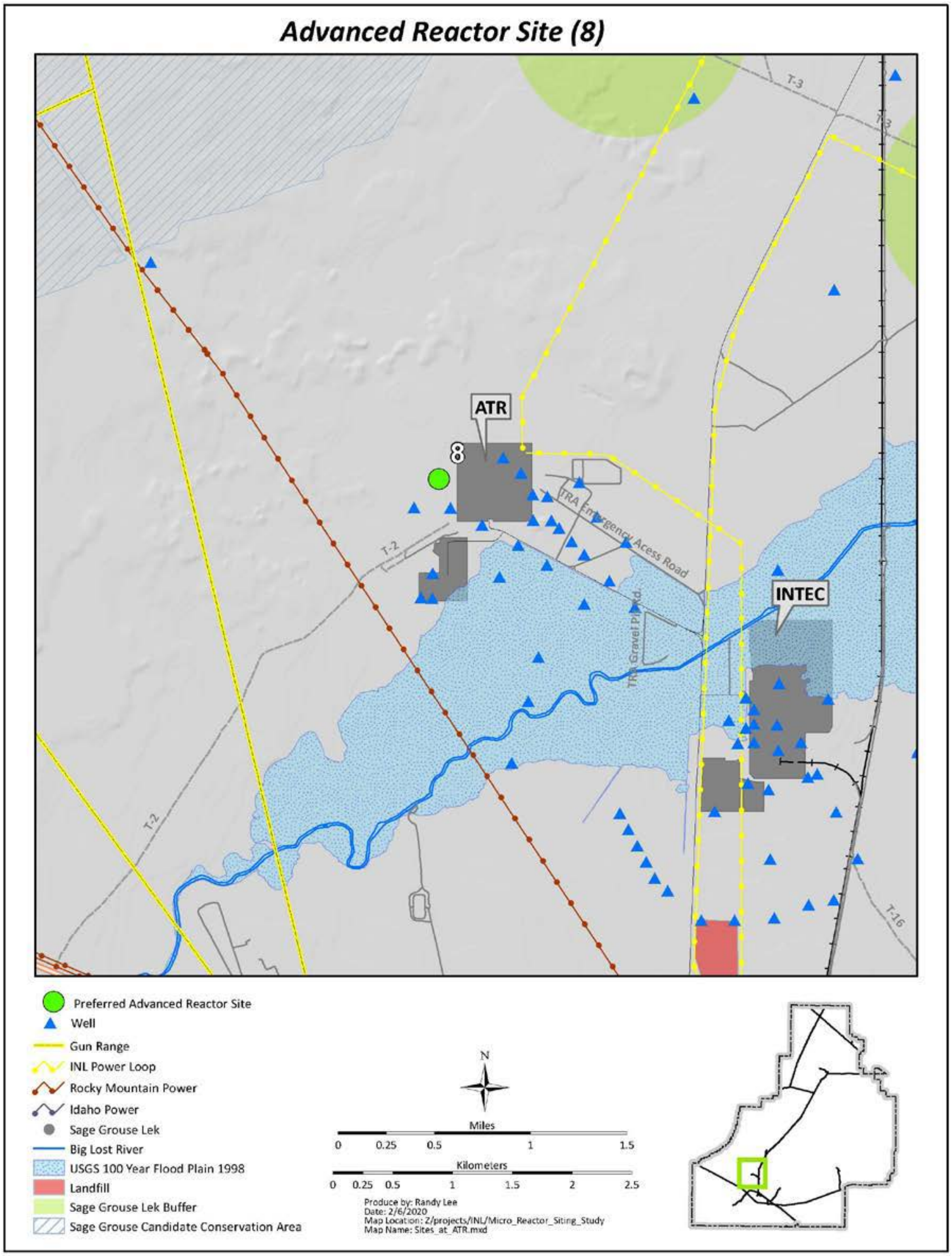


Figure 20. Preferred Sites #8 near ATR (Connor et al. 2020)

# 6.0 Issues Associated with Microreactor Transport

This section discusses issues that have been identified with microreactor transport. Throughout this section, the most significant issues are associated with shipping the microreactor together with its contents by any transport mode, or shipping microreactor fuel by air.

In general, transporting a microreactor without its contents prior to irradiation would not be an issue as the microreactor would not be a hazardous material shipment. However, the shock and vibration associated with the transportation environment would have to be considered in the design of the microreactor. Shipping a microreactor without its contents after irradiation by highway, rail, or barge would be similar in concept to shipping an irradiated commercial nuclear power plant reactor vessel. Shipping of these reactor vessels has been done intact, such as from the Trojan nuclear power plant or the La Crosse nuclear power plant, or segmented, such as from the Rancho Seco nuclear power plant.

## 6.1 Microreactor Fuel Types

Two microreactor fuel types are evaluated in this analysis, TRISO fuel and sodium bonded UZrH fuel. TRISO fuel is specified in the Project Pele Request for Solutions and sodium bonded UZrH fuel is representative of the fuel used in the SNAP-10A reactor. Figure 21 illustrates TRISO fuel particles, fuel compacts, prismatic graphite blocks, and spherical fuel pebbles. Figure 22 illustrates a SNAP-10A fuel pin.

The TN-FSV transportation cask (Docket No. 71-9523) is currently certified to ship irradiated high-temperature gas-cooled reactor TRISO fuel elements from the Fort St. Vrain nuclear power plant and BISO fuel elements from Peach Bottom Unit 1, Core 2. For the Fort St. Vrain fuel, the maximum enrichment allowed by the certificate of compliance (CoC) is 93.5 percent, the maximum burnup is 70,000 MWd/MTIHM, and the minimum cooling time is 1600 days. For the Peach Bottom fuel, the maximum enrichment allowed by the CoC is 93.15 percent, the maximum burnup is 73,000 MWd/MTIHM, and the minimum cooling time is 27 years. The TN-FSV is a Type B(U)F-96 package. The CoC for the TN-FSV does not authorize the air transport of fissile material.

Based on the ability of the TN-FSV transportation cask to transport Fort St. Vrain TRISO and Peach Bottom BISO fuel elements, it is likely that transporting microreactor TRISO irradiated fuel elements separately from the microreactor is achievable. However, structural, thermal, shielding, and criticality analyses would be required to show that a microreactor containing TRISO irradiated fuel elements would meet the requirements of 10 CFR Part 71, particularly for very short cooling times. These structural, thermal, shielding, and criticality analyses would be required to go through the regulatory body review process before a CoC for the transportation package would be issued.

The FSV-3 package (Docket No. 71-6347) was certified to ship unirradiated high-temperature gas-cooled reactor TRISO fuel elements from the Fort St. Vrain nuclear power plant. The CoC allowed enrichments up to about 93 percent. The CoC expired on October 1, 2008. The FSV-3 was a Type AF package which means that the total quantity of radioactive material in the package may not exceed a Type A quantity. The CoC for the FSV-3 did not authorize the air transport of fissile material.

Based on the ability of the FSV-3 package to transport Fort St. Vrain unirradiated fuel elements, it is likely that transporting microreactor TRISO unirradiated fuel elements separately from the microreactor is achievable. However, structural, thermal, and criticality analyses will be required to show that a microreactor containing TRISO unirradiated fuel elements will meet the requirements of 10 CFR Part 71.

The T-3 transportation cask (DOE Certificate No. 9132) is currently certified to ship irradiated sodium bonded fuel pins with enrichments up to 40 percent. These fuel pins would be similar in design to SNAP-10A fuel pins that could be used in some microreactor designs. As with TRISO fuel elements, it is likely that transporting microreactor sodium bonded irradiated fuel elements separately from the microreactor is achievable. However, structural, thermal, shielding, and criticality analyses would be required to show that a microreactor containing sodium bonded irradiated fuel elements would meet the requirements of 10 CFR Part 71, particular for very short cooling times. These structural, thermal, shielding, and criticality analyses would be required to go through the regulatory body review process before a CoC for the transportation package would be issued.

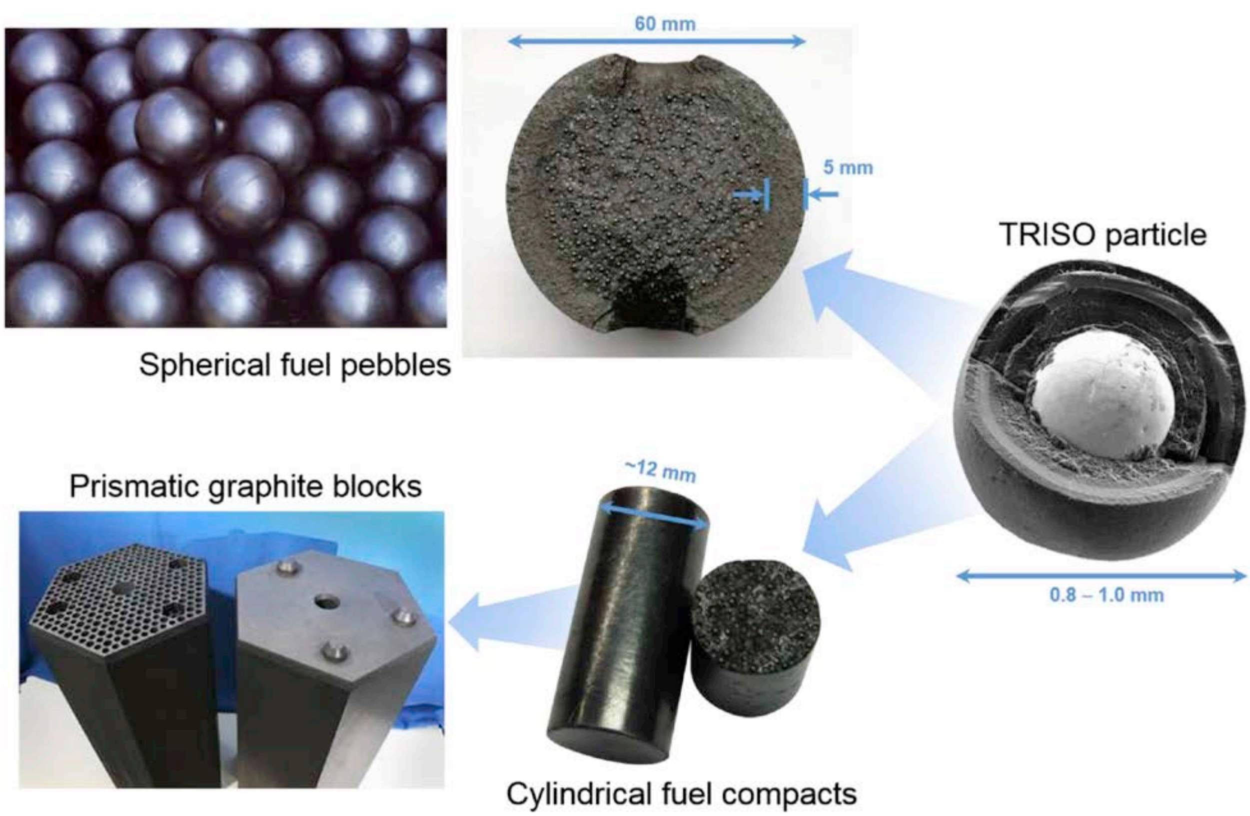


Figure 21. TRISO Particles, Fuel Compacts, Prismatic Graphite Blocks, and Spherical Fuel Pebbles (Demkowicz et al. 2019)

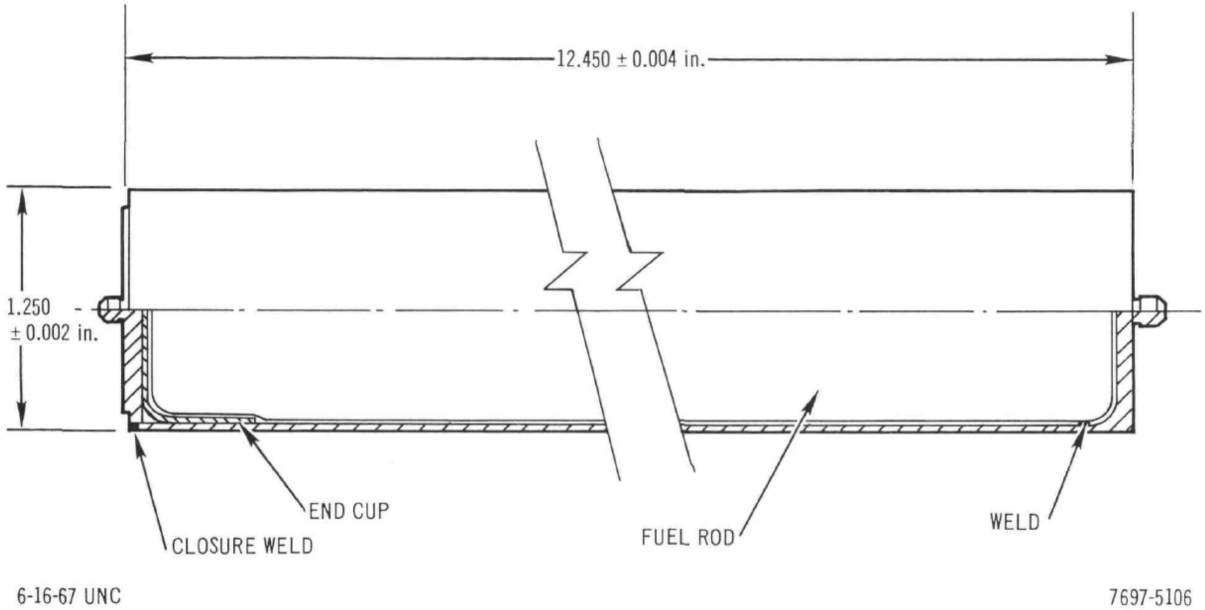


Figure 22. SNAP-10A Fuel Pin Schematic (Golding 1967)

## 6.2 Fissile Material Packages

Packages used to ship microreactor unirradiated and irradiated fuel must meet the fissile material requirements in 10 CFR 71.55, including requirements for normal conditions of transport (10 CFR 71.71) and hypothetical accident conditions (10 CFR 71.73). Section 4.2 contains the detailed schedule for fissile material packages. For unirradiated fuel shipped separately from the microreactor, it is likely that compliance with these regulations is achievable based on existing and past certified Type AF packages. However, unirradiated fuel that is derived from HALEU may require a Type BF package because of the presence of plutonium in the HALEU. A Type BF package certified specifically for HALEU unirradiated fuel has not been designed although potential package designs have been evaluated (Eidelpes et al. 2019).

In their white paper (NEI 2018), the Nuclear Energy Institute discusses the need to develop criticality benchmark data to be used in certifying HALEU transport packages. This need is especially acute for uranium hexafluoride packages as opposed to packages designed to ship unirradiated fuel and should not be an impediment to shipping unirradiated microreactor fuel.

If it is desired to ship unirradiated fuel within the microreactor, then as discussed in Section 6.1, structural, thermal, shielding, and criticality analyses would be required to show that a microreactor containing TRISO or sodium bonded fuel elements would meet the requirements of 10 CFR Part 71. These structural, thermal, shielding, and criticality analyses would be required to go through the regulatory body review process before shipping would be approved.

## 6.3 Type B Packages

Packages used to ship microreactor unirradiated and irradiated fuel must meet the fissile material requirements in 10 CFR 71.51, including requirements for normal conditions of transport (10 CFR 71.71) and hypothetical accident conditions (10 CFR 71.73). Section 4.3 contains the detailed schedule for Type B packages. For irradiated fuel shipped separately from the microreactor, it is likely that compliance with these regulations is achievable based on existing and past certified Type B packages.

If it is desired to ship unirradiated fuel within the microreactor, then as discussed in Section 6.1, structural, thermal, shielding, and criticality analyses would be required to show that a microreactor containing TRISO or sodium bonded fuel elements would meet the requirements of 10 CFR Part 71. These structural, thermal, shielding, and criticality analyses would be required to go through the regulatory body review process before shipping would be approved.

## 6.4 Microreactor Shielding and Weights

The principal sources of radiation during the operation of a microreactor are:

- Fast neutrons arising from fission in the core.
- Thermal neutrons from fast flux removal in the moderator and neutron shield.
- Gamma radiation resulting from prompt fission in the core.
- Gamma radiation from fission products developed during operation.
- Gamma radiation from neutron capture in the core, shield, and structural members.

During the transport of a microreactor, the gamma radiation from fission products and neutron capture are likely to be the principal sources of radiation.

It is important to recognize that shielding will be a major contributor to the size and weight of a microreactor (Aerojet-General Nucleonics 1963). In addition, there is an inherent trade-off among the shielding associated with a microreactor, the weight of a microreactor, and radiation dose rates. For this reason, it is important to establish radiation dose rate and weight performance specifications that a microreactor must meet in order to be transportable. This may involve time constrained scenarios and time unconstrained scenarios.

In past microreactor designs such as the ML-1 reactor or the ASTR, several types of shielding have been discussed:

- Shutdown shielding. The shielding provided to reduce the radiation levels from the reactor following shutdown from extended operation at full power to the values contained in the specifications for the reactor.
- Operational shielding. The shielding provided in addition to the shutdown shield to minimize, as possible within the weight and size limits contained in the reactor specifications, the radiation levels from the reactor during operation.
- Preferential shielding. The practice of providing more shielding in one direction when compared to another direction.

- Divided shielding. Most often used for an airborne reactor. As discussed in Westfall (1959), there are essentially two types of shields that may be used in an aircraft, the unit shield and the divided shield. The unit shield concentrates all the attenuating material at the reactor. At the shield's outer surface, the radiation has been reduced to established permissible levels. This type of shield provides the crew freedom of movement, reduces radiation damage to materials to a minimum, and considerably eases aircraft maintenance. The price for it is an extremely large, concentrated weight and a huge, ungainly size. The divided concept places a portion of the shield at the reactor, and the remainder at the crew compartment. This involves the definition of two permissible dose rates, one for the crew and the other for equipment between the crew compartment and reactor shields. The saving in weight and size effected by the more efficient use of materials in this type of shield is most attractive. In comparison, attendant disadvantages, such as cramped crew quarters, high radiation damage to materials outside the reactor shield and crew shield, and difficult remote-handling maintenance, assume less importance.
- Expedient shielding. Expedient shielding consists of shielding materials commonly available in the field such as water, dry sand, wet sand, limestone, soil, and wood.

For the ML-1 reactor, the weight specification was 15 tons, which included the weight of the reactor and its shielding. Table 6 lists the radiation dose rate specifications that were established for the ML-1 reactor. The shutdown radiation dose rate was defined as 24 hours after shutdown, following 10,000 hours of full power operation, 25 feet from the reactor, with the reactor in transport condition. The operating radiation dose rate was defined at the control cab, 500 feet from the reactor, during full power operations.

Table 6. Radiation Dose Rate Specifications for the ML-1 Reactor

| **Scenario** | **Radiation Dose Rate (mrem/hr)** |
|---|---|
| Shutdown | |
| Front | 15 |
| Top | 1500 |
| Sides and bottom | 150 |
| Operating | |
| Control cab | 5 |
| Source: Aerojet-General Nucleonics (1966). | |

As discussed in Aerojet-General Nucleonics (1963), during the design of the ML-1 reactor shielding, several shielding concepts were studied to select the general approach which would result in a shield of minimum weight. The studies evaluated the use of mercury, tungsten or depleted uranium as the primary shield; the feasibility of reducing the core size; the feasibility of preferential shielding; and the feasibility of flooding the core with mercury after shutdown. It was determined that the use of depleted uranium was not feasible because this material was quite expensive and would be activated by fast neutrons during reactor operation. A shield made wholly of tungsten was eliminated from further consideration because of the fabrication difficulties (tungsten must be canned to prevent oxidation) and undesirable mechanical properties (extremely brittle) associated with the use of such material and because tungsten, like uranium, would be activated by neutron capture. The use of mercury involved problems of corrosion of the core and retention of residual mercury after the core draining and, for these reasons, was not considered further. Preferential shielding appeared to be a feasible concept.

In the design of the ML-1A reactor shield, several other concepts were considered. For example, Aerojet-General Nucleonics (1965) discusses providing an aqueous shield during operations which could be drained to reduce the transport weight of the reactor and increasing the amount of heavy metal in the inner regions of the shield, which would reduce the volume and weight of the shield.

In the MCR design, the shielding was divided into two packages, where Package I (denoted Shield) contained removable shielding to be used during reactor operations and Package II (denoted Power Generation) contained shutdown shielding (Allison Division 1964).

The design of microreactor shielding could also make use of field expedient shielding materials. These are defined as common materials that would be available in the field. Examples of these materials are water, dry sand, wet sand, limestone, soil, and wood (Wheeler and Bostick 1960). Shielding experiments using these materials have evaluated neutron and primary- and secondary-gamma-ray attenuation, and neutron activation. These experiments concluded that:

- Fast-neutron attenuation of expedient materials is significantly increased by moisture contents as low as 8% by weight. Dose rates for 5 feet of sand and limestone with no appreciable moisture content were of from 1 to 2 orders of magnitude greater than for the mixture, the clay, or the wet sand with moisture content of from 8 to 15% by weight.
- Secondary-gamma rays produced in the dry limestone and sand added significantly to the measured surface dose rates. Eight percent by weight water in the clay and 15% by weight water in the wet sand reduced gamma-ray dose rates significantly by reducing the number of secondaries and by causing them to originate nearer the reactor and further from the shield surface.
- Expedient shield thickness requirements may be reduced by inhibiting secondary gamma-ray production in the structures near the reactor (pressure vessel, primary shield, etc.) and in the expedient shielding material.
- The results of the experimental analyses and the probability of significant amounts of induced activity, due to elements present in only trace amounts, indicate the desirability of conducting simple activation tests on materials from proposed sites.

Aerojet-General Nucleonics (1965) evaluated the use of water, wood, dry sand, and wet sand as expedient shield materials and also discussed the use of sandbags, an open trench, and an earth berm to shield the ML-1A reactor.

## 6.5 Mode Specific Issues

This section discusses mode specific issues related to microreactor transport.

### 6.5.1 Highway

The typical tractor-trailer weighs about 35,000 lb. As discussed in Section 3.3, state permits are required if the gross vehicle weight exceeds 80,000 lb., which limits the weight of the ISO container and its microreactor contents to about 45,000 lb. without obtaining a state permit. A state permit would also be required if the ISO container and its microreactor contents were overdimension.

It is likely that a microreactor with its irradiated fuel contents would be a highway route controlled quantity truck shipment and would require a hazardous materials safety permit [49 CFR 385.403(a)], which would require a written route plan and a pre-trip CVSA Level VI inspection. This requirement is not unique to shipping a microreactor and its irradiated fuel and should not be an issue.

Likewise, the requirements in 49 CFR 397, Subpart D for the routing of Class 7 (radioactive) materials, including the requirements for motor carriers and drivers (49 CFR 397.101) and requirements for state routing designations (49 CFR 397.103), are not unique to microreactors and should not be an issue.

### 6.5.2 Rail

As discussed in Section 3.4, it is the railroad's expectation that shipments of irradiated fuel be conducted using AAR Standard S-2043 railcars. AAR Standard S-2043 railcars have been developed and are currently under development; however, the minimum test load for these railcars is likely to greatly exceed the weight of a microreactor and its components. This issue would need to be discussed with the AAR Equipment Engineering Committee to determine if additional testing would be required to ship a microreactor and its components in compliance with AAR Standard S-2043 or if additional ballast weights could be added to the railcar to satisfy the requirements of AAR Standard S-2043.

### 6.5.3 Barge or Ship

No barge or ship issues that are unique to microreactor transport were identified.

### 6.5.4 Air

The schedule presented in Section 4.4 lists the requirements for radioactive material package design and testing, including those for fissile material shipments shipped by air [see 10 CFR 71.55(f)]. Specifically, 10 CFR 71.55(f)(1)(iv) requires enhanced puncture, thermal, and drop tests, e.g., a fire of one hour duration, double the duration of required for a fissile material package not shipped by air, and an impact onto an unyielding surface with a velocity of 90 m/s. In addition, 10 CFR 71.74 contains additional tests for the air transport of plutonium, including an impact onto an essentially unyielding surface of with a velocity of 129 m/s and a terminal free-fall velocity test. Because of these enhanced tests, if a microreactor containing its unirradiated or irradiated fuel were to be shipped by air, it could be a significant challenge to meet the regulatory requirements in 10 CFR 71.55(f) or 10 CFR 71.74. In addition, a Type B package certified for air transport of irradiated fuel would also be certified as a fissile material package and would have to meet the enhanced testing requirements. Table 7 lists the packages currently certified for air transport in the U.S. Table 7 does not include packages licensed by DOT for import/export shipments.

Table 7. Packages Currently Certified for Air Transport In the U.S.

| Package ID Number | Revision | Model | Expiration Date |
|---|---|---|---|
| USA/0361/B(U)F-96 | 11 | PAT-1 | 12/31/2021 |
| USA/9315/B(U)F-96 | 15 | ES-3100 | 04/30/2021 |
| USA/9315/B(U)F-96 (DOE) | 16 | ES-3100 | 09/30/2020 |
| USA/9330/AF-96 | 15 | ATR FFSC | 05/31/2024 |
| USA/9330/AF-96 (DOE) | 1 | ATR FFSC | 01/31/2024 |
| USA/9342/AF-96 | 15 | VERSA-PAC (VP-55 and VP-110) | 05/31/2024 |
| USA/9980/AF-96 (DOE) | 3 | 9980 | 10/31/2023 |

The schedule contained in Section 4.5 contains the requirements for military air shipments of fissile material. These requirements reference 10 CFR Part 71.

If a microreactor and its irradiated fuel were shipped by air internationally, it would likely be required to meet IAEA requirements for a Type C package because the irradiated fuel would contain an activity greater than 3000 $A_2$. The schedule provided in Section 4.6 presents the IAEA requirements for Type C packages.

## 6.6 Package Evaluations

This section discusses package safety basis evaluations and issues related to microreactor transport.

DOT regulates the shipment, regardless of the mode of transport, of all hazardous materials, substances, and wastes in United States commerce in 49 CFR 100-185. DOT also establishes the requirements for the manufacture, fabrication, marking, maintenance, repair, and testing of packagings which are used for transport. The NRC establishes the procedures and standards for approval of packaging and shipping procedures for Type B and fissile materials packagings in 10 CFR 71. Outside the United States, the International Atomic Energy Agency (IAEA) is generally responsible for establishing regulations related to the international transport of radioactive materials through SSR-6 (IAEA 2018). The requirements contained in SSR-6 are generally adopted by member states.

Associated regulations are presented in Section 4. In summary, the regulations require that radioactive material packaging be able to remove heat generated by radioactive decay, shielding the public from radioactive particle emissions, ensuring nuclear subcriticality control, and mitigate the dispersion of radioactive material. Design and licensing of packages within the United States can involve the application of a number of consensus standards and guidance, such as applicable ASME, ANSI, and ASTM national standards, and guidance from NRC Regulatory Guides. These will flow down requirements and dictate aspects of mechanical design, material selection, fabrication (including welding), examination, testing, SARP preparation, and certification. A suggested format for a SARP, and documentation of the package evaluations establishing the safety basis, has been provided by the NRC in Regulatory Guide (RG) 7.9 (NRC 2005).

As discussed in Section 6.1, transportation packages have been designed and certified for fuel types that are similar to microreactor TRISO or sodium bonded fuel. For cases where the microreactor was shipped separately from its unirradiated or irradiated fuel, no structural, thermal, containment, shielding, or criticality issues unique to microreactors were identified.

In addition, shipping the microreactor without irradiated fuel would be similar to shipping an irradiated reactor vessel, except that the microreactor would likely be smaller and weigh less. Because the ability to ship irradiated reactor vessels either intact or segmented has been demonstrated numerous times in the commercial nuclear power industry no structural, thermal, containment, shielding, or criticality issues unique to shipping an irradiated microreactor without its fuel were identified.

Shipping a microreactor with unirradiated or irradiated contents requires that the package design/definition meet appropriate 49 CFR, 173 Subpart I and 10 CFR 71 requirements, as well as the recommendations of U.S. NRC RG 7.11 (NRC 1991). Generally, 49 CFR 173.417 permits transportation of fissile material in Type AF, B(U)F, or Type B(M)F packages, and the fissile material meets the applicable standards in 10 CFR 71, as a SARP will be required to be prepared and submitted to a regulatory body for all three. By definition, a Type B package is required if the radionuclide inventory exceeds one $A_2$ quantity (49 CFR 173.431). Evaluations performed for transport of fresh (unirradiated) HALEU comprised of recovered and polished material determined that approximately only 4 kg or more of HALEU are required to exceed one $A_2$ (Eidelpes et al. 2019). Any one of the proposed demonstration microreactors will likely require hundreds of kgs of HALEU to fuel the core. It is envisioned that the irradiated microreactor HALEU contents is likely to exceed $10^5$ $A_2$. As such, the quantities to be transported can be readily characterized as requiring a Type B(U)F or Type B(M)F packaging definition.

RG 7.11 is the first regulatory guidance to introduce the graded approach based on content categories. The graded approach categorizes the packages into three categories based on the form and activity level of the contents. The three package categories I, II, and III indicate the ASME B&PV design requirements imposed on the package to ensure adequate design and development of the component safety groups. These include containment, subcriticality/criticality control, and other items important to safety. In this approach, Category I contents have the highest level of activity and require the highest standards and margins of safety.

According to RG 7.11, only 30 $A_2$ or greater are required to elevate the associated packaging requirements from Category III to Category II. This activity limit is reached by approximately 100 kg of unirradiated HALEU (Eidelpes et al. 2019). This leads to the conclusion that the transportation of unirradiated HALEU content of the magnitude required for microreactor demonstrations at INL requires a Category II containment. However, very little difference exists between Category I and Category II packaging design criteria per the applicable sections of the ASME BPVC per NUREG/CR-3854. To provide flexibility in case the cleanliness of unirradiated HALEU is less ideal than anticipated, it is advised that a Type B, Category I packaging design criteria be considered. If a Type B, Category I packaging design criteria is selected, it would also apply to irradiated microreactor HALEU contents at EOL which is likely to exceed $10^5$ $A_2$. Design and evaluation implications associated with content category are explained in greater detail in the sections that follow.

In the case where a microreactor was shipped either with or without its contents, the system used to ship the microreactor would have to be designed so that the microreactor or its contents were not subjected to excess shock and vibration that could damage the microreactor or its contents. However, the need to not subject cargo to excess shock and vibration is not unique to microreactors or to microreactor fuel. Potential sources of shock and vibration data include NNSA SG-100 (NNSA 2005), NUREG/CR-2146 (Fields 1983), and NUREG/CR-0128 (Magnuson 1978). MIL-STD-810H Method 514.8 (DoD 2019) also provides guidance for defining vibration environments that materiel may be exposed to throughout a life cycle and for the conduct of laboratory vibration tests.

For transporting a microreactor either with or without its contents by air, Section 6.5.4 discusses the enhanced testing requirements. As stated in Section 6.5.4, because of these enhanced testing requirements, it could be a significant challenge to meet the regulatory requirements in 10 CFR 71.55(f).

### 6.6.1 Structural

For shipping a microreactor with its unirradiated or irradiated contents, there is insufficient microreactor design detail to evaluate the structural issues associated with microreactor transport at this time, other than to say that microreactor designers should consider the need to demonstrate compliance with the requirements for the normal conditions of transport (NCT) and hypothetical accident conditions (HAC) in 10 CFR Part 71 in their microreactor designs.

The regulations serve to protect the worker, public, and environment from the inherent risks of transporting radioactive materials by requiring that radioactive material packaging be able to maintain containment of its radioactive content, provide shielding, and maintain capability of thermal management and nuclear subcriticality. Each one of these items tightly revolve around the structural evaluation discipline to establish the necessary safety basis. Defining the microreactor with its unirradiated or irradiated contents as the package, approval standards in 10 CFR 71.41 state that, to demonstrate compliance, the effects of tests specified in 10 CFR 71.71 and 10 CFR 71.73 must be evaluated. Breaking the component safety groups into containment, criticality, and other safety components, they can be further defined as follows.

Containment components are defined as all the components required for retaining the radioactive contents. The function of all the containment vessel and closure components, which could include or be defined by the reactor vessel depending on the microreactor packaging definition, is to maintain the containment boundary so that all NCT and HAC containment requirements are met. Included in this component safety group are any closure lids, seals, port components, and bolts. Type B, Category I packaging design criteria dictates that the structural evaluations and stress limits need to comply with ASME BPVC, Section III, Division 1, Subsection NB per NUREG/CR-3854. Stress limits differ between NCT and HAC such that meeting NCT structural performance requirements tends to be more challenging than to meet HAC structural performance requirements.

Analytical methods should be used to demonstrate that the containment vessel meets the vessel design criteria presented in Subsection NB, Article NB-3000 as amended by RG 7.6 (NRC 1978). Also, in the case of closure bolts, due to their importance, applicants/developers are directed to use acceptance criteria provided in NUREG/CR-6007 (Mok et al 1993). Limits for release of contents are specified in 10 CFR 71.51 for both NCT and HAC evaluations. Demonstration of compliance with the specified limits must be in accordance with the methods laid out in ANSI N14.5. Additionally, in accordance with 10 CFR 71.61, a Type B package containing more than $10^5$ $A_2$ must be designed so that its undamaged containment system can withstand an external water pressure of 2 MPa (290 psi) for a period of not less than 1 hour without collapse, buckling, or in-leakage of water.

Criticality components are defined as all components required in controlling nuclear criticality during transport of fissile material in the package. Included in this component safety group are neutron absorbers and related structures required to retain the relative position of the fissile materials and/or neutron absorbers. Type B, Category I packaging design criteria dictates that the structural evaluations and stress limits need to comply with ASME BPVC, Section III, Division 1, Subsection NG (ASME 2019a) per NUREG/CR-3854 (NRC 1984).

Other safety components are defined as all other packaging safety-related components. This includes but is not limited to both gamma and neutron shielding components; secondary seals, bolts, and closures; impact limiters; and lifting lugs and tie-down devices. Type B, Category I packaging design criteria dictates that the structural evaluations and stress limits need to comply with ASME BPVC, Section VIII, Division 1 (ASME 2019b), or Section III, Subsection NF (ASME 2019c) per NUREG/CR-3854.

ASME BPVC, Section III, Division 1, Subsection NB (ASME 2015) contains the requirements for materials, design, fabrication, examination, and testing of Class 1 reactor components to form acceptable design criteria for shipping containment vessels. A critical consideration to consider is that the choice of materials is limited in number and temperature use limits are 700 °F for carbon and low alloy (ferritic) steels and 800 °F for austenitic and high alloy steels. As such, if the reactor vessel is defined so as to provide reactor containment during operation as well as content containment during transport, a code case will likely need to be developed and leveraged to accommodate the higher temperatures customary or normally expected with the microreactor demonstration definitions.

### 6.6.2 Thermal

For shipping a microreactor with its unirradiated or irradiated contents, there is insufficient microreactor design detail to evaluate the thermal issues associated with microreactor transport at this time, other than to say that microreactor designers should consider the need to demonstrate compliance with the requirements for the NCT and HAC in 10 CFR Part 71 in their microreactor designs.

Similar to the structural discipline, the thermal requirements of 10 CFR 71 and 49 CFR Parts 100-185 must be met before a package can be certified for the transportation of radioactive materials. Packaging definitions used to transport radioactive material must be capable of withstanding intense thermal environments while preventing the release of contents and maintaining shielding and nuclear subcriticality. Achieving this capability requires the use of construction materials that enable the package to withstand serious thermal insult. Accordingly, all safety significant components of a packaging definition comprised of a microreactor with unirradiated or irradiated contents must be demonstrated to survive a broad temperature range and significant temperature differential exposure as identified in associated regulations presented in Section 4.

Additionally, a microreactor with irradiated contents or associated spent fuel, possibly anticipated to be shipped separately, must employ design strategies that account for contents that generate a relatively large amount of heat as the issue of thermal protection becomes much more complicated. In this case, insulating material must work effectively to reduce the heat added to the package during an upset or accident condition while also allowing internally generated heat to escape under regular operating conditions. These requirements are in conflict with one another and must be carefully balanced during the packaging design process. Also, when there is a significant heat source within the package, such as the microreactor with irradiated contents, an effective thermal insulation may cause the interior portions of the package to overheat under HAC or even possibly NCT conditions. This could then lead to failures of safety significant items. This must also be evaluated and demonstrated to not be the case.

Following NCT, a package may appear visually fully functional, but it must be shown that there is no substantial reduction in the effectiveness of the package. The failure of safety significant containment items as it relates to thermal insult is most likely during or after an accident scenario involving a fire. Therefore, it is important that the packaging definition be designed such that all containment items withstand the highest expected temperature under HAC after the entire structural impact loading sequence. After the HAC structural and thermal loading sequences of the packaging definition, a maximum leak rate of an $A_2$ per week (or 10 $A_2$ of krypton-85 per week) is permissible under HAC as specified in 10 CFR 71.51(a)(2).

Loss of radiation shielding from the packaging definition, due to either melting of gamma shielding and burning or pyrolysis of the neutron shielding material, can result in severe circumstances. A typical design evaluation approach is to not take credit for any material that may be consumed or lost during a thermal (or any other type) accident. This may prove to be especially challenging when attempting to demonstrate that the public, worker, and environment are being protected.

Generally, criticality control is provided by geometric spacing and strategic poisoning. As such, these items are always considered to be safety significant and must be demonstrated to remain intact during NCT as well as HAC evaluation scenarios. Additionally, it is possible to create a criticality event by simply flooding the contents of a package. This must also be evaluated per 10 CFR 71 and the potential must be shown to not exist.

### 6.6.3 Containment

For shipping a microreactor with its unirradiated or irradiated contents, there is insufficient microreactor design detail to evaluate the containment issues associated with microreactor transport at this time, other than to say that microreactor designers should consider the need to demonstrate compliance with the requirements for the NCT and HAC in 10 CFR Part 71 in their microreactor designs.

The design of a packaging definition typically starts with the containment system. The containment system is defined as an assemblage of all the components required to retain the radioactive contents. In general, this includes items such as the containment vessel, possible seals and port components, and closure bolts. The containment boundary is an assemblage of all the components required to retain the contents and is in direct communication with the internal cavity of the containment vessel. The structural design criteria for certain package component safety groups are based on the ASME Boiler and Pressure Vessel Code as discussed in Section 6.6.1.

As previously discussed, in the development of a compliant packaging design definition, the following four key features should be incorporated:

- Containment system
- Thermal management system or convention
- Shielding
- Criticality controls.

A containment system is always required to provide strict retention of the radionuclide inventory. An alternate containment boundary definition may very well need to be exercised or defined in the instance of a *reactor* containment vessel which then becomes the *content* containment during transport. If TRISO is used for fueling and relied upon as partial definition of containment due to its built-in radionuclide retention boundaries, codified regulatory requirements will still not be met. As such, some sort of defense-in-depth approach as outlined in Section 6.7 will need to be applied to obtain a CoC.

The use of impact limiting feature(s) or energy-consuming devices is typically incorporated to protect vital containment boundary components (i.e., end closures and ports) in the design of a package against severe NCT loads (i.e., free drops) and HAC loads (i.e., free drop, crush, puncture, and fire). Adequate protection and satisfactory performance of the containment vessel is typically demonstrated by subjecting the packaging definition to NCT and HAC regulatory performance tests to verify the containment vessel maintains containment and structural integrity.

Containment design requirements for packaging definition designs that are used to transport radioactive materials must be developed to ensure that any release of radioisotopes during postulated NCT or HAC events falls within the specified regulatory limits. Primary regulatory documents that contain the general requirements for containment are 49 CFR Parts 100-185 and 10 CFR Part 71 and condition specific requirements are listed in 10 CFR 71.51 and 10 CFR 71.71 for NCT and in 10 CFR 71.51 and 10 CFR 71.73 for HAC. Containment requirements are specified in 10 CFR 71.43, General Standards for All Packages. The phrase “no loss or dispersal of radioactive contents” is clarified in 10 CFR 71.51, Additional Requirements for Type B Packages.

Although shipping packages are designed to contain radioactivity and to maintain their structural integrity under the most severe reasonably anticipated conditions, leak testing is necessary to ensure that the packages are manufactured and assembled correctly and that no unacceptable leak paths have developed from subsequent use (NUREG/CR-6487). The limits for maximum permissible rate of release of contents is specified in 10 CFR 71.51 for both NCT and HAC and are 10-6 $A_2$ per hour and one $A_2$ in one week (except 10,000 Ci for 85Kr in one), respectively. Additionally, NCT testing is to be conducted at the most unfavorable conditions of external temperature (between -29 °C [-20 °F] and +38 °C [+100 °F]) and pressure (between 25 kPa [3.5 psi] absolute and 140 kPa [20 psi] absolute).

Complete detailed requirements are presented in the codified regulatory requirements presented in Section 4 of this report. Demonstration of compliance with these specified limits should be in accordance with the methods outlined in ANSI N14.5-2014 as it provides the bridge from the regulatory release rate requirement to a measurable allowable leakage rate. ANSI N14.5-2014 also provides a list and descriptions of several accepted leakage rate test methodologies. More often than not, designers/developers will alternatively select a leaktight definition (ANSI N14.5-2014 defines a leakage rate of 10-7 ref-cm3/s or less as leaktight) as a less-complex means of determination of acceptance. If this is done, then establishment of a content-dependent leakage rate determination is not required.

Demonstration and successful determination of an adequate containment system is typically expected and readily achievable for microreactor associated spent fuel anticipated to be shipped separately with a purpose-built spent fuel shipping package. However, shipping a microreactor with irradiated contents is more challenging because the reactor vessel has to serve as a containment vessel for reactor operation, as well as meeting the previously stated requirements for transportation, after being potentially partially disassembled for transportation purposes. A microreactor with irradiated contents will likely not meet a leaktight definition. This is especially true when considering the significant structural and thermal loading evaluation prescribed by the regulations prior to demonstrating the efficacy of the containment system.

Leakage rate testing is required prior to first use, periodically (annually for standard definition Type B packaging) during package life, and following maintenance or repair activities. Leakage rate tests may also be required during design and associated verification testing, fabrication, and preshipment. NNSA SG-100 (NNSA 2005) describes and gives excellent examples of leak testing methods and supported details to consider while applying ANSI N14.5-2014.

Finally, the use of pressure vents and valves is not encouraged on packages. Pressure vents and valves must comply with 10 CFR 71.43(e) if deemed necessary for use, and the concept of a fail-safe mode must also be demonstrated.

### 6.6.4 Shielding

For shipping a microreactor with its unirradiated or irradiated contents, there is insufficient microreactor design detail to evaluate the associated shielding issues at this time. Microreactor designers must consider the need to demonstrate compliance with the radiation dose rate requirements for the NCT and HAC in 10 CFR Part 71 in their designs.

The relationship among a microreactor's shielding, weight, and the resulting radiation dose rates is discussed in Section 6.4, along with several strategies that might be used to shield a microreactor that would also be transportable. These strategies could make use of shutdown shielding, operational shielding, preferential shielding, divided shielding, and expedient shielding. In addition, transportability may involve time constrained scenarios and time unconstrained scenarios. Section 6.4 also discusses studies that evaluated various shielding concepts, such as the use of mercury, tungsten or depleted uranium as the primary shield; the feasibility of reducing the core size; the feasibility of preferential shielding; the feasibility of flooding the core with mercury after shutdown; and the use of several packages to transport shielding.

Design of packaging radiation shielding is concerned with establishing that the regulatory radiation dose rate limits on the exterior of the packaging definition are not exceeded. The same calculations that produce radiation source term evaluations for shielding analyses are also typically used to determine the heat sources used in the thermal analyses. In addition to shielding, other aspects of the package that are included are subcriticality, structural integrity, containment (for both the contents escaping from the package or outside material entering), thermal management, and the thermal conditions presented by an external heat source. Shielding performance requirements are listed in 10 CFR 71.47 and 10 CFR 71.51.

10 CFR 71.47 specifies dose rate limits for the microreactor packaging definition anticipated to be used for the purposes of transport. Per these codified regulatory requirements as featured in Section 4, a package containing radioactive material must be designed and prepared for shipment such that under NCT, the radiation dose rate does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package, as specified by 10 CFR 71.47, 49 CFR 173.441 and IAEA SSR-6. The maximum dose rate at one meter from any external surface position of the package under NCT must also not exceed 0.1 mSv/h (10 mrem/h).

The NCT dose rate limits apply to a shipping package without regard to the method of shipment. If the package is shipped as exclusive use, which will likely be the case in this instance, the NRC limits can be relaxed to take into account the material and geometric shielding properties of the conveyance vehicle (see 10 CFR 71.4 for the definition of "exclusive use"). A maximum package external dose of 10 mSv/h (1000 mrem/h) for NCT is allowed in a closed vehicle if the 2 mSv/h (200 mrem/h) limit is met on the external surface of the vehicle. The details of exclusive use limits are given in 10 CFR 71.47(a) and (b).

The maximum dose rate at one meter from any external surface position of the package under HAC must not exceed 10 mSv/h (1000 mrem/h), as specified in 10 CFR 71.51(a)(2). For HAC, the dose rate of the external package surface is assumed to be that defined by the configuration conservatively established by its post-accident geometric state.

### 6.6.5 Criticality

For shipping a microreactor with its unirradiated or irradiated contents, there is insufficient microreactor design detail to evaluate the criticality issues associated with microreactor transport at this time, other than to say that microreactor designers should consider the need to demonstrate compliance with the requirements for the NCT and HAC in 10 CFR Part 71 in their microreactor designs.

Subcriticality design and performance requirements are described in 10 CFR 71.55 through 10 CFR 71.61. NNSA SG-100 (NNSA 2005) gives excellent recommendations regarding establishing a criticality safety basis for package licensing. Those considerations and recommendations have been summarized below.

Fissile material is defined in 10 CFR Part 71 and IAEA SSR-6 as material that contains the following nuclides: $^{239}Pu$, $^{241}Pu$, $^{233}U$, and $^{235}U$. Criticality safety is the practice of ensuring that adequate protection is provided against an accidental self-sustaining or divergent fission chain reaction. The criticality state of a system (subcritical, critical, or supercritical) is often discussed in terms of an effective multiplication factor, $k_{eff}$, which is defined as the ratio of the neutron production rate to the neutron loss rate in the system. For the system to remain subcritical, $k_{eff}$ must be less than unity.

All performance standards and regulatory requirements for U.S. certification of fissile material packages are prepared by the NRC and provided in 10 CFR 71. The NRC and the DOT work together to ensure that the DOT regulations for transport of hazardous material (49 CFR Part 173 and 10 CFR 71) are consistent. The performance standards and requirements for certification of packages containing fissile material are only included in 10 CFR Part 71 (featured in Section 4). For international shipments, the IAEA sets forth performance standards and requirements in IAEA SSR-6 (also featured in Section 4). Minor differences exist between the performance standards of IAEA SSR-6 and 10 CFR Part 71 regulations, but the fissile material requirements are essentially the same.

For packages that transport fissile material, such as a microreactor with its unirradiated or irradiated contents, adequate protection is provided by using a design and safety-assessment philosophy that effectively eliminates the possibility of a criticality event occurring under any and all credible non-operating as well as transport scenarios. As such, the microreactor system (defining the package) must always maintain subcriticality in all conceivable transport configurations and during all transportation modes.

A detailed consideration of the many parameters that interact to influence the neutron behavior is needed to provide an adequate safety basis for the package design definition. Principal parameters that affect criticality safety are: 1) type, mass, and form of the fissile material; 2) moderator-to-fissile material ratio (degree of moderation); 3) amount and distribution of absorber materials; 4) package geometry—internal and external; and 5) reflector effectiveness.

The conditions prescribed by the regulations require computational evaluations that incorporate statistical techniques to model neutron transport and predict $k_{eff}$ for the system. Calculational biases and uncertainties are also part of this determination. The margin of subcriticality allowed for a package configuration must include the effect of these biases and uncertainties, together with design uncertainties, and an additional subcritical margin that would provide subcriticality for all non-operating credible scenarios even in the absence of all uncertainties.

Restriction of fissile mass or using a favorable geometry to provide enhanced neutron leakage from the package definition as a means of controlling the neutron balance are not feasible options for a microreactor with unirradiated or irradiated contents. Instead, strategic incorporation of neutron poison materials and moderators are the primary means of controlling neutron balance. Neutron poisons added to the package definition require special attention because their presence must be certain under all conditions and because their incorporation may change the mechanical and/or thermal properties of host materials. Additionally, the geometry of heterogeneous fissile material (e.g., TRISO fuel compacts), the design and placement of absorber materials, and the separation between fissile materials are all important to the criticality evaluation.

Whatever the control mechanism, an adequate margin of subcriticality must be demonstrated for both the single package in isolation and for arrays of packages, despite the fact that arrays of packages would be unlikely. Undamaged (normal transport conditions - NCT) and damaged (subsequent to accident conditions - HAC) packages must be considered using the credible fissile material configuration and the moderator and reflector conditions that provide the maximum effective neutron multiplication factor, $k_{eff}$.

Criticality safety evaluations must be performed in establishing the safety basis of the packaging definition to demonstrate that the package will remain in a subcritical condition under NCT (see 10 CFR 71.71) and HAC (see 10 CFR 71.73). Domestic and international regulations require that a single, water-flooded package be adequately subcritical both in the undamaged or damaged condition. The specific domestic requirements that must be met for a single package certified to carry fissile material are described in 10 CFR 71.55.

The undamaged package is considered to be the physical condition of the package under the NCT; the damaged package refers to the physical condition of the package following its exposure to the tests for the HAC. All internal voided volumes of the package, including the containment vessel, must be assumed to be filled with optimum water moderation for this evaluation. The fissile material contents used in the evaluation must also be in the most reactive credible condition consistent with NCT and HAC. All forms of hydrogenous moderation are intended for consideration in determining the optimum moderation (i.e., moderation conditions for highest $k_{eff}$ value).

Regulations state that the criticality safety evaluation must include an analysis to determine whether the portion of the package defined as the containment system, if closely reflected by water, would have a greater reactivity (higher $k_{eff}$) than the packaging in combination with water. If the package and containment system are not the same, then two analyses must be done for the package in its undamaged condition—one with a water-flooded and water-reflected containment system separate from the package and one with a water-flooded and water-reflected package. The results from these two system analyses should be compared to select the one with the highest $k_{eff}$ as the limiting case for the certification process. In short, the packaging design definition must evaluate all possible moderation and reflection configurations as part of establishing their safety basis.

A requirement included in the domestic 10 CFR 71.55(f) and international regulations applies to packages containing fissile material that will be shipped by air. This requirement is provided to preclude a rapid approach to criticality that may arise from potential geometrical changes in a single package (thus, water in-leakage does not need to be considered) subsequent to the tests (developed to be consistent with HAC that might arise from air transport) prescribed in 10 CFR 71.55(f).

### 6.6.6 Quality Assurance

There are many critical aspects to consider when establishing a QA program geared to lead the development of a microreactor that can be shipped with its unirradiated or irradiated contents. Quality control throughout the design process is as important to the successful certification of a package as the package's ability to successfully complete the regulatory testing and verification of safety basis (simulated or physical). DOE as well as NRC certifying bodies require applicants for packaging certification and shipment to adhere to 10 CFR 71, Subpart H requirements. QA programs based on implementation of a full-featured NQA-1program (AMSE 2019) are acceptable as well.

A description requirement to partially address 10 CFR 71.31, is to identify established codes and standards proposed for use in the package design, materials of fabrication, fabrication, assembly, testing, maintenance, and use. In the absence of codes, standards, and applicable code cases, the basis and rationale used to formulate the QA program needs to be described and justified to the regulatory faction.

It is strongly recommended that the QA program ensure that activities important to safety and applicable to the design, purchase, fabrication, and testing of packaging be described by written procedures and instructions that will be approved by a certifying agency official and be in effect prior to engaging in these activities. A Quality Assurance Plan (QAP) developed for the program should address all 18 elements required and identify the procedures that will be used to achieve the applicable development quality requirements for the packaging definition. The QAP should be developed, submitted to the certifying regulatory body for approval, and available for direct application prior to the initiation of the design and development effort.

QA specialist should have experience with packaging regulations, DOE orders, and national and international standards relating to quality assurance in addition to 10 CFR 71, Subpart H requirements. The applicant's QA program should detail their approach to the control of purchased items and services in order to fulfill the requirements of 10 CFR 71.115, Control of Purchased Material, Equipment, and Services and §71.109, Procurement Document Control. Vendors should be carefully selected based on their capability to comply with applicable sections of 10 CFR 71, Subpart H, their facility and QA program, and their previous records and performance. Also, all activities related to fabrication should be documented in a SARP and conducted under a certifying regulatory body's approved QA program.

RG 7.10 (NRC 2005b) was developed to provide individuals subject to the QA requirements of 10 CFR 71, Subpart H, with guidance on developing QA programs for implementation with respect to the transport of radioactive materials in Type B and fissile material packagings. RG 7.10 establishes a graded quality safety category system that delineates packaging definition items between: 1) critical to safe operation, 2) has a major influence on safety, 3) only has a minor influence on safety. NNSA SG-100 (NNSA 2005) gives examples of this delineation process.

Radiation shielding evaluation aspects, all physical testing initiatives, leakage rate testing, and instrument calibration also need to be performed in accordance with a written and accepted QA program and QA plan that conform with the applicable requirements of 10 CFR 71, Subpart H, and other relevant codes and standards. Additionally, measures must be established to ensure that test results are documented, evaluated, and maintained as QA records to meet the requirements of 10 CFR 71.123.

## 6.7 Defense-in-Depth

Defense-in-depth approaches have primarily been used in the certification of SNF transportation casks to address uncertainties in the performance of HBU SNF cladding during NCT or HAC. For example, for the transport of HBU SNF that has been in storage for longer than 20 years, NUREG-2224 (Ahn et al. 2018) discusses the option of performing supplemental safety analyses assuming fuel reconfiguration scenarios. In addition, NUREG-2216 (Borowski et al. 2020) discusses fuel reconfiguration-based analyses as defense-in-depth strategies for HBU SNF.

These fuel reconfiguration scenarios would involve performing thermal, shielding, and criticality evaluations that include the fuel reconfiguration scenarios contained in NUREG/CR-7203 (NRC 2015). Burn-up credit and water in-leakage could also potentially be used as defense-in-depth strategies.

For microreactor fissile material and Type B transportation packages, defense-in-depth strategies could also be used during the transportation package certification process. However, the defense-in-depth strategies used in the certification of light-water-reactor SNF transportation casks are based on light-water-reactor fuel, not on microreactor fuel, and would need modification to adequately assess microreactor fuels.

# 7.0 Options for Addressing Issues and Recommended Approaches

This section discusses options for addressing the issues identified with transporting microreactors.

## 7.1 Transport Microreactor and Fuel Separately

One option for addressing most of the issues associated with transporting a microreactor is to ship the microreactor without unirradiated or irradiated fuel. New transportation packages may have to be designed depending on the fuel type of the microreactor, but for TRISO and sodium bonded fuel, these types of packages have been designed and certified by the NRC or DOE and there is no reason to believe that it would not be feasible to design and certify new transportation packages for these fuel types.

The ability to ship an irradiated reactor vessel either intact or segmented has been demonstrated numerous times in the commercial nuclear power industry. Shipping the microreactor without irradiated fuel would be similar to shipping an irradiated reactor vessel and there is no reason to believe that it would not be feasible to ship a microreactor without irradiated fuel either intact or segmented.

For transport by air, shipping the unirradiated or irradiated fuel separately from the microreactor might simplify the design and certification of the fissile material package for the fuel because the design would not have to consider the design of the microreactor, but the fissile material packages would still have to meet the enhanced testing standards discussed in Section 6.5.4 for transport by air.

## 7.2 Transport Microreactor and Fuel Together

A second option for transporting a microreactor is to ship the microreactor together with its contents, i.e., unirradiated or irradiated fuel. As discussed in Section 6, this option is likely to be much more challenging than shipping the microreactor and its fuel separately because it would not be feasible from a weight and size perspective to deploy a microreactor that was also designed and certified as a fissile material package or as a Type B package and consequently the microreactor together with its contents would not meet the standards for these packages in 10 CFR Part 71 (see Section 4.4). It should be noted that NRC has approved special package authorizations for Type B packages with a containment that is not leak tight but that demonstrated compliance with 10 CFR Part 71 leakage rates for NCT in 10 CFR 71.51(a)(1) and with HAC in 10 CFR 71.51(a)(2) (NRC 2015).

NRC regulations [10 CFR 71.41 (c)] allow for environmental and test conditions different from those specified for NCT (10 CFR 71.71) and HAC (10 CFR 71.73) to be approved by the NRC if the controls proposed to be exercised by the shipper are demonstrated to be adequate to provide equivalent safety of the shipment. For onsite transportation, DOE Order 460.1D also allows for the preparation of a Transportation Safety Document to demonstrate equivalent safety to the requirements in the schedules in Section 4.

Probabilistic risk assessment (PRA) is one method that could be used to demonstrate the equivalent safety of transporting a microreactor together with its contents. For nuclear reactors, PRA has been conducted since the 1970s [e.g., see WASH-1400 (NRC 1975), NUREG-1150 (NRC 1990), and NUREG-1935 (Chang et al. 2012)]. PRA has also been used to assess a dry cask storage system at a nuclear power plant [see NUREG-1864 (NRC 2007)]. PRA techniques have also been applied to the transportation of SNF, most notably in NUREG/CR-4829 (Fischer et al. 1987), NUREG/CR-6672 (Sprung et al. 2000), and NUREG-2125 (NRC 2014). Additional guidance is provided in IAEA (2003).

A PRA for transporting radioactive materials would be based on accident event trees that represent a set of possible transportation accidents. These event trees include accidents involving collisions and accidents that do not involve collisions. Collision accidents include accidents with non-fixed object (trains, trucks, other vehicles, etc.) and fixed objects (bridges, buildings, walls, etc.). Non-collision accidents include fires and explosions, jackknifes, rollovers, etc. Event trees are typically constructed using transportation accident data and geographic information system (GIS) data. As such, event trees can be made country-specific and also modified to include additional branches or exclude branches that are not applicable or of no interest.

Figure 23 and Figure 24 present event trees for truck accidents in the U.S. and for truck accidents specifically on interstate highways in the U.S. from Mills et al. (2006). Figure 25 presents an event tree for train accidents from Sprung et al. (2000).

The event tree portrayed in Figure 23 first divides truck accident initiating events into two groups:

- Fires, mechanical failures, accidents where the truck overturns, or jackknife accidents where the truck leaves the road and then runs into or hits something.

- Collisions where the truck runs into another vehicle or impacts an on-road structure.

So that an appropriate accident speed distribution can be selected to use in the estimation of truck accident risks, the event tree in Figure 23 indicates whether the accident occurred: (1) at a highway/railway grade crossing, (2) on level ground (i.e., not on a steep grade), (3) involved in a fall from a bridge, or (4) a plunge down an embankment. The event tree in Figure 23 specifies the type of object or surface that the truck runs into or hits but does not indicate whether this impact initiates fire.

The event tree in Figure 24 restructures collisions with non-fixed objects from six branches into four branches:

- Trains (the only non-fixed object large enough to threaten the containment integrity of a transportation cask during a collision).

- Gasoline tank-trucks (not important for collisions but important for fire scenarios initiated by a collision).

- Other vehicles (motorcycles, cars, other trucks).

- Other small non-fixed objects (e.g., cones, animals, pedestrians).

In Figure 24, collisions with fixed objects now appear as sub-branches of a single branch, "Collision with a fixed object." The sub-branches of the "Collision with a fixed object" branch of the event tree in Figure 23 (paths 7 through 18 in Figure 23) have been restructured. The bridge railing and column and abutment branches are now treated as possible outcomes of bridge accidents, which are now divided into accidents that lead to falls from the bridge and accidents that lead to collisions with bridge components (columns, abutments), but not a fall from the bridge. Structures less massive than columns and abutments (e.g., buildings, walls) have been combined into a single path (path 12 in Figure 24), and all collisions with small fixed objects (trees, signs, barriers, posts, guard rails) have been combined into a single path (path 13 in Figure 24).

In Figure 24, accidents in which the truck slides along the ground, perhaps into a culvert or a ditch, have been combined into a single path (path 14 in Figure 24). All non-collision paths that do not involve fires (e.g., mechanical problems, truck jackknifes or overturns) have been combined into a single pathway (path 19 in Figure 24). The descriptors of the Surface Struck branches, called "Hard Soil, Soft Rock" and "Clay, Silt" in Figure 1 have been changed to "Soft Rock, Rocky Soil" and "Other Soils, Clay, Silt" in Figure 24 because even a very high speed impact onto hard soil poses no threat to a transportation cask, while after soil compaction has occurred, impact onto rocky soil may lead to significant cask damage.

The "Over Embankment" branch in Figure 23 (paths 22 through 25 in Figure 23) has been eliminated because the cask impact speed for these accidents should be bounded by the initial speed of the accident. The initial accident speed should bound the sliding speed because sliding friction should cause the transportation cask (or the truck that is carrying the cask) to slow down, rather than accelerate as it slides along the ground or down a slope. Therefore, since there is no good way to estimate the actual sliding speed of a truck or a cask, elimination of this event tree branch causes this set of accidents to be apportioned into branches 14 through 17 in Figure 24. For these branches in Figure 24, use of the initial accident speed to characterize the severity of the cask impact leads to an overestimate of cask damage.

In a transportation PRA, mode specific accident frequencies would be required. For truck transport, highway accident frequencies would be developed from databases such as:

- Fatality Analysis Reporting System (FARS)
- General Estimates System (GES)
- Motor Carrier Management Information System (MCMIS).

For rail transport, railroad accident frequencies would be developed from the railroad accident data maintained by the Federal Railroad Administration. These data are available at https://safetydata.fra.dot.gov/OfficeofSafety/Default.aspx.

Velocity distributions corresponding to event tree branches would also be required. Figure 26 and Figure 27 contain velocity distributions for hard rock from NUREG/CR-6672 (Sprung et al. 2000). In Figure 26 and Figure 27, velocity distributions V1 through V4 correspond to the velocity distributions for level ground, bridges, slopes, and highway-rail crossings, respectively.

In a transportation PRA, knowledge of potential radionuclide source terms would be required. This would include radionuclide inventories and the response of the fuel and microreactor to various classes of accidents, including collision-only accidents, fire-only accidents, and accidents that involve a collision and a fire. Determining the response of fuel and microreactor to these accidents could involve detailed structural, thermal, shielding, and criticality analyses.

At this time, microreactor designs are not finalized. Therefore, it is not known what specific NRC regulatory requirements will not be met.  If a microreactor design does meet some of the NRC regulatory requirements, these areas could be excluded from the transportation PRA and a limited scope transportation PRA could be performed for those areas of the regulations that the microreactor design does not meet.

In order to establish safety equivalency using a transportation PRA, a safety goal will need to be established.  For nuclear power plants, there are two quantitative safety goals (51 FR 30028):

- The risk to an average individual in the vicinity of a nuclear power plant of prompt fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1 percent) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed.

- The risk to the population in the area near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1 percent) of the sum of cancer fatality risks resulting from all other causes.

It should be noted that in transportation accident consequence assessments, the thresholds for prompt radiation-related fatalities are rarely if ever approached. For either of the safety goals associated with nuclear power plants, a consequence assessment would have to be performed. Potentially relevant consequence assessments include Reiss (2020) and the consequence assessment contained in NUREG-2125 (NRC 2014).

For NRC special package authorizations [see 10 CFR 71.41(d)], the applicant must demonstrate that the overall level of safety in transport for the shipment is at least equivalent to that which would be provided if all the applicable requirements had been met. In the context of a transportation PRA, the resulting safety goal could be “the probability of an accident that could result in a release greater than allowed by transportation regulations is very small.” A quantitative assessment of what constitutes “very small” in the context of a transportation PRA has not been conducted, but previous transportation risk assessments (e.g., NUREG-2125 or NUREG/CR-6672) could provide insights.

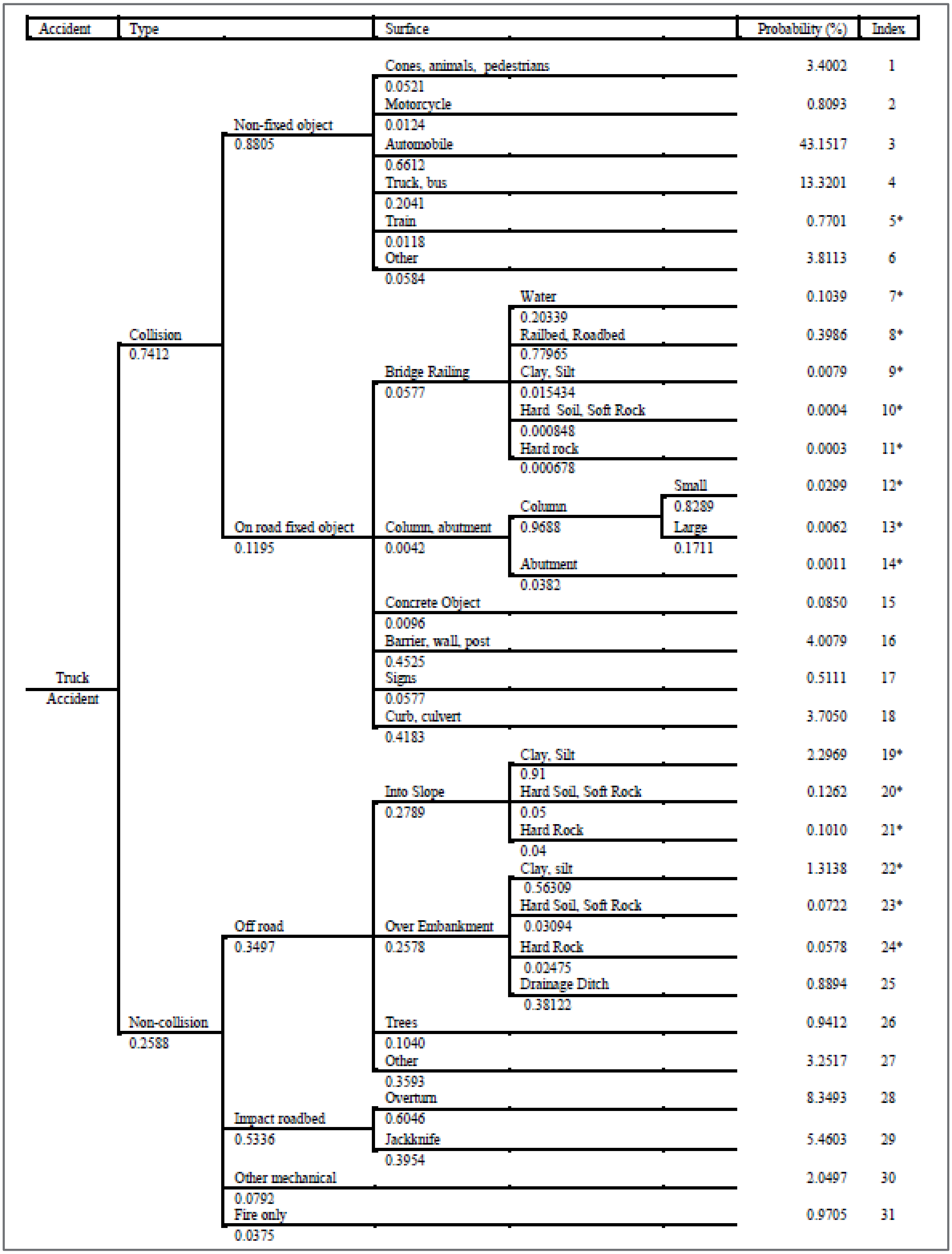


Figure 23. U.S. Truck Accident Event Tree (Mills et al. 2006)

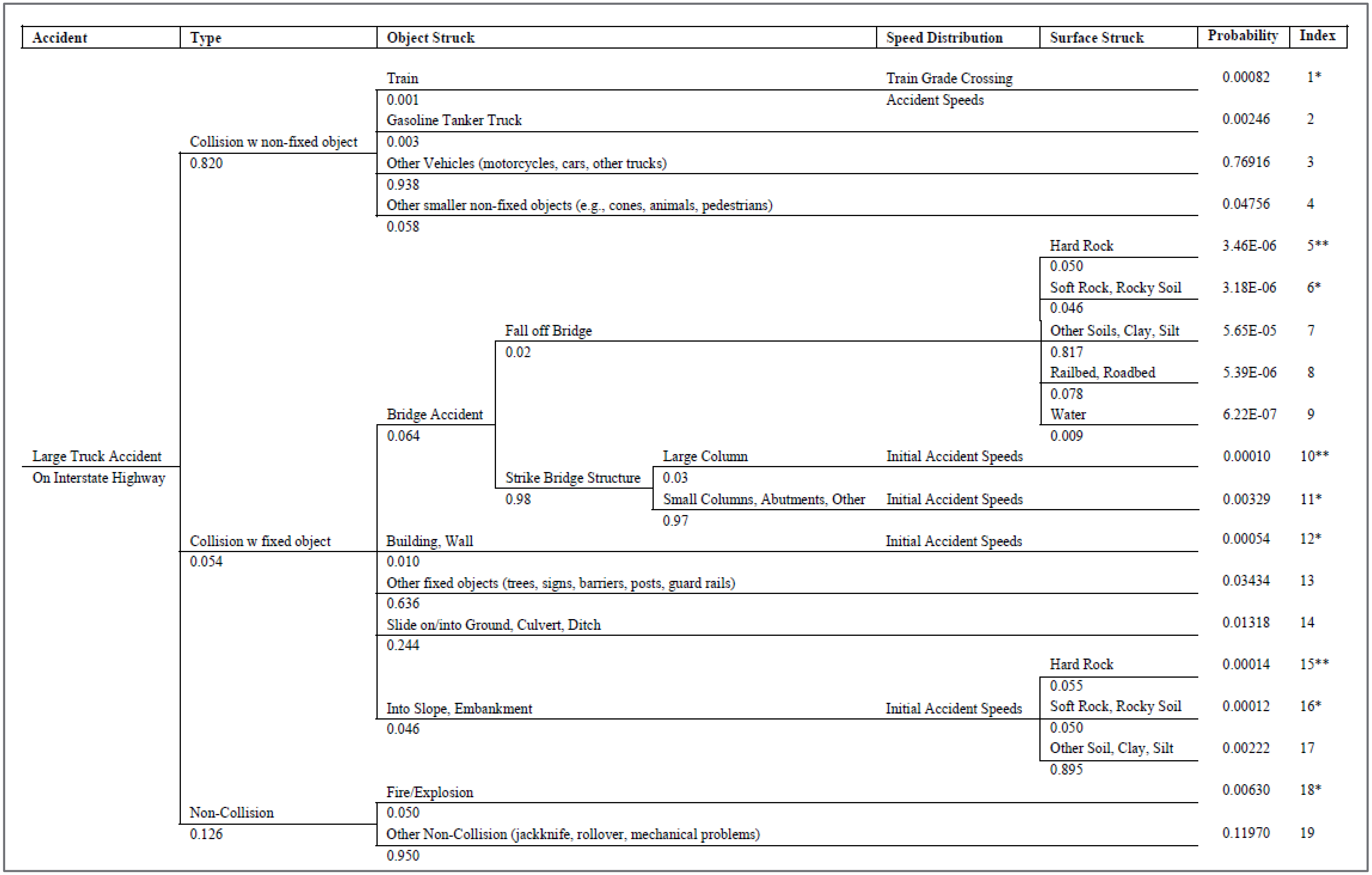


Figure 24. U.S. Interstate Highway Truck Accident Event Tree (Mills et al. 2006)

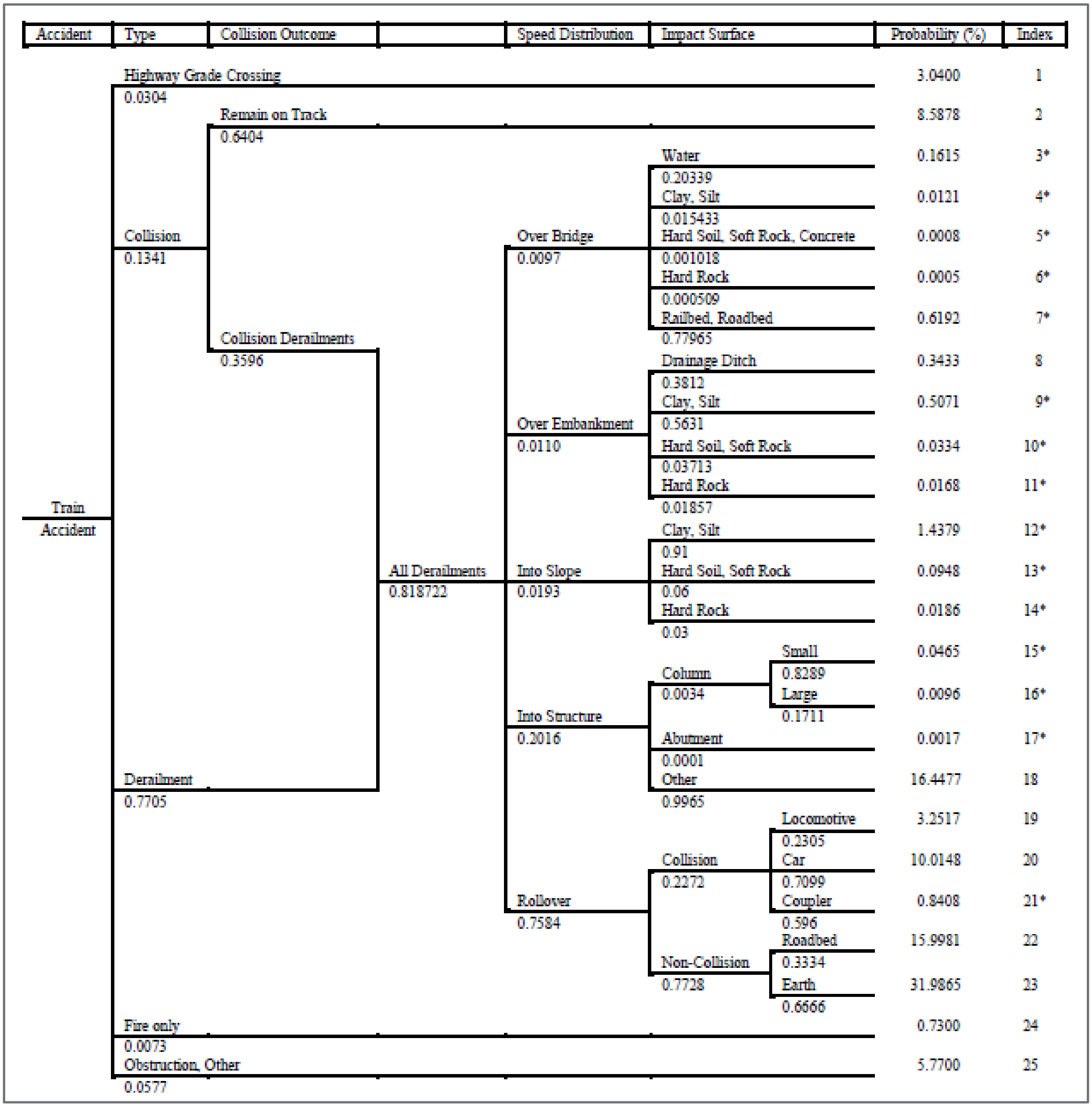


Figure 25. U.S. Rail Accident Event Tree (Sprung et al. 2000)

| Surface | Hard Rock | | |
|---|---|---|---|
| Orientation | End | Corner | Side |
| P(orientation) | 0.056 | 0.722 | 0.222 |

| Velocity Distribution V1, Scenarios 12-14,19-21 | | | | | | |
|---|---|---|---|---|---|---|
| End | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.74353 | 7.435300E-01 |
| v60 | 60 | 58 | 62 | 0.97634 | 0.98383 | 9.800850E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.99956 | 9.995600E-01 |
| v120=vseal | 120 | 110 | 150 | 0.99999 | 1.0 | 9.999925E-01 |
| Corner | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.74353 | 7.435300E-01 |
| v60 | 60 | 58 | 62 | 0.97634 | 0.98383 | 9.800850E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.99956 | 9.995600E-01 |
| v120=vseal | 120 | 110 | 150 | 0.99999 | 1.0 | 9.999925E-01 |
| Side | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.74353 | 7.435300E-01 |
| v60 | 60 | 58 | 62 | 0.97634 | 0.98383 | 9.800850E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.99956 | 9.995600E-01 |
| v120=vseal | 120 | 110 | 150 | 0.99999 | 1.0 | 9.999925E-01 |
| | End | Corner | Side | Wt Sum | | |
| P(v60)-P(v30) | 2.3656E-01 | 2.3656E-01 | 2.3656E-01 | 2.3656E-01 | | |
| P(v90)-P(v60) | 1.9475E-02 | 1.9475E-02 | 1.9475E-02 | 1.9475E-02 | | |
| P(vseal)-P(v90) | 4.3250E-04 | 4.3250E-04 | 4.3250E-04 | 4.3250E-04 | | |
| 1.0-P(vseal) | 7.5000E-06 | 7.5000E-06 | 7.5000E-06 | 7.5000E-06 | | |

| Velocity Distribution V2, Scenarios 7-11 | | | | | | |
|---|---|---|---|---|---|---|
| End | v | vL | vH | PL | PH | P |
| v30 | 30 | 28.95 | 30.95 | 0.6124 | 0.7464 | 6.827500E-01 |
| v60 | 60 | 0 | 60 | 0 | 1 | 1.000000E+00 |
| v90 | 90 | 0 | 90 | 0 | 1 | 1.000000E+00 |
| v120=vseal | 120 | 0 | 120 | 0 | 1 | 1.000000E+00 |
| Corner | v | vL | vH | PL | PH | P |
| v30 | 30 | 28.95 | 30.95 | 0.6124 | 0.7464 | 6.827500E-01 |
| v60 | 60 | 0 | 60 | 0 | 1 | 1.000000E+00 |
| v90 | 90 | 0 | 90 | 0 | 1 | 1.000000E+00 |
| v120=vseal | 120 | 0 | 120 | 0 | 1 | 1.000000E+00 |
| Side | v | vL | vH | PL | PH | P |
| v30 | 30 | 28.95 | 30.95 | 0.6124 | 0.7464 | 6.827500E-01 |
| v60 | 60 | 0 | 60 | 0 | 1 | 1.000000E+00 |
| v90 | 90 | 0 | 90 | 0 | 1 | 1.000000E+00 |
| v120=vseal | 120 | 0 | 120 | 0 | 1 | 1.000000E+00 |
| | End | Corner | Side | Wt Sum | | |
| P(v60)-P(v30) | 3.1725E-01 | 3.1725E-01 | 3.1725E-01 | 3.1725E-01 | | |
| P(v90)-P(v60) | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | | |
| P(vseal)-P(v90) | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | | |
| 1.0-P(vseal) | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | 0.0000E+00 | | |

Figure 26. Example Velocity Distributions V1 and V2 for Hard Rock (Sprung et al. 2000)

| Velocity Distribution V3, Scenarios 22-24 | | | | | | |
|---|---|---|---|---|---|---|
| End | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.28292 | 2.829200E-01 |
| v60 | 60 | 0 | 60 | 0 | 0.96178 | 9.617800E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.99901 | 9.990100E-01 |
| v120=vseal | 120 | 115 | 150 | 0.99999 | 1.0 | 9.999914E-01 |
| Corner | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.28292 | 2.829200E-01 |
| v60 | 60 | 0 | 60 | 0 | 0.96178 | 9.617800E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.99901 | 9.990100E-01 |
| v120=vseal | 120 | 115 | 150 | 0.99999 | 1.0 | 9.999914E-01 |
| Side | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.28292 | 2.829200E-01 |
| v60 | 60 | 0 | 60 | 0 | 0.96178 | 9.617800E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.99901 | 9.990100E-01 |
| v120=vseal | 120 | 115 | 150 | 0.99999 | 1.0 | 9.999914E-01 |

| | End | Corner | Side | Wt Sum |
|---|---|---|---|---|
| P(v60)-P(v30) | 6.7886E-01 | 6.7886E-01 | 6.7886E-01 | 6.7886E-01 |
| P(v90)-P(v60) | 3.7230E-02 | 3.7230E-02 | 3.7230E-02 | 3.7230E-02 |
| P(vseal)-P(v90) | 9.8143E-04 | 9.8143E-04 | 9.8143E-04 | 9.8143E-04 |
| 1.0-P(vseal) | 8.5714E-06 | 8.5714E-06 | 8.5714E-06 | 8.5714E-06 |

| Velocity Distribution V4, Scenario 5 | | | | | | |
|---|---|---|---|---|---|---|
| End | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.7421 | 7.421000E-01 |
| v60 | 60 | 58 | 62 | 0.97125 | 0.9806 | 9.759250E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.9993 | 9.993000E-01 |
| v120=vseal | 120 | 118 | 150 | 0.99999 | 1.0 | 9.999906E-01 |
| Corner | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.7421 | 7.421000E-01 |
| v60 | 60 | 58 | 62 | 0.97125 | 0.9806 | 9.759250E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.9993 | 9.993000E-01 |
| v120=vseal | 120 | 118 | 150 | 0.99999 | 1.0 | 9.999906E-01 |
| Side | v | vL | vH | PL | PH | P |
| v30 | 30 | 0 | 30 | 0 | 0.7421 | 7.421000E-01 |
| v60 | 60 | 58 | 62 | 0.97125 | 0.9806 | 9.759250E-01 |
| v90 | 90 | 0 | 90 | 0 | 0.9993 | 9.993000E-01 |
| v120=vseal | 120 | 118 | 150 | 0.99999 | 1.0 | 9.999906E-01 |

| | End | Corner | Side | Wt Sum |
|---|---|---|---|---|
| P(v60)-P(v30) | 2.3383E-01 | 2.3383E-01 | 2.3383E-01 | 2.3383E-01 |
| P(v90)-P(v60) | 2.3375E-02 | 2.3375E-02 | 2.3375E-02 | 2.3375E-02 |
| P(vseal)-P(v90) | 6.9063E-04 | 6.9063E-04 | 6.9063E-04 | 6.9063E-04 |
| 1.0-P(vseal) | 9.3750E-06 | 9.3750E-06 | 9.3750E-06 | 9.3750E-06 |

Figure 27. Example Velocity Distributions V3 and V4 for Hard Rock (Sprung et al. 2000)

## 7.3 Cost

Feldman et al. (2019) evaluated the costs associated with rail transportation casks used to transport irradiated fuel. In Feldman et al. (2019), a large rail transportation cask for irradiated fuel was estimated to cost $11.2M. The associated impact limiters were estimated to cost $1.1M and a transportation cask cradle was estimated to cost $361K. The costs associated with designing a new cask are estimated to be $2.5M to $4M and take three to five years.

However, it may not be necessary to design a new package but rather modify the content for an existing package. The costs associated with licensing an existing transportation cask to ship microreactor irradiated fuel is estimated to be $1.5M to $2M and take two to three years.

For transport by rail, the cost of a cask-carrying railcar that meets AAR Standard S-2043 was estimated to be $1.5M. The cost of a buffer railcar was estimated to be $350K and the cost of a rail escort vehicle was estimated to be $7.7M (Feldman et al. 2019).

Expenses associated with regulatory review and licensing can range from $1.5M to $2.5M and take one to three years. Table 9 provides resource estimates for various transportation licensing actions. As shown in Table 9, there is a wide variation in the effort required, and thereby the funding needed, depending on the complexity of the license action undertaken.

DOE and DoD are in the process of negotiating settlement agreements with the Class I railroads that operate in the continental United States. These agreements ensure favorable rail rates are charged by these railroads as long as specific stipulations are met, including the use of AAR Standard S-2043 railcars. Currently, settlement agreements have been reached with three railroads (Union Pacific, BNSF, and Norfolk Southern) and negotiations are taking place or will take place soon with the other four Class I railroads (Canadian National, Canadian Pacific, CSX Transportation, and Kansas City Southern). It is anticipated that these settlement agreements would be applicable to the shipments discussed in this report.

Table 8. Resource Estimates for Transportation Licensing Actions

| Licensing Action | NRC Direct Staff Hours – Low Estimate of Level of Effort | NRC Direct Staff Hours – High Estimate of Level of Effort | NRC Direct Staff Hours – Average Estimate of Level of Effort |
|---|---|---|---|
| New Spent Fuel/Type B Waste Certificate of Compliance (CoC) | 1,700 | 2,250 | 2,000 |
| Spent Fuel/Type B Waste Amendment—simple | 10 | 700 | 325 |
| Spent Fuel/Type B Waste Amendment—complex | 75 | 4,400 | 1,650 |
| New Unirradiated Fissile Package CoC | 650 | 875 | 775 |
| Unirradiated Fissile Package Amendment—simple | 10 | 200 | 100 |

| | | | |
|---|---|---|---|
| Unirradiated Fissile Package Amendment—complex | 325 | 700 | 500 |
| CoC Renewal | 5 | 50 | 10 |
| Vendor and Fabricator Inspection | 80 | 240 | 160 |
| Note: Resource estimates are for February 2020.<br>Source: https://www.nrc.gov/waste/spent-fuel-storage/resource-estimates.html | | | |

## 7.4 Conclusions

The ability to transport a microreactor and its unirradiated fuel or SNF contents in compliance with transportation regulations is a critical component of the successful deployment of microreactors in the U.S. and overseas. At the same time, it is likely that a microreactor would not meet the codified regulatory requirements that a fissile material or Type B or C package must meet.

For this reason, future microreactor transportation work should be concentrated in the area of building the framework for a transportation PRA that would provide the basis for approving the transport of a microreactor and its contents by transportation regulators. It is also recommended that the framework first be developed for onsite shipment at a DOE site, because this scenario would be logistically simple when compared to offsite shipment. The onsite transportation PRA would build upon the microreactor's operating history and experience to compensate for absence of meeting codified regulatory transport requirements, specifically in the areas of leakage rates; absence of application of consensus structural codes, standards, and leverageable code cases; and absence validation of analytical predictive capability of reactor shutdown, transport, shock and vibration influence, and reestablishment of operation. Although not required for the approval of the onsite transportation PRA, during the development of the onsite transportation PRA, dialogue with the NRC should be initiated.

After onsite transportability is demonstrated, the transportation PRA should be expanded to include offsite transportation. As with the onsite transportation PRA, the offsite transportation PRA would continue to build on the microreactor's operating history and experience, benchmarked and validated analytical reactor predictive codes with data collected during onsite operation/demonstration, and would leverage developed code cases. During the development of the offsite transportation PRA, significant dialogue with the NRC would be required, with the goal of moving beyond one-at-a-time approvals using the special package authorization process to a process that is similar to the traditional package certification process. The ultimate goal of the transportation PRA would be the international transport of the microreactor which would require approval of a foreign competent authority.

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