PNNL-34816 Revision 1

Microreactor Transportation Emergency Planning Challenges

September 2024

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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
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Summary

This report fulfils the FY2024 M3 Milestone M3AT-24PN0802062, *Assessment of Transportation Emergency Response Planning Challenges*, and is an update of the FY2023 M3 Milestone M3AT-23PN0802052*, Submit Summary Report on Microreactor Emergency Planning and Response Considerations.*

This report discusses microreactor transportation emergency planning and response challenges. The emphasis of the report is on transporting a microreactor containing irradiated fuel by highway and rail. The report first discusses microreactors in general, including microreactor fuel types and the use of hazardous material in microreactor designs. The report presents a microreactor concept of operations for transport highway, rail, and vessel and presents several transportation regulatory challenges associated with microreactors. Included in this update is a discussion of the transportation implications of revising the uranium lung absorption category for tri-structural isotropic (TRISO) particle fuel.

The report then discusses the roles of local authorities, States, Tribes, and the federal government in emergency management and describes the contents of typical transportation emergency response plans.

The report also discusses potential compensatory measures that may be required to obtain microreactor transportation package approval from the U.S. Nuclear Regulatory Commission (NRC). Potential transportation emergency planning and response challenges are then discussed.

These challenges are organized into cross-cutting emergency response challenges and specific transportation emergency response challenges, which include:

- The need to revise the Emergency Response Guidebook (ERG) to provide a guide that is specific to microreactors. This guide may have to be design- and fuel-type specific.
- The use of a risk-informed process for microreactor transportation package approval. The specific issue identified is a microreactor containing irradiated fuel which may not meet the 10 mrem/h at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441 and it may require a stand-off distance of approximately 30 meters to obtain a dose rate of 10 mrem/h, depending on the amount of shielding and storage time prior to transport. This could have implications for transportation emergency response planning if package external dose rates keep responders and recovery crews from meeting necessary objectives for recovery and mitigation.
- Managing the interface between safety and security for microreactor shipments.

Specific transportation emergency response planning challenges were identified by comparing microreactor characteristics to the contents of typical transportation emergency response plans. These challenges include:

- Assignment of Responsibility
- Emergency Response Organization
- Emergency Response Support and Resources
- Emergency Classification System/Emergency Action Levels

- Notification Methods and Procedures
- Emergency Communications
- Public Education and Information
- Emergency Facilities and Equipment
- Accident Assessment
- Protective Response
- Radiological Exposure Control
- Medical and Public Health Support
- Recovery, Reentry, and Post-Accident Operations
- Exercises and Drills
- Radiological Emergency Response Training
- Responsibility for the Planning Effort: Development, Periodic Review, and Distribution of Emergency Plans

Several additional challenges were also identified:

- The use of hazardous materials in microreactor designs. Two specific hazardous materials are discussed: beryllium and sodium. The presence of these hazardous materials could require emergency response jurisdictions to have specialized equipment that may not be part of the standard capabilities of many jurisdictions.
- The need to conduct external engagement prior to transporting a microreactor containing its irradiated fuel. This is a planning challenge because a microreactor containing its irradiated fuel has not been shipped in the United States, and State and Tribal emergency responders along potential truck and rail routes are likely to be unfamiliar with microreactor transport. This engagement could take 2 – 3 years.
- The potential need to conduct emergency response training along transport routes as a compensatory measure required in the NRC transportation certificate of compliance for the microreactor.
- The potential need to develop transportation accident recovery plans as a compensatory measure required in the NRC transportation certificate of compliance for the microreactor.

The report also discusses exercises and drills including the 2024 Naval Spent Nuclear Fuel Transportation Accident Demonstration with the Shoshone-Bannock Tribes and the State of Idaho and Tribal and State perspectives on microreactor transportation emergency response planning. Additional microreactor transportation external engagement activities conducted during FY2024 are also discussed. The report discusses the implications of the recent East Palestine, Ohio, rail accident for transportation emergency response planning. Included in this update is a discussion of H.R. 8996, the Railroad Safety Enhancement Act of 2024.

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Acronyms and Abbreviations

AAR	Association of American Railroads
ANSI	American National Standards Institute
C3RS	Confidential Close Call Reporting System
CVSA	Commercial Vehicle Safety Alliance
DHS	U.S. Department of Homeland Security
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOT	U.S. Department of Transportation
EAL	Emergency Action Level
ECL	Emergency Classification Level
EMS	Emergency Medical Services
ERG	Emergency Response Guidebook
FBI	U.S. Federal Bureau of Investigation
FEMA	U.S. Federal Emergency Management Agency
FRA	Federal Railroad Administration
HALEU	high assay low enriched uranium
HBD	hot bearing detector
HRCQ	highway route-controlled quantity
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IMO	International Maritime Organization
INF	Irradiated Nuclear Fuel
INL	Idaho National Laboratory
LEU	low enriched uranium
MP	milepost
NNPP	Naval Nuclear Propulsion Program
NPP	Nuclear Power Plant
NRC	U.S. Nuclear Regulatory Commission
NS	Norfolk Southern Railway
NTSB	National Transportation Safety Board
NTSF	National Transportation Stakeholders Forum
NVIC	Navigation and Vessel Inspection Circular
PHMSA	Pipeline and Hazardous Materials Safety Administration
PNTL	Pacific Nuclear Transport Limited
PSAP	Public Safety Answering Point
RPM	Radiological Emergency Preparedness Program Manual

SWL	safe working load
TRISO	tri-structural isotropic
USCG	U.S. Coast Guard

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1.0 Introduction

Microreactors are compact reactors capable of producing less than 50 megawatts of electrical energy. Microreactors are generally assumed to be factory fabricated and transportable, and are typically designed to be transportable by truck, rail, vessel, or air. Microreactor designs often assume that the microreactor is transported containing unirradiated or irradiated fuel. Interest in microreactors is driven by a number of factors, including the need to generate power on a small scale in remote locations, at deployed military installations, and in locations recovering from natural disasters.

The U.S. Department of Defense (DoD) is pursuing the microreactor concept as its military operations become more energy intensive and require portable, dense power sources. Commercial vendors are also pursuing microreactor concepts. Remote, rural communities in the United States, many of which fly or truck in diesel to run generators, are considering microreactors since they could generate on-site power.

Transportability is a key characteristic of microreactors, and the purpose of this report is to identify potential emergency planning challenges associated with transporting microreactors containing their irradiated fuel. The report first presents a microreactor concept of operations for transport by highway, rail, and by vessel, and presents several transportation regulatory challenges associated with microreactors.

The report then discusses the roles of local authorities, including States, Tribes, and the federal government in emergency management and describes the contents of typical transportation emergency response plans. The report then discusses potential compensatory measures that may be required to obtain microreactor transportation package approval from the NRC. Potential transportation emergency planning challenges are then discussed, including transportation exercises and drills. The discussion is based on transporting a microreactor containing irradiated fuel by highway and rail.

1.1 Microreactor Fuel Types

TRISO particle fuel is often postulated as a potential microreactor fuel type (see Table 1). Figure 1 illustrates TRISO fuel particles, fuel compacts, prismatic graphite blocks, and spherical fuel pebbles. While TRISO has unique characteristics that make it particularly well suited to transportable microreactors, the goal of this report is to identify transportation emergency planning challenges that are independent of fuel type.

1.2 Hazardous Materials Used in Microreactor Designs

Beryllium-containing materials are currently being investigated for use in microreactors as replacements for graphite as a neutron moderator (Cheng et al. 2022). Beryllium is a hazardous material and if these beryllium-containing materials were incorporated into a microreactor, the presence of these materials would have to be considered in the transportation emergency response planning for these specific microreactors.

In addition, the use of sodium-containing heat pipes is being investigated for use in some microreactors, such as the Westinghouse eVinci microreactor. Sodium is a hazardous material and the presence of sodium would have to be considered in the transportation emergency response planning for these microreactors, specifically in two areas: (1) the ability of sodium in combination with water to exacerbate releases of radioactive material during a transportation accident, and (2) the need to modify transportation accident fire-fighting guidelines if sodium was present.

Table 1. Microreactor Characteristics

Developer	Name	Type	Power Output (MWe/MWth)	Fuel	Coolant	Moderator	Refueling Interval
Aalo Atomics	Aalo One	STR	7 MWe/20MWth	U-Zr-H	Sodium	H	3-5 years
Alpha Tech Research Corp	ARC Nuclear Generator	MSR	12 MWe/30 MWth	LEU	Flouride Salt		intermittent
Antares Industries	R1	Heat Pipe	1.2 MWth	TRISO	Sodium	Graphite	
BWXT	BANR	HTGR	17 MWe/50 MWth	TRISO	Helium	Graphite	5 years
Deep Fission	DB-PWR	PWR	1-15 MWE	LEU	Water	Water	4-6 years
General Atomics	GA Micro	HTGR	1-10 MWe		Gas		
HolosGen	HolosQuad	HTGR	13 MWe	TRISO	Helium/CO2		10 years
Micro Nuclear, LLC	Micro Scale Nuclear Battery	MSR/Heat Pipe	10 MWe	UF4	FLiBe	YH	10 years
Nano Nuclear	Zeus/Odin	HTGR/MSR	1.0 MWe/2.5 MWth	UO2	Helium		
NuCube	Nu3	Heat Pipe	1 MWe/3 MWth	TRISO	Sodium	Graphite	10+ years
NuGen, LLC	NuGen Engine	HTGR	2-4 MWe	TRISO	Helium		
NuScale Power	NuScale Microreactor	LMTM/Heat Pipe	<10 MWe	Metallic	Liquid Metal	Liquid Metal	10 years
Oklo	Aurora	SFR	15 MWe	Metallic (U-Zr)	Sodium		10+ years
Radiant Nuclear	Kaleidos Battery	HTGR	1.2 MWe	TRISO	Helium	Graphite	4-6 years
Ultra Safe Nuclear	Micro Modular Reactor	HTGR	5 MWe/15 MWth	TRISO	Helium	Graphite	20 years
Westinghouse	eVINCI	Heat Pipe	5 MWe/15 MWth	TRISO	Sodium	Graphite	8 years
X-Energy	XENITH	HTGR	5 MWe/10 MWth	TRISO	Helium	Graphite	3+ years

Source: Jackson (2024)

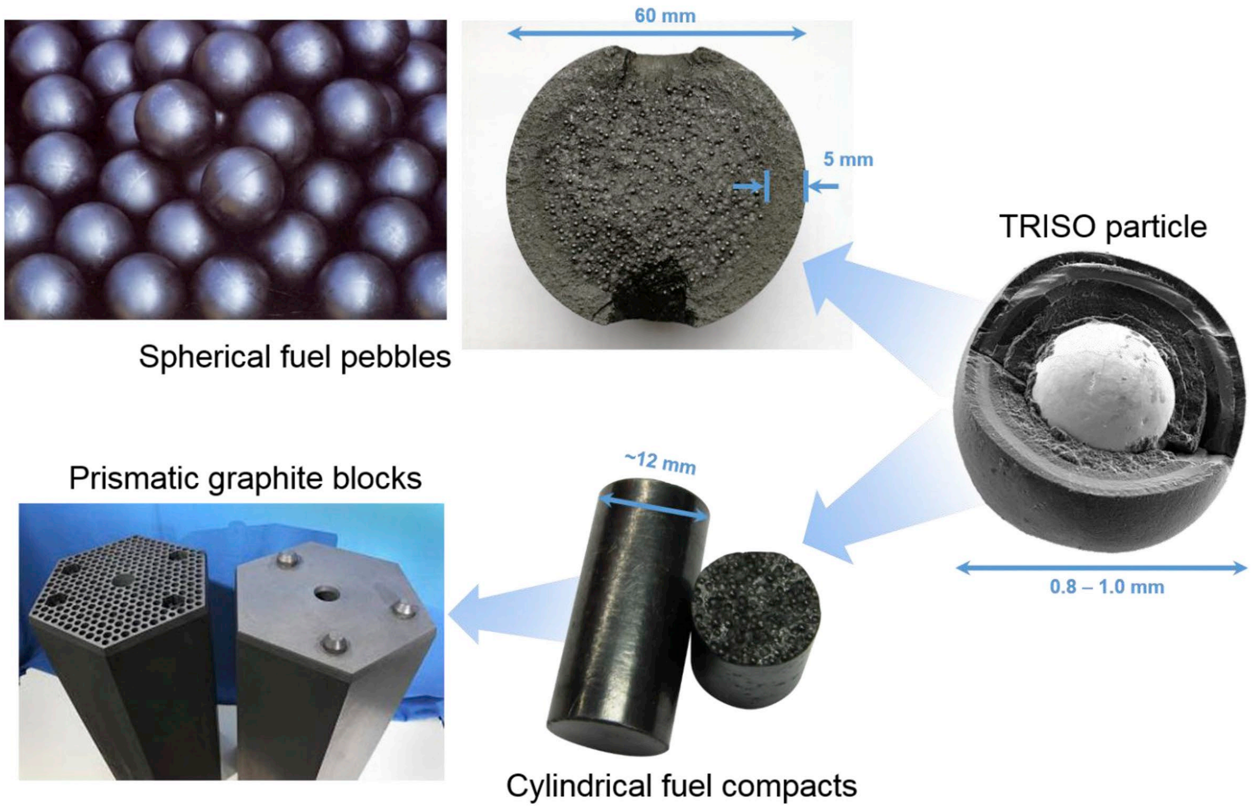


Figure 1. TRISO Particles, Fuel Compacts, Prismatic Graphite Blocks, and Spherical Fuel Pebbles (Demkowicz et al. 2019)

2.0 Microreactor Concept of Operations

This section provides a summary level concept of operations for microreactor transport by highway, rail, and vessel. Transport by air is not discussed. This section also discusses microreactor transportation regulatory challenges.

For highway, rail, and shipment by vessel, the following assumptions have been made for the purpose of establishing a concept of operations:

- The microreactor will be shipped containing irradiated fuel.
- The microreactor shipment will be a commercial shipment between NRC licensees, not a DOE or DoD shipment. As such, the microreactor will receive transportation package approval by the NRC and will be subject to the requirements of NRC regulation 10 CFR Part 71 and the U.S. Department of Transportation (DOT) Hazardous Materials Regulations (49 CFR Parts 171-180).
- NRC transportation package approval will be through a risk-informed process. *Proposed Risk-Informed Regulatory Framework for Approval of Microreactor Transportation Packages* discusses a proposed risk-informed regulatory framework for approval of microreactor transportation packages (Coles et al. 2021). A consequence of using a risk-informed transportation package approval process is that the microreactor containing its irradiated fuel may not meet the deterministic requirements contained in 10 CFR Part 71. In addition, the microreactor containing its irradiated fuel may not meet the 10 mrem/h at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441 and 10 CFR 71.47.
- The microreactor will also be subject to the security requirements contained in 10 CFR 73.37, Requirements for Physical Protection of Irradiated Reactor Fuel In Transit. These requirements are discussed in NRC (NRC 2013). This includes NRC approval of transport routes.
- States and Tribes will receive advance notification of microreactor shipments (see 10 CFR 71.97).
- The microreactor is fueled by low-enriched uranium (LEU)[1] or high assay low enriched uranium (HALEU)[2].
- The microreactor would be brought to its deployment site and fully burned. The microreactor would then be stored for some period of time to reduce radiation dose rates and to allow the microreactor to cool prior to initiating its transport.

2.1 Highway

For microreactor shipments by highway, the concept of operations is as follows:

- The shipment of a microreactor containing unirradiated or lightly irradiated fuel would originate at a factory or depot.
- The weight of the microreactor cargo, trailer, and vehicle would be greater than 80,000 lb. This means that the microreactor would be overweight and may be overdimension

[1] LEU is uranium enriched to less than five percent.
[2] HALEU has enrichments that range from 5 – 20 percent.

and would require a state-issued overweight/overdimension permit. However, it was assumed that the weight of the microreactor cargo, trailer, and vehicle would be less than would require permitting as a superload (about 150,000 lb.).

- After storage reduces the radiation dose rates and the microreactor has cooled, the microreactor containing its irradiated fuel would be shipped from its deployment site to a factory or depot. The microreactor was assumed to contain a highway route-controlled quantity (HRCQ) of radioactive materials (> 3000 A_2) and would require a hazardous material safety permit [49 CFR 385.403(a)] and Commercial Vehicle Safety Alliance (CVSA) Level VI inspection [49 CFR 385.415(b)] (CVSA 2024).

2.2 Rail

For microreactor shipments by rail, the concept of operations is as follows:

- The shipment of a microreactor containing unirradiated or lightly irradiated fuel would originate at a factory or depot.
- The microreactor would be brought to its deployment site and fully burned. The microreactor would then be stored for some period of time to reduce radiation and heat levels prior to initiating its transport.
- After storage reduces the radiation dose rates and the microreactor has cooled, the microreactor containing irradiated fuel would be shipped from its deployment site to a factory or depot. The microreactor was assumed to contain a HRCQ of radioactive materials (> 3000 A_2), and would be shipped according to the requirements contained in 49 CFR 172.820 and 49 CFR 172, Appendix D.
- The microreactor containing its irradiated fuel would be shipped on a railcar that meets the requirements of Association of American Railroads (AAR) Standard S 2043 (AAR 2024a). There are two railcars (Atlas and Fortis) that are currently being designed, fabricated, and tested by the DOE to meet the requirements contained in AAR Standard S-2043. The Atlas railcar, buffer railcar, and rail escort vehicle were approved by AAR in May 2024.[1] Figure 2 shows the Atlas railcar, Figure 3 shows the buffer railcar, and Figure 4 shows the rail escort vehicle. Table 2 lists the characteristics of the Atlas railcar.
- The microreactor on its railcar would meet the dimensional requirements of AAR Plate B, C, or E. Figure 5 illustrates AAR Plate E (AAR 2024b).

[1] https://www.energy.gov/sites/default/files/2024-06/209.240%20DOE%20Atlas%20Consist%20Conditional%20Approval.pdf

Figure 2. Atlas Railcar with Test Weight

Figure 3. Buffer Railcar

Figure 4. Rail Escort Vehicle

Table 2. Characteristics of the Atlas railcar

Element Name	Value
Number of Axles	12
Length	938 inches (78 ft. 2 in.)
Width	128 inches (10 ft. 8 in.)
Deck Height	59 inches (4 ft. 11 in.)
Gross Rail Load	710,700 lb.
Tare Weight	225,700 lb.
Load Limit	485,000 lb.
Plate Code	E

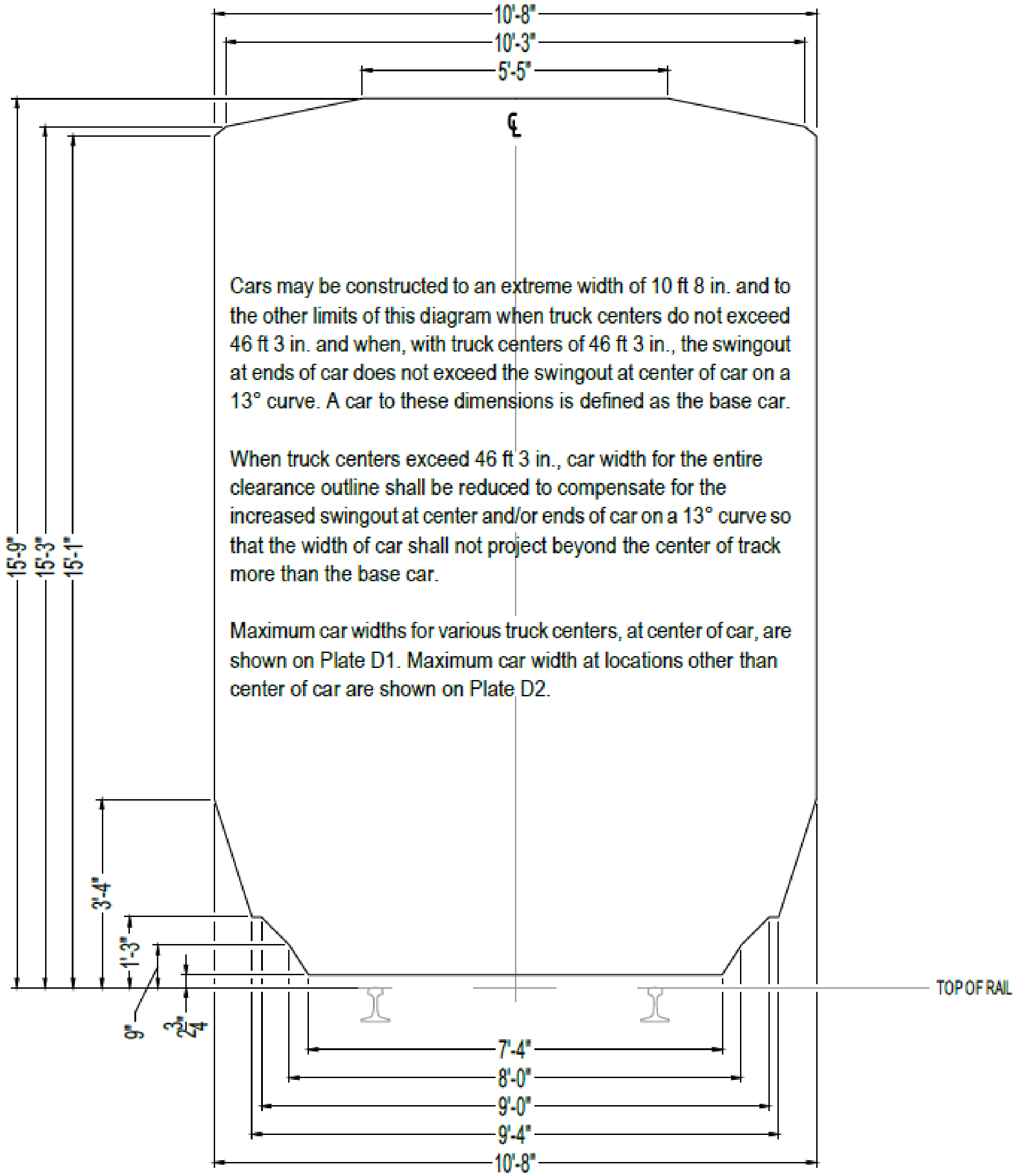


Figure 5. AAR Plate E (AAR 2024b)

2.3 Vessel

For microreactor shipments by vessel, the concept of operations is as follows:

- The shipment of a microreactor containing unirradiated or lightly irradiated fuel would originate at a factory or depot.

- The microreactor would be brought to its deployment site and fully burned. The microreactor would then be stored for some period of time to reduce radiation and heat levels prior to its transport.
- After storage reduces the radiation dose rates and the microreactor has cooled, the microreactor containing its irradiated fuel would be shipped from its deployment site to a factory or depot. The microreactor was assumed to contain a HRCQ of radioactive materials (> 3000 A_2), and would require a Class INF-3 vessel, if transported by a vessel at sea, or a barge if shipped on a river or close to shore.

2.3.1 Transport by Vessel at Sea

The *International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes On Board Ships* (INF Code)[1] contains specific requirements for three classes of ships transporting radioactive material, irradiated fuel, high-level radioactive waste, and plutonium; including requirements for damage stability, fire protection, temperature control of cargo spaces, structural considerations, cargo securing arrangements, electrical supplies, radiological protection equipment, and management, training, and shipboard emergency plans (see Table 3). An INF ship must also comply with the International Convention for the Safety of Life at Sea (SOLAS), the International Convention for the Prevention of Pollution from Ships (MARPOL), and the International Maritime Dangerous Goods Code requirements. The INF Code does not apply to warships, naval auxiliary, or other ships used only in government noncommercial service.

Based on current microreactor core inventory calculations, a Class INF 3 ship would likely be required to transport a microreactor containing irradiated fuel. There are only three Class INF 3 ships available for commercial hire from Pacific Nuclear Transport Limited (PNTL).[2] The PNTL ships are United Kingdom (UK) flagged; there are no United States-flagged Class INF 3 ships. Figure 6 illustrates a Class INF 3 ship with its safety features. The key safety features include the following:

- Double hulls and hull reinforcement to withstand collision damage, with additional strengthening surrounding the holds
- Enhanced buoyancy provided by extensive compartmentalization within the hull, cargo areas, and throughout each ship to make sure the ship will continue to float even in extreme circumstances
- Dual navigation, communications, cargo monitoring, and cooling systems
- Satellite navigation and tracking
- Twin engines, rudders and propellers, with separate machinery and steering gear rooms
- Bow thrusters—single propellers in a duct that runs through the bow—provide optimum maneuverability in ports
- Hold cooling plant located outside of holds for easier maintenance
- Integrated bridge system
- No oil tanks adjacent to the outer hull

[1] See https://www.imo.org/en/OurWork/Safety/Pages/INF-Code.aspx
[2] PNTL is part of Nuclear Transport Solutions.

- Security features incorporated into the design
- Improved environmental and safety performance
- Advanced fire detection and firefighting systems, including a multi-zone and multi-sensor fire detection system linked to alarms on the bridge, a hold flooding system and spare electrical generators in the bow and stern to make sure power is available to operate essential systems, such as firefighting equipment, even in extreme circumstances
- Fixed radiation monitors for each hold that are linked to an alert system on the bridge.

The specific regulatory requirements met by the three PNTL Class INF 3 ships—the Pacific Egret, Pacific Grebe, and Pacific Heron—include the following:

- Certified by UK Department of Transportation as meeting International Maritime Organization (IMO) INF 3
- Class A carrier under UK Nuclear Industry Security Regulations
- Japanese Ministry of Transport regulation KAISA 520
- International Atomic Energy Agency (IAEA) Regulations for the Safe Transport of Radioactive Material
- IAEA Planning and Preparing for Emergency Response to Transport Accidents Involving Radioactive Material
- Convention on the Physical Protection of Nuclear Material
- IAEA INFCIRC/225/Rev.5 security requirements
- IMO SOLAS (International Convention for the Safety of Life at Sea)
- IMO MARPOL (International Convention for the Prevention of Pollution from Ships)
- IMO IMDG Code (International Maritime Dangerous Goods)
- IMO INF Code (International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships)
- IMO ISM Code (International Safety Management)
- UNCLOS (United Nations Convention on the Law of the Sea)
- IMO ISPS Code (International Ship and Port Facility Security).

In addition to the regulatory requirements noted above, U.S. Coast Guard (USCG) Navigation and Inspection Circular No. 3-94 (USCG 1994) calls the attention of USCG field units, marine surveyors, shippers and carriers of nuclear materials to the IMO Code for the Safe Carriage of Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes in Flasks on Board Ships (USCG 1994).

Table 4 lists the characteristics of the Pacific Egret, Pacific Grebe, and Pacific Heron. Figure 7, Figure 8, and Figure 9 show the Pacific Egret, Pacific Grebe, and Pacific Heron at sea. Figure 10 shows a view from Pacific Heron with the Pacific Egret approaching.

Table 3. Classes of INF Ships

Class of INF Ship	Criteria
INF 1	Ships that are certified to carry materials that have an aggregate radioactivity of less than 4,000 TBq (1.1×10^5 Ci).
INF 2	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes that have an aggregate radioactivity less than 2×10^6 TBq (5.4×10^7 Ci) and ships that are certified to carry plutonium that has an aggregate radioactivity less than 2×10^5 TBq (5.4×10^6 Ci).
INF 3	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes, and ships that are certified to carry plutonium that has no restriction on the aggregate radioactivity of the materials.

Table 4. Pacific Egret, Pacific Grebe, and Pacific Heron Characteristics

Length	103.92 meters
Beam (Width)	17.25 meters
Draft	6.75 meters
Number of Holds	4
Capacity	20 transportation casks
Design Speed	14 knots
Deadweight	4,916 metric tons
Displacement	9,667 metric tons
Engine	Two diesel engines, each with 3,600 hp
Principle Cargo Carried	Mixed Oxide Fuel Assemblies (Pacific Egret and Pacific Heron) High-Level Waste and Compacted Waste (Pacific Grebe)

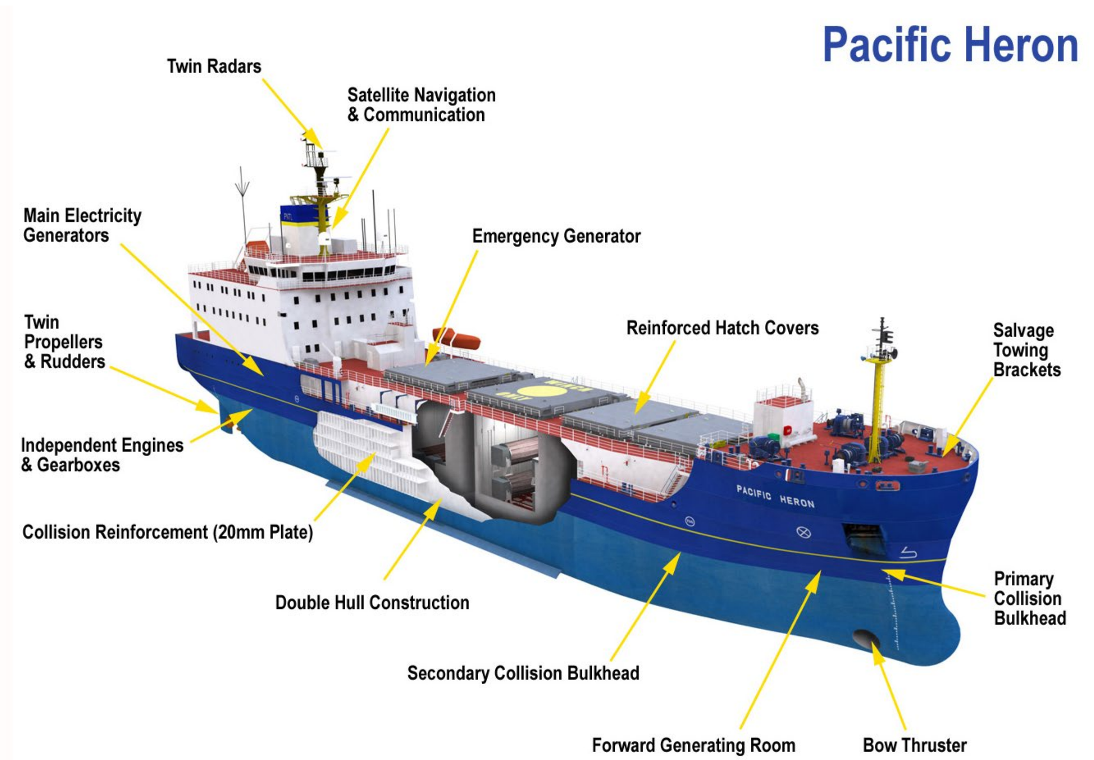


Image courtesy of PNTL

Figure 6. Diagram of a PNTL INF 3 Class Ship Illustrating Safety Features

Image courtesy of PNTL

Figure 7. Pacific Egret at Sea

Image courtesy of PNTL

Figure 8. Pacific Grebe at Sea

Image courtesy of PNTL

Figure 9. Pacific Heron at Sea

Figure 10. View from Pacific Heron with the Pacific Egret Approaching

2.3.2 Transport by Barge

USCG Navigation and Vessel Inspection Circular (NVIC) No. 2-87 (USCG 1987) summarizes the requirements contained in American National Standards Institute (ANSI) Standard N14.24-1985, *Highway Route Controlled Quantities of Radioactive Materials – Domestic Barge Transport* (ANSI 1985). ANSI N14.24 was reaffirmed in 1993, but is not currently active (ANSI 1985).

ANSI N14.24 identifies the organizations, equipment, operations, and documentation involved in barge shipments of radioactive materials between United States ports by inland waterways and in coastal and ocean service (ANSI 1985). The standard includes requirements pertaining to the following:

- selection of the cask, barge, and towing vessel;
- certification and documentation;
- radiological and nonradiological operations;
- insurance;

- emergency planning; and
- physical protection and security of the shipment.

These requirements apply to the water mode phase of a typically multimodal operation. Barge shipments would also require transloads (highway to barge, barge to highway, barge to rail, etc.).

As discussed in NVIC 2-87, ANSI N14.24 describes four phases in the movement of a HRCQ of radioactive material: the planning phase, the pre-operational phase, the operational phase, and the post-operational phase (ANSI 1985). The shippers have overall responsibility that the shipment is conducted in accordance with ANSI N14.24, and must consult and coordinate with numerous organizations throughout each of the phases of the operation.

ANSI N14.24 provides guidance for the selection of the barge (ANSI 1985). The standard specifies the following:

- The barge must be steel, at least 125 feet long, and classed by a recognized classification society.
- It must have intact stability in accordance with Subpart E of 46 CFR Part 172 for a Type II hull under 46 CFR Part 151.
- Its damage stability must be to a one-compartment standard as for a Type II hull. This does not mean that the barge must be a Subchapter 0 barge; it must meet those stability requirements.
- The barge must have the following ancillary equipment:
    - a Class A Emergency Position Indicating Radiobeacon;
    - a passive radar reflector;
    - a sonar pinger with a one-mile range, good for 30 days; and
    - an emergency towing wire made up and laid out on deck with a messenger line trailing in the water.
- When in coastal or ocean service, the barge must have a current loadline certificate and a certificate of Inspection for its intended route.

ANSI N14.24 places great emphasis on the design of the tiedowns for the cask (ANSI 1985). Tiedown design must be based on collision accelerations and be modeled on the requirements for independent chlorine tanks in 46 CFR 151.15 and the wave action accelerations in both head and beam seas.

The Standard advises the shipper of a barge shipment to prepare a shipping plan in considerable detail, and to provide the carrier with handling instructions and an emergency response plan covering both radiological and nonradiological emergencies. The standard advises the shipper developing an emergency response plan to consult with the USCG Captains of the Port that have jurisdiction over the planned shipping route.

The section of the standard related to operations contains requirements for loading and off-loading the radioactive material, both as lift-on/lift-off and roll-on/roll-off cargo. The operations section contains requirements for docking, mooring, and towing conditions, as well as for the physical protection of the package, security, and radiological monitoring.

NVIC 2-87 states that ANSI N14.24 is intended to be a voluntary industry standard, and that compliance would be enforced by insurers, state and local licensing bodies, and partly by the NRC (ANSI 1985). As a statement of USCG policy, NVIC 2-87 states that ANSI N14.24 may also be used by USCG Captains of the Ports when issuing permits and controlling the movement of a barge being used to transport highway route-controlled quantities of radioactive materials (ANSI 1985).

2.4 Microreactor Transportation Regulatory Challenges

This section describes regulatory challenges associated with microreactor transport.

2.4.1 Uranium Lung Absorption Category for Uranium Carbide

TRISO particle fuel is often postulated as a potential microreactor fuel type. The uranium in TRISO fuel is generally in the form of UO_2 or UCO, a heterogeneous mixture of UO_2 and UC_2 (Demkowicz et al. 2019).

In U.S. and IAEA regulations [10 CFR 71, Appendix A, Table A-1; 49 CFR 173.435; IAEA SSR-6, Table 2 (IAEA 2018); IAEA SSG-26, Table I.2 (IAEA 2022a)], the A_1 and A_2 values for uranium enriched to 20 percent or less are listed as unlimited. This means that unirradiated HALEU fuel can be shipped in a Type AF transportation package as opposed to requiring a Type BF transportation package. It should be noted that the unlimited determination is based on the low specific activity of uranium enriched to 20 percent or less (see SSG-26, para. I.62). The inhalation dose coefficients used in this determination were ultimately taken from International Commission on Radiological Protection (ICRP) Publication 68 (ICRP 1994) (see Figure 11). It should also be noted that the A_1 and A_2 values in the U.S. regulations are harmonized with the A_1 and A_2 values in the IAEA regulations.

In the current IAEA regulations (IAEA 2018), uranium is categorized into the three lung absorption types in ICRP Publication 68 (ICRP 1994):

- F – Most hexavalent compounds, e.g. UF_6, UO_2F_2 and $UO_2(NO_3)_2$. These are materials that are readily absorbed into blood from the respiratory tract.
- M – Less soluble compounds, e.g. UO_3, UF_4, UCl_4 and most other hexavalent compounds. These are materials that have intermediate rates of absorption into blood from the respiratory tract.
- S – Highly insoluble compounds, e.g. UO_2 and U_3O_8. These are materials that are relatively insoluble in the respiratory tract.

The current IAEA regulations and ICRP Publication 68 do not specifically discuss uranium carbide.

Figure 11. Inhalation Dose Coefficients Flowchart

In revising SSR-6 (IAEA 2023; IAEA 2024), the IAEA is considering breaking out uranium into the lung absorption categories in ICRP Publication 137 (ICRP 2017) with the following definitions:

- Fast – Fast lung absorption values apply only to compounds of uranium that take the chemical form of UF_6 and uranyl tri-butyl-phosphate in both normal and accident conditions of transport.
- Fast/Medium – Intermediate fast/medium lung absorption values apply only to compounds of uranium that take the chemical form of uranyl nitrate [$UO_2(NO_3)_2$], UO_4, ammonium diuranate (ADU) and UO_3 in both normal and accident conditions of transport.
- Medium – Medium lung absorption values apply only to compounds of uranium that take the chemical form of uranyl acetylacetonate, UF_4 and depleted uranium aerosols from use of kinetic energy penetrators in both normal and accident conditions of transport.

- Medium/Slow – Intermediate medium/slow values apply only to compounds of uranium that take the chemical form of U_3O_8 and UO_2 in both normal and accident conditions of transport.
- Slow – Slow lung absorption values apply to all compounds of uranium other than those specified above.

ICRP Publication 137 does not specifically discuss uranium carbide.

The concern is that if TRISO fuel is categorized as Type Slow, then shipping unirradiated TRISO fuel could require a Type BF transportation package as opposed to a Type AF transportation package, i.e., the A_1 and A_2 values for uranium enriched to 20 percent or less would no longer be unlimited as is currently the case in IAEA and U.S. regulations, and the upper bound on the uranium enrichment that could be considered as having unlimited A_1 and A_2 values is 11 percent (IAEA 2023). If TRISO fuel was categorized as Type Medium/Slow, then the A_1 and A_2 values for uranium enriched to 20 percent or less would be unlimited.

As noted in Section 1.1, TRISO fuel particles have diameters of 0.8-1.0 mm while respirable particles are generally less than 10 μm in diameter. In addition, TRISO particles are then further encapsulated in graphite pebbles or compacts. Based on the diameter of the TRISO particles and encapsulation of the particles in graphite, it is unlikely that respirable uranium would be released during a transportation accident, further supporting the case for the A_1 and A_2 values for uranium enriched to 20 percent or less remaining unlimited.

2.4.2 Low Power Testing and Lack of Radionuclide-Specific A_2 Values

A microreactor containing unirradiated fuel would likely be transported as a Type AF transportation package. However, if a microreactor underwent low power testing before transport, sufficient radioactive material (greater than 1 A_2) could be generated to require a Type BF transportation package, presenting a potential obstacle to obtaining NRC transportation package approval for ground or air transport. In addition, the requirements for the type of transportation package (i.e., Type A or Type B) are based on the radionuclide-specific A_2 values contained in 10 CFR Part 71, Appendix A, Table A-1, and in 49 CFR 173.435. These A_2 values are in turn based on the A_2 values contained in IAEA SSG-26, *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material, 2018 Edition*, Appendix I, Table I.2 (IAEA 2022a). Based on current microreactor core inventory calculations, the tabulations of radionuclides for which there are A_2 values do not include all radionuclides that could be present in microreactor irradiated fuel.

The lack of radionuclide-specific A_2 values would not be an issue for shipping a microreactor after irradiation at full power because sufficient radioactive material would be present to require a Type B transportation package. To determine the transportation package requirements after low power testing, the total A_2 value for radionuclide inventory in the microreactor would need to be determined. If the total A_2 exceeded 1 A_2 the microreactor would be required to meet Type B transportation package requirements, as opposed to Type A transportation package requirements. In both cases, fissile material transportation package requirements would need to be met (*i.e.*, the microreactor would be transported as a Type AF or BF transportation package). The current practice is to use general values for A_2 if the radionuclide-specific value is not known (see 10 CFR Part 71, Appendix A, Table A-3); however, the general A_2 values are likely to be lower than calculated radionuclide-specific A_2 values, which could lead to a situation where the microreactor would need to meet Type B transportation package requirements after low power testing because of the lack of radionuclide-specific A_2 values. Based on current microreactor core inventory calculations, it is possible this issue could be partially ameliorated by performing low power testing for short periods of time at very low power levels and by radioactive decay after testing, but more refined calculations would be required to definitively address this issue. In addition, NRC and DOT regulations allow radionuclide-specific A_2 values to be calculated, but prior NRC or DOT approval is required before these calculated A_2 values can be used to determine transportation package requirements. The development of a cost and schedule estimate is beyond the scope of this analysis, but performing these radionuclide-specific A_2 calculations is likely to require significant effort.

2.4.3 Reactor Design Changes

NRC regulations allow changes to be made to reactor or storage system designs without prior NRC approval (see 10 CFR 50.59 and 10 CFR 72.48). However, there is no equivalent process in 10 CFR Part 71 for transportation package designs. If a microreactor transportation package containing its unirradiated or irradiated fuel was approved by the NRC and the design of the microreactor was subsequently modified, then the microreactor transportation package might need to be reapproved by the NRC. This would entail revising the microreactor transportation package safety analysis report, resubmitting the safety analysis report to the NRC, responding to potential requests for additional information, and issuing a final safety analysis report.

2.4.4 Use of HALEU Derived From Previously Irradiated Uranium

A microreactor containing unirradiated fuel would likely be transported as a Type AF transportation package. However, evaluations performed for transport of fresh (unirradiated) HALEU comprised of recovered and polished material have determined that approximately only 4 kg or more of HALEU are required to exceed one A_2, which would require the transport of the microreactor as a Type BF transportation package even when unirradiated (Eidelpes et al. 2019).

2.4.5 Highway Transport

For transport by highway, the primary challenge related to transportation regulations would be obtaining NRC transportation package approval for a microreactor containing its unirradiated or irradiated fuel. This would be achieved using a risk-informed process and would likely involve compensatory measures that would be at least partially unique to highway transport. This could involve radiation dose rate buffer areas around a microreactor transportation package that are larger than the current radiation dose rate requirement of 10 mrem/h at 2 m from the conveyance contained in DOT and NRC regulations (see 49 CFR 173.441 and 10 CFR 71.47). Figure 12 shows firefighters responding to a roadside vehicle fire.

Figure 12. Firefighters Responding to Roadside Vehicle Fire

According to 49 CFR Part 397, additional regulatory challenges would be the need to obtain oversize/overdimension permits in each state through which the microreactor would be transported, adapting CVSA Level VI inspections to microreactors and adapting highway routing requirements to microreactors (CVSA 2024).

2.4.6 Rail Transport

As with transport by highway, the primary challenge related to transportation regulations for rail transport of a microreactor would be obtaining NRC transportation package approval for a microreactor containing unirradiated or irradiated fuel. This would be achieved using a risk-informed process and would likely involve compensatory measures that would be at least partially unique to rail transport. This could involve radiation dose rate buffer areas around a microreactor transportation package that are larger than the current 10 mrem/h at 2 m from the conveyance contained in DOT and NRC regulations (see 49 CFR 173.441 and 10 CFR 71.47).

An additional challenge would be the availability of railcars that meet the requirements of AAR Standard S-2043 (AAR 2024a) and adapting rail transportation routing requirements to microreactor (see 49 CFR 172.820 and 49 CFR 172, Appendix D).

2.4.7 Vessel Transport

As with transport by highway and rail, the primary challenge related to transportation regulations for transport by vessel of a microreactor would be obtaining NRC transportation package approval for an microreactor containing unirradiated or irradiated fuel. This would be achieved using a risk-informed process and would likely involve compensatory measures that would be at least partially unique to transport by vessel. This could involve radiation dose rate buffer areas around a microreactor transportation package that are larger than the current 10 mrem/h at 2 m from the conveyance contained in DOT and NRC regulations.

An additional challenge would be the availability of Class INF 3 vessels (as discussed in Section 2.3.1.

3.0 Roles of Federal, State, Tribal, and Local Authorities

The National Response Framework discusses the roles of federal, State, Tribal, and local authorities in emergency management (DHS 2019).

3.1 Local Authorities

As discussed by the U.S. Department of Homeland Security (DHS), the responsibility for responding to natural and human-caused incidents that have recognizable geographic boundaries generally begins at the local level with individuals and public officials in the county, parish, city, or town affected by an incident. The following discussion was taken from (DHS 2019).

- Chief Elected or Appointed Official: Jurisdictional chief executives are responsible for the public safety and welfare of the people of their jurisdiction. Officials provide strategic guidance and resources across all five mission areas. Chief elected or appointed officials must have a clear understanding of their emergency management roles and responsibilities and how to apply the response core capabilities because they may need to make decisions regarding resources and operations during an incident to stabilize community lifelines. Elected and appointed officials also routinely shape or modify laws, policies, and budgets to aid preparedness efforts and improve emergency management and response capabilities. The local chief executive's response duties may include the following:
    - Obtaining assistance from other governmental agencies,
    - Providing direction for response activities, and
    - Making sure appropriate information is provided to the public.
- Local Emergency Manager: The jurisdiction's emergency manager oversees the day-to-day emergency management programs and activities. The emergency manager works with chief elected and appointed officials to establish unified objectives regarding the jurisdiction's emergency plans and activities. This role entails coordinating and integrating all elements of the community. The emergency manager coordinates the local emergency management program. This includes assessing the capacity and readiness to deliver the capabilities most likely required to stabilize community lifelines during an incident and identifying and correcting shortfalls. The local emergency manager's duties often include the following:
    - Advising elected and appointed officials during a response;
    - Conducting response operations in accordance with the National Incident Management System;
    - Coordinating the functions of local agencies;
    - Coordinating the development of plans and working cooperatively with other local agencies, community organizations, private sector businesses, and non-governmental organizations;
    - Developing and maintaining mutual aid and assistance agreements;
    - Coordinating resource requests during an incident through the management of an emergency operations center;

    - Coordinating damage assessments during an incident;
    - Advising and informing local officials and the public about emergency management activities during an incident to facilitate response operations such as sheltering, avoiding, evacuating, and resupply of food and water;
    - Developing and executing accessible public awareness and education programs;
    - Conducting training and exercises to rehearse response activities; test personnel, plans and systems; and identify areas for improvement;
    - Coordinating integration of individuals with disabilities, individuals from racially and ethnically diverse backgrounds, and others with access and functional needs into emergency planning and response; and
    - Helping to ensure the continuation of essential services and functions through the development and implementation of continuity of operations plans.
- <u>Other Departments and Agencies:</u> Local government department and agency heads collaborate with the emergency manager during the development of local emergency plans and provide key response resources. Participation in the planning process helps to ensure that specific capabilities are integrated into a workable plan to safeguard the community. The department and agency heads and their staffs develop, plan, and train on internal policies and procedures to meet response needs safely, and they participate in interagency training and exercises to develop and maintain necessary capabilities.

3.2 States

As discussed in DHS, State governments supplement local efforts before, during, and after incidents by applying in-state resources first (DHS 2019). When an incident expands or has the potential to expand beyond the capability of a local jurisdiction and responders cannot meet the needs with mutual aid and assistance resources, local officials must contact the State.

Upon receiving a request for assistance from a local or Tribal government, State officials may do the following:

- Coordinate warnings and public information through the activation of the State's public communications strategy;
- Distribute supplies that are stockpiled to meet the needs of the emergency;
- Provide technical assistance and support to meet the response and recovery needs;
- Suspend or waive statutes, rules, ordinances, and orders, to the extent permitted by law, to make sure timely performance of response functions;
- Implement State volunteer and donations management plans, and coordinate with the private sector and voluntary organizations;
- Order or recommend evacuations ensuring the integration and inclusion of the requirements of populations, such as:
    - children;
    - individuals with disabilities and others with access and functional needs;
    - those from religious, racial, and ethnically diverse communities;
    - people with limited English proficiency; and

  - owners of animals, including household pets and service and assistance animals.
- Mobilize resources to meet the requirements of individuals with disabilities and others with access and functional needs in compliance with federal civil rights laws.

If additional resources are required, States can request assistance from other States through interstate mutual aid and assistance agreements, such as the Emergency Management Assistance Compact. Administered by the National Emergency Management Association, Emergency Management Assistance Compact is an interstate mutual aid agreement that streamlines the interstate mutual aid and assistance process. If a State anticipates that its resources may be exceeded, the Governor may request assistance from the federal government through a Stafford Act declaration.

The following paragraphs describe some of the roles and responsibilities of key officials, as well as other departments and agencies.

Governor: The public safety and welfare of a State's residents are the fundamental responsibilities of every governor. The governor coordinates State resources and provides the strategic guidance for response to all types of incidents. This includes supporting local governments, as needed, and coordinating assistance with other States and the federal government. A governor also does the following during response:

- In accordance with State law, may make, amend, or suspend certain orders or regulations associated with response efforts;
- Communicates to the public in an accessible manner (*i.e.,* effective communications to address all members of the whole community) and helps people, businesses, and organizations cope with the consequences of and protective actions for any type of incident;
- Coordinates with Tribal governments within the State; and
- Commands the State military forces (National Guard personnel not in federal service and State defense forces).

State Homeland Security Advisor: Many States have designated homeland security advisors who serve as counsel to the governor on homeland security issues and may serve as a liaison between the governor's office, the State homeland security structure, and other organizations inside and outside of the State. The advisor may chair a committee composed of representatives of relevant State agencies, including public safety, the National Guard, emergency management, public health, environment, agriculture, and others charged with developing prevention, protection, mitigation, response, and recovery strategies.

State Emergency Management Agency Director: All States have laws mandating the establishment of a State emergency management agency, as well as the emergency plans coordinated by that agency. The director of the State emergency management agency is responsible to make sure the State is prepared to deal with large-scale emergencies and coordinate the statewide response to such incidents. This includes supporting local and Tribal governments, as needed; coordinating assistance with other States and the federal government; and, in some cases, with non-governmental organizations and private sector organizations. The State emergency management agency may dispatch personnel to assist in the response and recovery effort.

National Guard: The National Guard is an important State resource available for planning, preparing, and responding to natural or human-caused incidents. National Guard members have expertise in critical areas, such as emergency medical response; communications; logistics; search and rescue; civil engineering; chemical, biological, radiological, and nuclear response and planning; and decontamination.

The governor may order members of the National Guard to State active-duty status to support State functions and activities. The governor or the State adjutant general may assign members of the National Guard to assist with State, regional, and federal emergency management plans. In American Samoa, the governor coordinates response activities with the U.S. Army Reserve because it is the sole United States territory with no National Guard.

Other State Departments and Agencies: State department and agency heads and their staffs develop, plan, and train on internal policies and procedures to meet response and recovery needs. As discussed earlier, these departments and agencies represent the full range of authorities and resources of the State government, such as law enforcement, transportation, housing, economic development, public works, health, social services, and agriculture. State department and agency heads also provide important links to regional voluntary organizations, business, and industry. Staff from these departments and agencies also participate in interagency training and exercises to develop and maintain the necessary capabilities and share resources through mutual aid agreements. State department and agency heads are vital to the State's overall emergency management program because they bring expertise spanning various response functions and serve as core members of the State Emergency Operations Center and Incident Command Post. Many State department and agency heads have direct experience in providing accessible and vital services to the whole community during response operations. State departments and agencies typically work in close coordination with their federal counterpart agencies during joint State and federal responses. Under some federal laws, they may request assistance from these federal partners.

3.3 Tribal Governments

As discussed in DHS, in accordance with the Stafford Act, the chief executive of an affected Tribal government may submit a request for a declaration by the president (DHS 2019). Tribal governments are responsible for coordinating resources to address actual or potential incidents. When coordinating with Tribes, language and cultural differences must be considered, as well as overlapping authorities.

Tribes are encouraged to build relationships with local jurisdictions and States because these entities may have resources most readily available. The national response framework's Tribal coordination support annex outlines processes and mechanisms that Tribal governments may use to request federal assistance during an incident.

Chief Executive: The chief executive is responsible for the public safety and welfare of his/her respective tribe. The chief executive coordinates Tribal resources and helps guide the response to all types of incidents. This includes coordinating assistance with States, as well as the federal government. The chief executive does the following during response:

- In accordance with the law, make, amend, or suspend certain orders or regulations associated with the response;
- Communicates with the public in an accessible manner, and helps people, businesses, and organizations cope with the consequences of all types of incidents;

- Negotiates mutual aid and assistance agreements with other local jurisdictions, States, Tribes, territories, and insular area governments; and
- Can request federal assistance.

3.4 Federal Government

As discussed in DHS, the federal government maintains a wide range of capabilities and resources that may be required to deal with domestic incidents in order to save lives and protect property and the environment while ensuring the protection of privacy, civil rights, and civil liberties and supporting the stabilization of community lifelines (DHS 2019). To be successful, any approach to the delivery of response capabilities will require an all-of-nation approach. All federal departments and agencies must cooperate with one another and with local, State, Tribal, territorial, and insular area governments, community members, voluntary organizations, and the private sector to the maximum extent possible.

The federal government becomes involved with a response when federal interests are involved; when local, State, Tribal, territorial, or insular resources are insufficient and federal assistance is requested; or as authorized or required by statute, regulation, or policy. Accordingly, in some instances, the federal government may play a supporting role to local, State, Tribal, territorial, or insular area authorities by providing federal assistance to the affected parties. For example, the federal government provides assistance to local, State, Tribal, territorial, and insular area authorities when the president declares a major disaster or emergency under the Stafford Act. In other instances, the federal government may play a leading role in the response where the federal government has primary jurisdiction, or when incidents occur on federal property (*e.g.,* national parks and military bases).

Regardless of the type of incident, the president leads the federal government response effort to make sure the necessary resources are applied quickly and efficiently to large-scale and catastrophic incidents. Different federal departments or agencies lead coordination of the federal government's response, depending on the type and magnitude of the incident, and are also supported by other agencies that bring their relevant capabilities to bear in responding to the incident.

Secretary of Homeland Security: In conjunction with these efforts, the statutory mission of the DHS is to act as a focal point regarding natural and human-caused crises and emergency planning. Pursuant to the Homeland Security Act and presidential directive, the Secretary of Homeland Security is the principal federal official for domestic incident management. The Secretary of Homeland Security coordinates preparedness activities within the United States to respond to and recover from terrorist attacks, major disasters, and other emergencies. The Secretary of Homeland Security coordinates with federal entities to provide for federal unity of efforts for domestic incident management. As part of these responsibilities, the Secretary of Homeland Security does the following during response:

- Provides the executive branch with an overall architecture for domestic incident management, and coordinates the federal response, as required; and
- Monitors activities, assesses risk, and activates specific response mechanisms to support other federal departments and agencies without assuming the overall coordination of the federal response during incidents that do not require the Secretary of Homeland Security to coordinate the response or do not result in a Stafford Act declaration.

Other federal departments and agencies carry out their response authorities and responsibilities within this overarching construct of DHS coordination.

Unity of effort differs from unity of command. Various federal departments and agencies may have statutory responsibilities and lead roles based on the unique circumstances of the incident. Unity of effort provides coordination through cooperation and common interests and does not interfere with federal departments' and agencies' supervisory, command, or statutory authorities. The Secretary of Homeland Security does the following during response:

- Makes sure the overall federal actions are unified, complete, and synchronized to prevent unfilled gaps in the federal government's overarching effort. This coordinated approach makes sure that the federal actions undertaken by DHS and other departments and agencies are harmonized and mutually supportive.
- Executes these coordination responsibilities, in part, by engaging directly with the president and relevant cabinet, department, agency, and DHS component heads to maintain a focused, efficient, and unified federal preparedness posture. All federal departments and agencies, in turn, cooperate with the Secretary of Homeland Security in executing domestic incident management duties.

The Secretary of Homeland Security's responsibilities also include management of the broad emergency management and response authorities of the Federal Emergency Management Agency (FEMA) and other DHS components. DHS component heads may have lead response roles or other significant roles, depending on the type and severity of the incident. For example, the U.S. Secret Service is the lead agency for security design, planning, and implementation of national special security events, while the Assistant Director for Cybersecurity for DHS's Cybersecurity and Infrastructure Security Agency coordinates the response to significant cyber incidents.

<u>FEMA Administrator:</u> The FEMA administrator is the principal adviser to the president, the Secretary of Homeland Security, and the National Security Council regarding emergency management. The FEMA administrator's duties include the following:

- Assisting the president, through the Secretary of Homeland Security, in carrying out the Stafford Act; operation of the National Response Coordination Center and Regional Response Coordination Centers; the effective support of all emergency support functions; and preparation for, protection against, response to, and recovery from all types of incidents.
- Reporting to the Secretary of Homeland Security, the FEMA administrator is also responsible for managing the core DHS grant programs supporting homeland security activities.

<u>Attorney General:</u> The Attorney General has lead responsibility for criminal investigations of terrorist acts or terrorist threats by individuals or groups inside the United States or directed at United States citizens or institutions abroad, where such acts are within the federal criminal jurisdiction of the United States. The Attorney General is also responsible for related intelligence collection activities within the United States, subject to the National Security Act of 1947 (as amended) and other applicable laws, Executive Order 12333 (as amended), and Attorney General-approved procedures pursuant to that executive order.

- Acting through the U.S. Federal Bureau of Investigation (FBI), the Attorney General, in cooperation with other federal departments and agencies engaged in activities to protect the national security, shall also coordinate the activities of the other members of the law enforcement community to detect, prevent, preempt, and disrupt terrorist attacks against the United States.

- In addition, the Attorney General, generally acting through the FBI director, has primary responsibility for searching for, finding, and neutralizing weapons of mass destruction within the United States.
- The Attorney General approves requests submitted by State governors, pursuant to the Emergency Federal Law Enforcement Assistance Act, for personnel and other federal law enforcement support during incidents.
- The Attorney General also enforces federal civil rights laws, such as the Americans with Disabilities Act of 1990, the Rehabilitation Act of 1973, and the Civil Rights Act of 1964. Further information on the Attorney General's role is provided in the National Prevention Framework and Prevention Federal Interagency Operational Plan.

Secretary of Defense: The Secretary of Defense has authority, direction, and control over DoD. DoD resources may be committed when requested by another federal agency and approved by the Secretary of Defense or when directed by the president. Certain DoD officials and component heads, by statute and/or DoD policy, are authorized to approve or delegate the authority to approve certain types of support to civil authorities. DoD policy regarding defense support of civil authorities can be found in DoD Directive 3025.18, Defense Support to Civil Authorities. When DoD resources are authorized to support civil authorities, command of those forces remains with the Secretary of Defense. Under the command and control of the Secretary of Defense, the operational coordination and employment of such resources are normally led by the designated combatant command (*e.g.*, U.S. Northern Command, Southern Command, or Indo-Pacific Command). DoD elements in the incident area of operations coordinate closely with response organizations at all levels.

Secretary of State: A domestic incident may have international and diplomatic implications that call for coordination and consultation with foreign governments and international organizations. The Secretary of State is responsible for all communication and coordination between the U.S. federal government and other nations regarding the response to a domestic crisis. The Department of State also coordinates international offers of assistance and formally accepts or declines these offers on behalf of the United States government, based on needs conveyed by federal departments and agencies, as stated in the International Coordination Support Annex. Some types of international assistance are pre-identified, and bilateral agreements are already established. For example, the U.S. Department of Agriculture/Forest Service and Department of the Interior have joint bilateral agreements with several countries for wildland firefighting support.

Director of National Intelligence: The Director of National Intelligence serves as the head of the intelligence community, acts as the principal advisor to the president for intelligence matters relating to national security, and oversees and directs implementation of the National Intelligence Program. The intelligence community, comprising 17 elements across the federal government, functions consistent with laws, executive orders, regulations, and policies to support the national security-related missions of the United States government. The Director of National Intelligence provides a range of analytic products, including those that assess threats to the homeland and inform planning, capability development, and operational activities of homeland security enterprise partners and stakeholders. In addition to intelligence community elements with specific homeland security missions, the Office of the Director of National

Intelligence maintains a number of mission and support centers that provide unique capabilities for homeland security partners.

4.0 Contents of Typical Transportation Emergency Response Plans

The Radiological Emergency Preparedness Program Manual (RPM) lists the elements that are typically contained in radiological emergency response plans, including transportation emergency response plans (FEMA 2019). These elements are listed in Table 5. The RPM superseded FEMA-REP-5 which had a slightly different list of planning elements (FEMA 2000). The elements contained in the RPM and Table 5 are consistent with the elements developed by the IAEA in SSG-65, *Preparedness and Response for a Nuclear or Radiological Emergency Involving the Transport of Radioactive Material* (IAEA 2022b).

Table 5. Elements Contained in Typical Transportation Emergency Response Plans

Element	Element
Assignment of Responsibility	Accident Assessment
Emergency Response Organization	Protective Response
Emergency Response Support and Resources	Radiological Exposure Control
Emergency Classification System	Medical and Public Health Support
Notification Methods and Procedures	Recovery, Reentry, and Post-Accident Operations
Emergency Communications	Exercises and Drills
Public Education and Information	Radiological Emergency Response Training
Emergency Facilities and Equipment	Responsibility for the Planning Effort: Development, Periodic Review, and Distribution of Emergency Plans

Source: FEMA (2019)

5.0 Potential Compensatory Measures

Compensatory measures would be used to reduce the risks associated with transporting microreactors containing irradiated fuel, and it is likely that compensatory measures would be required as a condition of NRC transportation package approval.

Microreactors containing irradiated fuel shipped by highway would contain a HRCQ of radioactive materials (> 3000 A_2) and would need to meet the routing requirements in 49 CFR Part 397. This requires transport to be conducted using interstates, beltways around cities, and State identified preferred routes. Transport on these types of roads would be a potential compensatory measure because these types of roads are typically of higher quality and capacity than other roads.

A microreactor containing irradiated fuel shipped by highway would also likely be subject to a CVSA Level VI inspection (CVSA 2024). This inspection would also be considered as a potential compensatory measure.

Microreactors transported by highway would also likely be overweight/overdimension loads and would require state permitting when transported by highway. Typical permit conditions include maximum length, width, and height requirements; escort vehicle requirements; pole car requirements; law enforcement escort requirements; and route survey requirements. These permit conditions would be considered as potential compensatory measures.

Other potential compensatory measures include:

- Real-time health/fitness onboard monitoring/diagnostics of microreactor package;
- Escorting of the microreactor forward and aft for the entire route;
- Travel at reduced speeds;
- Closure of public roadways during transport;
- Choosing a route that avoids bodies of water (balanced by quality of road);
- Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic);
- Judicious use of time-of-day and day-of-week restrictions;
- Avoid shipping during severe weather; and
- Conduct training for emergency responders along the route.

5.1 External Engagement

A microreactor containing unirradiated or irradiated fuel has not been shipped in the United States, and State and Tribal emergency responders along potential truck or rail routes are likely to be unfamiliar with microreactor transport. For this reason, it is recommended that 2 – 3 years before shipping, external engagement with States and Tribes along potential transport routes be initiated using the DOE National Transportation Stakeholders Forum (NTSF) as the means of conducting the external engagement and as a potential compensatory measure.

A similar approach was used for shipments of highly enriched uranium liquid target residue. From 2017 – 2020, 115 truck shipments containing 161 kg of highly enriched uranium liquid target residue were made from Chalk River Laboratories in Ontario, Canada, to the Savannah River Site in Aiken, South Carolina. Preparations for the shipping campaign began years before the first truck departed Canada. The DOE used the NTSF, an annual DOE-sponsored transportation conference, to develop contacts in the affected States and Tribal Nations. These relationships were further developed by conducting in-person meetings with representatives of the involved Tribes and State entities. Additional meetings were conducted with participating federal entities, such as law enforcement and homeland security entities (the FBI and DHS). These early outreach efforts facilitated trust between the parties, opened lines of communication, and made shipment planning more efficient.

To further enhance communication and coordination, DOE organized training for emergency responders along the transportation routes. More than 2,000 people from numerous State and local organizations participated. Additionally, a two-week demonstration shipment (that included a real NAC-LWT transportation cask) was undertaken to familiarize local officials and first responders with the equipment that would be used to make the shipments (see Figure 13 and Figure 14).[1] It was important to communicate regularly with the affected stakeholders to make sure they received the information and training needed to support the shipping campaign. However, to comply with regulatory requirements and best practices for information security and operational security, project details were not shared with the general public until after the effort was completed.

[1] One potential way to provide training is through the DOE Transportation Emergency Preparedness Program (https://teppinfo.com/) by adding microreactor modules to the Modular Emergency Response Radiological Transportation Training program.

Figure 13. Transportation Equipment Demonstration Road Show (1)

Figure 14. Transportation Equipment Demonstration Road Show (2)

Such pre-shipment exercises and trainings are extremely helpful to make sure a clear understanding of the various entities' roles and responsibilities during such a shipment, and they help fully elaborate the operational, public safety, and public security-related functions required for a spent nuclear fuel (SNF) shipment.

5.2 Transportation Accident Recovery Plans

It is likely that the NRC would require a microreactor transportation accident recovery plan as a condition of transportation package approval. The transportation accident recovery plan would be considered as a potential compensatory measure. This section describes the content of recovery plans and provides lists of equipment used in transportation accident recovery.

The initial response to a microreactor transportation accident is expected to be by State, Tribal, or local emergency response agencies. In addition, DOT regulations contain guidance for how to respond if a transportation package is damaged as a result of a transportation accident (from DOE 2017):

- When a package of radioactive materials is damaged during the course of public highway transportation, 49 CFR 177.823 and 177.854 authorize the further movement of the package, under specified conditions. Under 49 CFR 177.854(b), packages that cannot be overpacked may be repaired in accordance with the safest practice known and available. If the repair to the package is adequate to prevent a release to the environment or the contamination of other lading on the vehicle, the package may be shipped to a facility for further repair, repackaging or disposal, as appropriate.
- Additionally, under the provisions of 49 CFR 177.843, a vehicle in which radioactive material has been spilled may not be returned to service until the radiation dose rate at any accessible surface is less than 0.5 millirem per hour and there is no significant (above the established limits of 22 alpha and 220 dpm/cm^2 beta gamma DOT limits) removable surface contamination. Movement in accordance with 49 CFR 177.854 does not require an exemption or any other form of approval by the DOT.
- If, due to the extent of the damage, the package cannot comply with the conditions specified in 49 CFR 177.854, DOT may issue an emergency exemption in accordance with 49 CFR 107.117. This section authorizes the issuance of an emergency exemption by DOT provided that an emergency exists and that there is adequate justification for the exemption.
- The information required to be submitted is found in 49 CFR 107.105. An exemption will specify the controls that must be used during transportation to move a package safely to its destination.

Transportation accident recovery plans for radioactive material shipments will typically cover the following areas:

- roles and responsibilities
- recovery events
- recovery methods
- recommended package hoisting, rigging, and recovery equipment
- package and transporter disposition

- restoration activities
- potential environmental contamination and radiation dose rates
- protection strategy requirements

Table 6 lists typical equipment that would be used to recover a 45,000 lb. transuranic waste transportation package. Table 7 lists typical equipment that would be used to recover a 55,000 lb. transuranic waste transportation package.

Table 6. Recovery Equipment List for a 45,000 lb. Transuranic Waste Package

Quantity	Description
1	Mobile crane, minimum 50-ton capacity, with two boom hooks and drag cable (minimum)
1	Tractor
2	Flatbed trailer, 45,000 lb. capacity with suitable commercial side-mounted tiedown structure. (Deck to have a significant wood area to which to fasten [nail] blocking and bracing.)
6	Nylon or cable slings, 5 ft, two eye loops, with safety clips, 25 ton SWL
6	Nylon or cable slings, 15 ft, two eye loops, with safety clips, 25 ton SWL
4	Nylon or cable slings, 30 ft, two eye loops, with safety clips, 25 ton SWL
6	Steel coil chain, 1/2 inch, 25 ft long with a hook at each end
6	Chain binder, 1/2 inch coil chain capacity with a hook on each end
6	Nylon rigging strap, 25 ft, eye loops on both ends, 7-1/2 ton SWL
4	Nylon web tiedown straps, 25 ft long (5,000 lb. minimum working load)
10	Shackles, 5 ton SWL
10	Shackles, 10 ton SWL
3	Snatch blocks, 10 ton SWL
3	Come-along hoists, 5 ton SWL
4	4 in. x 4 in. x 8 ft timber
18	Wood blocks, 6 in. x 8 in. x 24 in., 1-1/2 in. bevel on one 6 in. side
1	Chainsaw, if required
1	Spreader bar and end attachments

SWL= safe working load.
Source: DOE (2017)

Table 7. Recovery Equipment List for a 55,000 lb. Transuranic Waste Package

Quantity	Description
1	Mobile crane, 75 ton capacity, with two boom hooks, and drag cable (minimum)
1	Tractor
2	Flatbed trailer or low-boy trailer, 72,000 lb. capacity with suitable commercial side-mounted tiedown structure
4	Nylon or cable slings, 40 ft, two eye loops, 30 ton SWL
4	ISO container lifting lugs such as TANDEMLOC model 20901AA-4PA
6	Chain binder, 1/2 in. coil chain capacity with a hook on each end
6	G70 chain 1/2 in. x 30 ft, 11,300 lb. WLL
1	4-leg wire or chain bridle rated at a minimum of 30 tons with at least 10 ft legs (45 degree sling angle should be achieved with 10 ft legs)
4	Nylon rigging strap, 30 ft, eye loops on both ends
8	Nylon web tiedown straps min 4 in., 30 ft long (5,000 lb. minimum working load)
4	Shackles, minimum 20 ton SWL
3	Come-along hoists, 5 ton SWL
4	6 in. x 6 in. x 8 ft timber
1	Chainsaw, if required
1-2	Ladders 15–20 ft high or lift (used to position rigging and tiedowns)
1	Spreader bar and end attachments or ISO H lift fixture (optional)

ISO = International Organization for Standardization; SWL= safe working load; WLL= working load limit.
Source: DOE (2017)

5.3 Health Monitoring Information System

Incorporating a health monitoring instrumentation system into the design of a microreactor would enable data on the status of the microreactor to be collected during its transport, and could be used to reduce the risks associated with transporting a microreactor containing irradiated fuel. Three categories of data to be collected have been identified:

- Reactor Safety
- Shielding
- Radiological Containment.

The requirements for maintaining reactor safety during transport include the following:

- Maintain reactor subcriticality by monitoring ex-core neutron fluence and dose enroute. This can be achieved by active neutron fluence monitoring or neutron fluence dosimetry. BF_3[1]or HeF_3 proportional counters are often used for active neutron fluence monitoring and thermoluminescent dosimeters are often used for neutron fluence dosimetry.
- Making sure adequate reactor decay heat cooling is maintained both internally and externally by monitoring in-core, ex-core, and container temperature enroute. This can

[1] Boron trifluoride (BF_3) is a hazardous material and if neutron radiation detectors containing BF_3 gas meet the requirements contained in 49 CFR 172.102, Special Provision 238, then they may be transported by highway, rail, vessel, or cargo aircraft without additional limitations or requirements.

be achieved by monitoring the temperature of reactor internals, the reactor vessel, reactor shielding, etc. Type K thermocouples are often used for this purpose.

- Building a transportation dynamics envelope through instrumentation of vehicle shock/vibration and critical component shock/vibration/fatigue. This can be achieved by measuring the stress, strain, acceleration, and angle of tilt during transportation to build an envelope for performance of reactor components, dampening elements, container design, shielding addition effects, transportation support structure, and vehicle trailer vibration.

The requirements for maintaining shielding during transport include the following:

- Building a radiation exposure envelope to qualify container shielding design by placing radiation dosimetry around the vessel, container, and module shielding. Thermoluminescent dosimeters are often used for passive collection of radiation data.
- Using radiation dose rate monitors to provide enroute display, alarm, and acquisition capabilities to maintain personnel and transportation limits. Electronic dosimeters are often for active monitoring of radiation data.

The requirements for maintaining radiological containment during transport include the following:

- Keeping a primary containment boundary by monitoring and acquiring vessel pressure enroute. The primary system of a microreactor would typically be pressurized a small amount during shipment to maintain system integrity and prevent leakage of air and moisture. The simplest method of monitoring the internal pressure is a temporary pressure transducer that has a low-range calibration suitable for transportation and communication with an onboard monitoring network. The existing pressure instrumentation on the reactor system could also be used to monitor and collect data if feasible.
- Actively monitoring containment air for fission gas activity enroute and storing results in a data acquisition system. There are a variety of systems available for monitoring fission gas activity. In addition, relative humidity and temperature could also be measured.
- Maintaining radiological security by monitoring for container access point intrusion enroute. Shipping container access points should be outfitted with intrusion monitors and alarms to keep special nuclear material and radiological hazards remain secure during transport. This equipment should be coordinated with any safeguards and security plan related instrumentation.

6.0 Potential Transportation Emergency Planning Challenges

This section discusses the potential emergency planning challenges associated with transporting microreactors containing irradiated fuel. Highway and rail-based challenges are discussed. The challenges associated vessel transport of a microreactor are not discussed. In addition, the challenges are based on transporting a microreactor containing its irradiated fuel. The challenges associated with transporting a microreactor containing unirradiated fuel are not specifically discussed and would be enveloped by the challenges associated with transporting a microreactor containing irradiated fuel.

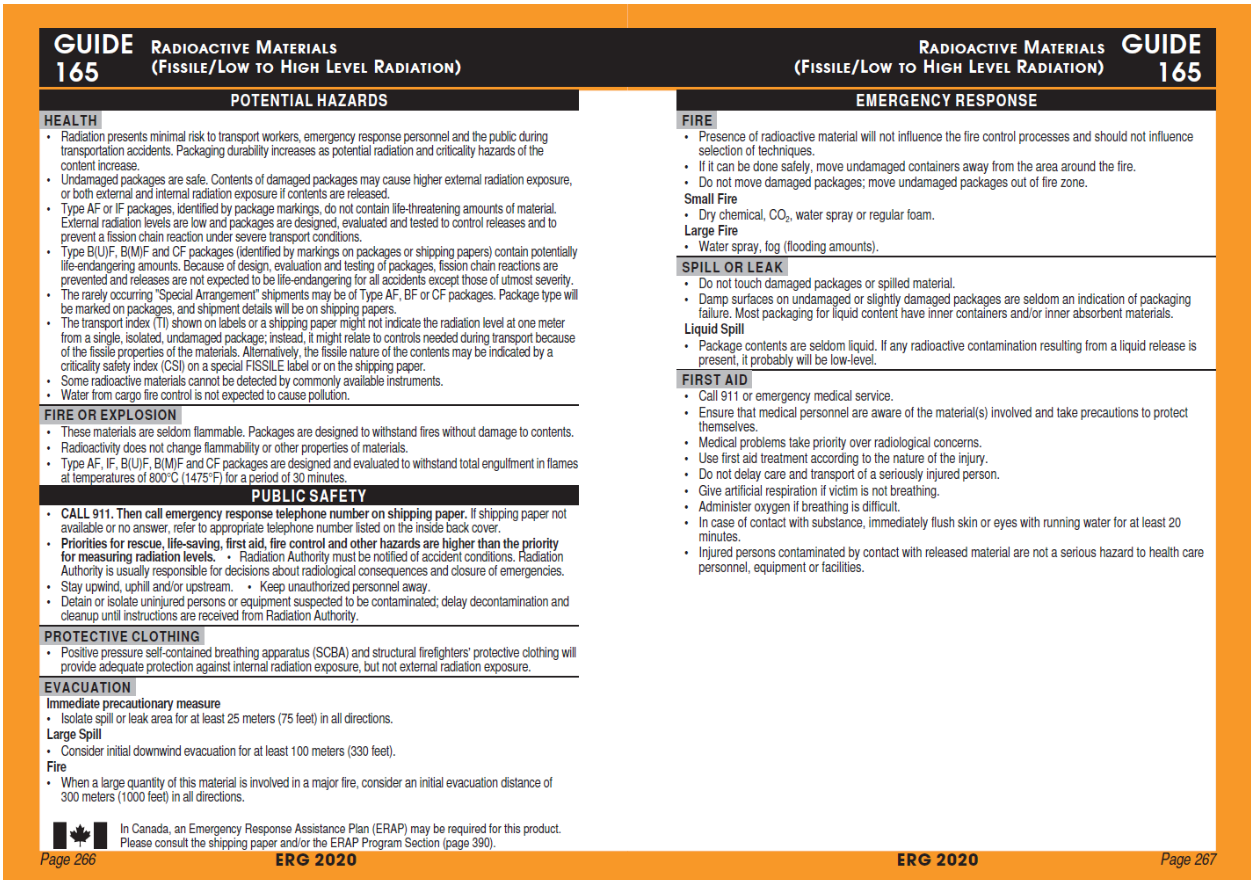
6.1 Cross-Cutting Emergency Response Planning Issues

This section discusses cross-cutting transportation emergency response planning issues associated with microreactor transport.

6.1.1 Emergency Response Guidebook

The DOT Pipeline and Hazardous Materials Safety Administration (PHMSA) ERG provides first responders with a manual to help deal with hazardous materials transportation accidents during the critical first 30 minutes after the accident (PHMSA 2020). Emergency responders are trained to use the shipping papers, numbered placard, or orange panel number to determine which emergency response guide to use in responding to the accident. Figure 15 shows Guide 165, which is used for radioactive materials that are fissile with low to high levels of radiation, such as Type AF, BF, and Type CF transportation packages. Guide 165 contains information on potential hazards, protective clothing and evacuation used for public safety, emergency response to fire, spills or leaks; and first aid that are specific to the contents in these types of transportation packages. Based on current microreactor designs, Guide 165 would be a potential starting point in developing a microreactor-specific guide.

The emergency response guides were not developed based on transportation accidents involving microreactors containing irradiated fuel. As a result, the ERG would have to be expanded to include an identification number and guide number that is specific to microreactor transportation accidents. In addition, the identification and guide number may have to be fuel-type specific because of the differences in potential releases from different microreactor fuel types.



GUIDE 165 RADIOACTIVE MATERIALS (FISSILE/LOW TO HIGH LEVEL RADIATION)

POTENTIAL HAZARDS

HEALTH

- Radiation presents minimal risk to transport workers, emergency response personnel and the public during transportation accidents. Packaging durability increases as potential radiation and criticality hazards of the content increase.
- Undamaged packages are safe. Contents of damaged packages may cause higher external radiation exposure, or both external and internal radiation exposure if contents are released.
- Type AF or IF packages, identified by package markings, do not contain life-threatening amounts of material. External radiation levels are low and packages are designed, evaluated and tested to control releases and to prevent a fission chain reaction under severe transport conditions.
- Type B(U)F, B(M)F and CF packages (identified by markings on packages or shipping papers) contain potentially life-endangering amounts. Because of design, evaluation and testing of packages, fission chain reactions are prevented and releases are not expected to be life-endangering for all accidents except those of utmost severity.
- The rarely occurring "Special Arrangement" shipments may be of Type AF, BF or CF packages. Package type will be marked on packages, and shipment details will be on shipping papers.
- The transport index (TI) shown on labels or a shipping paper might not indicate the radiation level at one meter from a single, isolated, undamaged package; instead, it might relate to controls needed during transport because of the fissile properties of the materials. Alternatively, the fissile nature of the contents may be indicated by a criticality safety index (CSI) on a special FISSILE label or on the shipping paper.
- Some radioactive materials cannot be detected by commonly available instruments.
- Water from cargo fire control is not expected to cause pollution.

FIRE OR EXPLOSION

- These materials are seldom flammable. Packages are designed to withstand fires without damage to contents.
- Radioactivity does not change flammability or other properties of materials.
- Type AF, IF, B(U)F, B(M)F and CF packages are designed and evaluated to withstand total engulfment in flames at temperatures of 800°C (1475°F) for a period of 30 minutes.

PUBLIC SAFETY

- **CALL 911. Then call emergency response telephone number on shipping paper.** If shipping paper not available or no answer, refer to appropriate telephone number listed on the inside back cover.
- **Priorities for rescue, life-saving, first aid, fire control and other hazards are higher than the priority for measuring radiation levels.** • Radiation Authority must be notified of accident conditions. Radiation Authority is usually responsible for decisions about radiological consequences and closure of emergencies.
- Stay upwind, uphill and/or upstream. • Keep unauthorized personnel away.
- Detain or isolate uninjured persons or equipment suspected to be contaminated; delay decontamination and cleanup until instructions are received from Radiation Authority.

PROTECTIVE CLOTHING

- Positive pressure self-contained breathing apparatus (SCBA) and structural firefighters' protective clothing will provide adequate protection against internal radiation exposure, but not external radiation exposure.

EVACUATION

Immediate precautionary measure

- Isolate spill or leak area for at least 25 meters (75 feet) in all directions.

Large Spill

- Consider initial downwind evacuation for at least 100 meters (330 feet).

Fire

- When a large quantity of this material is involved in a major fire, consider an initial evacuation distance of 300 meters (1000 feet) in all directions.

In Canada, an Emergency Response Assistance Plan (ERAP) may be required for this product. Please consult the shipping paper and/or the ERAP Program Section (page 390).

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RADIOACTIVE MATERIALS (FISSILE/LOW TO HIGH LEVEL RADIATION) GUIDE 165

EMERGENCY RESPONSE

FIRE

- Presence of radioactive material will not influence the fire control processes and should not influence selection of techniques.
- If it can be done safely, move undamaged containers away from the area around the fire.
- Do not move damaged packages; move undamaged packages out of fire zone.

Small Fire

- Dry chemical, CO_2, water spray or regular foam.

Large Fire

- Water spray, fog (flooding amounts).

SPILL OR LEAK

- Do not touch damaged packages or spilled material.
- Damp surfaces on undamaged or slightly damaged packages are seldom an indication of packaging failure. Most packaging for liquid content have inner containers and/or inner absorbent materials.

Liquid Spill

- Package contents are seldom liquid. If any radioactive contamination resulting from a liquid release is present, it probably will be low-level.

FIRST AID

- Call 911 or emergency medical service.
- Ensure that medical personnel are aware of the material(s) involved and take precautions to protect themselves.
- Medical problems take priority over radiological concerns.
- Use first aid treatment according to the nature of the injury.
- Do not delay care and transport of a seriously injured person.
- Give artificial respiration if victim is not breathing.
- Administer oxygen if breathing is difficult.
- In case of contact with substance, immediately flush skin or eyes with running water for at least 20 minutes.
- Injured persons contaminated by contact with released material are not a serious hazard to health care personnel, equipment or facilities.

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Figure 15. ERG Guide 165

6.1.2 Use of Risk-Informed Process for Transportation Package Approval

As discussed in Section 2.0, it is likely that NRC microreactor transportation package approval would be conducted using a risk-informed process and the microreactor containing irradiated fuel may not meet the 10 mrem/h at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441 and 10 CFR 71.47. As a result, it may require a stand-off distance of approximately 30 meters to obtain a dose rate of 10 mrem/h, depending on the amount of shielding and storage time (Coles et al. 2021). This could have implications for transportation emergency response planning if external package dose rates keep responders and recovery crews from meeting necessary objectives for recovery and mitigation.

6.1.3 Managing the Interface Between Safety and Security for Microreactor Shipments

IAEA discusses managing the interface between safety and security for normal commercial shipments of radioactive material (IAEA 2021). One potential area where this could apply to microreactor shipments containing irradiated fuel is the relationship between the stand-off distance discussed in Section 6.1.2, the radiation doses for security escorts, and the number of security escorts. A larger stand-off distance could require a larger number of security escorts; a smaller stand-off distance could reduce the number of security escorts but increase the radiation doses for these security escorts. Security elements would need training in the use of, and access to, personal dosimetry and contingency plans would need to be in place for events where dose rates are higher than anticipated. Even though dose rates during an accident may rise to unsafe levels, the material would still have to be under constant surveillance and protection by the security element at close distances. Figure 16 shows an emergency response field exercise that includes hazardous material responders and security elements.

6.2 Specific Transportation Emergency Response Planning Challenges

Emergency planning involving the nuclear enterprise has largely revolved around the nuclear industry and the associated hazards of large light-water reactor nuclear power plant design basis accident criteria. Many of the regulatory requirements are related to plant operations and address the consequences for both on-site and off-site. The emergency planning pertaining to microreactor operations (on-site and off-site) will have significant differences based on the characteristics of microreactor design. Smaller scale reactor, lower decay heat, and lower probability of a severe accident will most likely have a lower consequence, albeit in transport, storage (off-site) or in operations (on-site).

Figure 16. Transportation Emergency Response Field Exercise

Key emergency planning assumptions based on the estimated design-accident characteristics will need to be determined and accepted by both the NRC and the emergency response community. Microreactor emergency planning must be scalable and consequence focused based on the source term and design basis accident criteria to account for man-made and natural phenomena. In addition, a planning basis for microreactor transportation emergency response would need to be established.

6.2.1 Assignment of Responsibility

The primary responsibility for transportation emergency response planning will be the microreactor licensee in coordination and cooperation of State and local organizations. The plan and procedures must identify a single principal organization as the coordinating entity to make sure all of the planning elements are addressed and properly coordinated with supporting organizations in preparation for, and response to, an incident involving a microreactor (in transit, operational, or in storage).

Microreactor emergency planning guidance is very limited given the novelty of this technology. Typical radiological emergency response plans are centered on nuclear power plant (NPP) on-site and off-site emergency preparedness and response and address several planning factors incorporating multiple jurisdictions. Similarly, emergency response plans for microreactors will also incorporate multiple jurisdictions and identified roles and responsibilities to account for the phases of operation of the microreactor life cycle. Emergency planners typically have multiple guides, such as the FEMA RPM, at their disposal for aiding in developing emergency plans. Specific emergency planning guidance for microreactors is lacking and will need to be developed to aid emergency planners.

6.2.2 Emergency Response Organization

As identified above microreactor licensees will be responsible for coordinating emergency response planning to include identifying emergency response organizations that will have jurisdictional responsibility, technical competency, necessary equipment, and ability to manage incident response involving microreactor lifecycle operations. Figure 17 illustrates an emergency response drill involving several of these entities.

Emergency response to radiological incidents has proven to be a significant challenge at all (local, State and federal) levels of government. State and local government officials have primary responsibility for responding and protecting the public during a radiological incident (EPA 2017). Federal assistance may be required given the size, scope, complexity, and impact of a radiological incident.

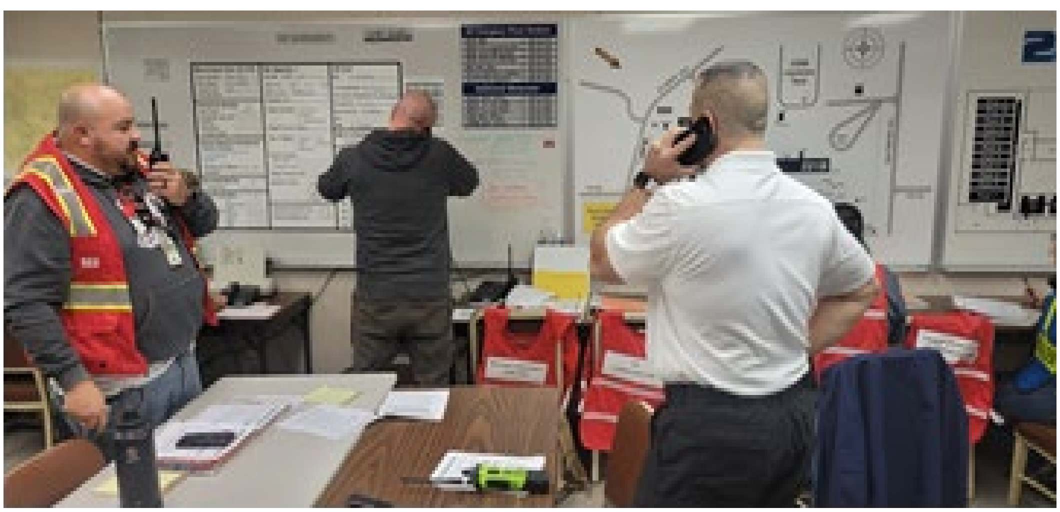

Figure 17. Emergency Response Drill

Emergency response organizations typically operate under the auspices of statues, agreements, memorandums of understanding or executive and presidential directives. These documents that prescribe the relationships and authorities of response organizations will require the inclusion of microreactor technology and responsible parties.

6.2.3 Emergency Response Support and Resources

The consequence from radiological incidents can vary and have a wide degree of impact on a local to national scale. With this, extensive planning considerations are required to be scalable and include the identification of multiple resources and support capabilities.

Emergency response support and resources are typically identified in emergency response planning documents and agreements. Planning for and assigning support elements and resources require diligent planning and awareness of existing and planned response capabilities. Figure 18 illustrates an emergency response field exercise.

Figure 18. Emergency Response Field Exercise

Support and resources needed in response to a radiological incident involving microreactors will require specialized knowledge of microreactor technology and the capability to address associated hazards. Pre-identifying responding organizations based on capability will be essential to the emergency response planning process.

6.2.4 Emergency Classification System/Emergency Action Levels

The NRC has established Emergency Classification Levels (ECLs) that group events or conditions according to the potential effects or consequences, The ECLs are also a system of identifying if the incident will result in an on-site or off-site response. Emergency action levels (EALs) are used as a means for determining protective action measures related to the design-based approach to estimate the potential consequences.

ECL/EALs may be applied to microreactor operations to group credible reactor events or off-normal conditions and prescribe actions related to these conditions. Due to the novelty of microreactors, further understanding of design basis accident criteria will support regulatory framework for developing ECLs/EALs that will further inform emergency planning and response.

Additional consideration for ECLs/EALs that may be unrelated to inherent microreactor operations could involve man-made or natural phenomena. These could include situations such as security threats, external threats like fire, natural weather, or geological events.

6.2.5 Notification Methods and Procedures

As noted above, defining ECLs will drive emergency actions, such as alert and notification, of on-site or off-site response organizations of an unusual event or accident.

Notifications are typically initiated via emergency dispatchers or command elements by calling the designated point of contact on the required shipping papers associated with the transport.

Current ERG guidance for responders who are unable to obtain contact with the entity designated on the shipping papers, is to call one of the organizations listed in the ERG. There are four 24-hour points of contact listed that are intended to assist emergency responders in handling incidents involving radioactive materials. The four organizations act as the middle person to connect responders to State and Federal radiation protection authorities, who then provide information and technical assistance on handling the emergency. Notifications are a process to inform, but they are also a process used to elicit support. Figure 19 shows emergency responders practicing a response to a hazardous material emergency.

Figure 19. Hazardous Material Release Field Exercise

Creating microreactor-specific notification processes and procedures with very specific actions to make sure all appropriate stakeholders are informed is very important. A process with built-in redundancies increases the chance that nothing gets missed.

The challenge lies in implementing the procedure during high-stress and rapidly evolving emergency situations. Having dedicated resources to implement the process, and the ability to delegate certain actions, is a challenge when a transportation event can happen anywhere. Pre-planning by notifying local stakeholders and response agencies when the transport is in their jurisdiction is one way to front-load preparation. A consistent process for this is imperative to the success of a response to, and recovery from, a potential incident.

6.2.6 Emergency Communications

Reliable communication throughout the route is needed for everyone involved in the shipment and must include security, drivers, convoy, etc. Gaps in communication capabilities or inability to reach needed emergency responders creates a safety and security concern. Gaps in communication capabilities slows emergency response and creates opportunities for malevolence.

The local Public Safety Answering Point (PSAP) is responsible for receiving 9-1-1 calls and processing those call. PSAP must know who to call and/or be aware that the transport is in their area. Very specific training may need to be conducted with emergency dispatchers. Skills, such as specific lines of questioning, training on the ERG, placard identification, and specific knowledge to dispatch fire apparatuses and make sure appropriate equipment is deployed, are all potential training needs. Arriving on scene without the correct equipment or personal protective equipment delays response and could exacerbate the emergency.

Providing shipping papers in advance to emergency management groups, fire departments, and the PSAPs along the route would be a best practice. However, there may be security implications to disseminating the exact route of the transport in advance. That relationship will need to be explored.

Local emergency management groups may need to create microreactor-specific emergency plans in preparation for the transport to create emergency planning zones based on worse case scenarios, emergency public messaging, and procedures for notifying the public, stakeholders, and Tribal, State and federal resources.

6.2.7 Public Education and Information

Depending on compensatory measures, the public's reaction to the shipment can vary. Education is key to gain and maintain support of local stakeholders and the public. Communities along the transportation route may have different values, awareness levels, and concerns. The media and political landscape may change at a moment's notice, which could impact the support.

6.2.8 Emergency Facilities and Equipment

Emergency response and support capabilities are a jurisdiction's ability to provide suitable emergency services in relation to identified hazards and should be documented in a jurisdiction's hazard mitigation plan. The intent is to reduce loss of life and property by minimizing the impact from disasters and emergency declarations. Pre-incident hazard analysis and post-incident consequence assessments would determine the appropriate level of response and related equipment.

Once identified as a hazard within a jurisdiction, response incidents involving microreactors will require technical response knowledge, specialized equipment, and mobile decontamination capabilities. Microreactor licensees and public responders will have to make sure adequate response capabilities and facilities are properly equipped and maintained in preparation for a response.

6.2.9 Accident Assessment

While the probability of a radiological and nuclear incidents is extremely low, these types of disasters are an inherent concern to many due to the related radioactive fission products, associated decay heat, and excess activity and the potential for external contamination. To mitigate the risk of loss of life or property, adequate procedures, policies and systems must address the consequence of a related incident. The requirement to analyze the incident is paramount in mitigating loss and managing the consequences.

An adequate accident assessment requires equipped and trained responders, access to hazard analysis tools and products, and competent emergency management organizations. The composition of these capabilities is a vital part of determining the severity of the accident. Transportation accidents can happen anywhere, so having rapid access to trained specialty responders will be the challenge.

Community emergency management teams may not be familiar with how to respond to or may not have the resources for responding to radiological emergencies. Due to potential delay in State or federal resource deployment, there may be a delay in initiating the accident assessment. Having the ability to stabilize the event quickly will be important.

6.2.10 Protective Responses

Protective responses are actions that have been developed to guide public health officials, emergency responders, and emergency workers to aid in recommending evacuation or shelter-in-place orders to the public within a specific region affected by a radiological incident or NPP event. Protective actions also incorporate recommendations to public health officers for ordering the issuance of medical countermeasures, such as potassium iodide to the public who are within the exposure pathway of a NPP emergency planning zone.

Development of microreactor design basis accident criteria and establishing credible event criteria will enable public health officials and emergency responders to take a risk-informed approach to recommending shelter-in place or evacuation of the public related to an incident involving a microreactor while in transport, storage, or in operation.

Significant gaps in awareness at the local, State, and even the federal level exist in relation to microreactor technology, logistics, and operational requirements. Further investment in raising awareness with public health and emergency responder communities on transportation emergency planning will be required as this technology becomes more universally accepted.

6.2.11 Radiological Exposure Control

The probability of a radiological and nuclear emergencies are extremely low; yet, public officials, emergency responders, and even health care workers have limited awareness of the hazards related to these types of incidents. Exposure control measures must be established and strictly adhered to.

During a radiological or nuclear incident, material handlers, radiation workers, and first responders are at great risk of exposure during the initial size-up of the event. A release to the outside environment can escalate quickly without prompt and targeted mitigation efforts. Appropriate personal protective equipment, radiological monitoring capabilities (see Figure 20), and mitigation supplies specific to the potential type and mechanism of the release need to be considered and made available to responders.

Figure 20. Emergency Response Field Exercise Using Radiation Detection Instruments

6.2.12 Medical and Public Health Support

Local hospitals will require training on radiological exposures and how to handle a contaminated patient. Medics and responders will also need to know how to package contaminated/exposed personnel. A lack of awareness, training, and supplies increases the chance of spreading contamination far outside the event area.

6.2.13 Recovery, Reentry, and Post-Accident Operations

Recovery may take a long time and specialized recovery equipment may need to be obtained such as the items listed in Table 6 and Table 7. In addition, the magnitude or type of incident will determine who handles it, its impact to communities, and who is in command.

6.2.14 Exercises and Drills

Training via exercise and drills is a critical part of preparation for shipper, receiver, transport crew, and responders along routes. Figure 21 illustrates a transportation emergency response field exercise.

Accidents can happen during loading, unloading, and transport. Drills and exercises should be conducted to practice a wide array of potential initiating events based on design basis accident criteria. Differing severities of releases should be exercised to include reentry and recovery actions. Exercises and drills should also be conducted with specialty emergency response organizations, local emergency management, and associated stakeholders. This allows for the practice of notification procedures, deployment of assets, and full-scale testing of the processes and procedure that are in place.

Figure 21. Transportation Emergency Response Field Exercise

If security elements that used for the transport, they need to be part of these preparations. Drills and exercises should also be conducted based on potential security events that do not necessarily include damage to the shipment or a radiological or hazardous release.

There may be regulatory requirements for training and drills regarding the transportation of radiological materials.

6.2.15 Radiological Emergency Response Training

Microreactor-specific emergency response training has not been developed. As discussed in Section 5.1, one potential way to provide training is through the DOE Transportation Emergency Preparedness Program by adding microreactor modules to the Modular Emergency Response

Radiological Transportation Training program.[1] In addition, external special response teams such as the DOE Radiological Assistance Program Team could be used to help prepare and train responders and those supporting the actual transport of the microreactor (drivers, escorts, security).

6.2.16 Responsibility for the Planning Effort: Development, Periodic Review, and Distribution of Emergency Plans

It is possible that microreactor transportation emergency response plans may need to be design specific. This is discussed further in Section 6.2.17. If there are multiple microreactor designs from multiple vendors, this could pose a configuration management challenge because vendors would have to develop, periodically review, and distribute multiple microreactor transportation emergency response plans and emergency response jurisdictions would need keep track of multiple microreactor transportation emergency response plans.

6.2.17 Use of Hazardous Materials in Microreactors

As discussed in Section 1.2, microreactors may contain hazardous materials, such as beryllium or sodium. These hazardous materials would have to be considered in the transportation emergency response planning for these microreactors. In addition, the presence of these hazardous materials may require a specific microreactor emergency response guide created to adequately capture the potential hazards associated with transporting these microreactors. Training would need to be conducted with emergency responders for the response to these uncommon materials, and compensatory measures must be in place which would likely be very different than that of the compensatory measures in place for microreactor transports that do not contain these materials. Fire suppression equipment used specifically in the response to a sodium fire[2] is much different than the equipment used to respond to a standard non-water reactive fire. Specialized equipment, such as dry chem suppression trucks (see Figure 22) and Class D extinguishers (Figure 23) are not part of the capabilities for most municipalities.

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[1] https://teppinfo.com/

[2] Fires are put into five separate categories, A, B, C, D, and K, largely based on what type of fuel is burning. Different categories require different types of firefighting agents to extinguish the flames successfully. Fires involving combustible metals (magnesium, titanium, zirconium, sodium, lithium, potassium) are categorized as Class D fires which require a specific type of dry powder for extinguishment. Class D extinguishers are considered specialty equipment.

Figure 22. Dry Chemical Suppression Truck

Figure 23. Class D Fire Extinguisher

6.2.18 External Engagement Prior to Microreactor Transport

As discussed in Section 5.1, a microreactor containing unirradiated or irradiated fuel has not been shipped in the United States and State and Tribal emergency responders along potential truck routes are likely to be unfamiliar with microreactor transport. For this reason, it is recommended that external engagement with States and Tribes along potential transport routes be initiated 2 – 3 years before shipping at NTSF as the means of conducting the external engagement.

6.2.19 Emergency Response Training Along Routes

For current shipments associated with the Waste Isolation Pilot Plant and future shipments associated with the Nuclear Waste Policy Act, as amended (42 U.S.C. 10101 et seq.), training of emergency responders along transport routes is provided, or would be provided. For commercial microreactor shipments, there is currently no obligation for the Federal Government to provide this training. As discussed in Section 5.0, NRC may require training to be conducted for emergency responders along transport routes as a condition associated with transportation package approval; however, there is no clear mechanism for providing funds for this training. Figure 24 shows firefighters and radiological control technicians practicing a response to a vehicle accident involving a radiological release.

Figure 24. Emergency Response Field Exercise Involving a Radiological Release

6.2.20 Development of Transportation Accident Recovery Plans

A certificate of compliance issued by the NRC for a transportation package would not normally include the requirement to have a transportation accident recovery plan in place. As discussed in Section 5.2, NRC may require a transportation accident recovery plan to be in place prior to shipping a microreactor containing its irradiated fuel. The microreactor vendor would have to coordinate the development of this plan with emergency responders along transport routes to make sure transportation emergency response planning is fully integrated.

6.3 Transportation Exercises and Drills

The need to conduct exercises and drills is discussed in IAEA SSG-65, *Preparedness and Response for a Nuclear or Radiological Emergency Involving the Transport of Radioactive Material* (IAEA 2022b):

> Periodic exercises should be conducted to evaluate major portions of emergency response capabilities. Periodic drills should be conducted to develop and maintain key skills. Evaluation of exercises and drills should define problem areas and identify corrective measures. The plans should indicate the frequency and participation of groups and agencies needed in the exercises and drills.

As used by the IAEA in SSG-65, drills are more limited in scope than exercises and should be developed to maintain the skills of response personnel. SSG-65 also states that drills for shipments that have little or no potential to cause adverse radiological consequences should nevertheless be performed to test, at a minimum, the notification procedures and channels, as well as the procedures for verification of the integrity of the package and for repackaging.

As discussed in SSG-65, exercises should be developed and implemented to ensure that scenarios involving shipments requiring a sizeable and resource intensive emergency response component are tested on a regular basis (IAEA 2022b). These exercises should be designed to test all organizational interfaces, should be based on a graded approach and should include the participation of all the organizations concerned. The exercises may be based on scenarios that exceed the hypothetical accident conditions specified in IAEA and U.S. regulations (SSR-6 and 10 CFR Part 71).

SSG-65 requires that exercises are required to be systematically evaluated in accordance with para. 6.33 of GSR Part 7, *Preparedness and Response for a Nuclear or Radiological Emergency* (IAEA 2015). Emergency plans and procedures should be reviewed and as needed revised, based on exercise evaluation reports and as part of the quality management program for emergency preparedness and response.

SSG-65 also requires that radiological assessors and response organizations that have personnel with expertise in radiation protection or other relevant technical expertise and that may be called on for support and response in the event of a transport emergency need a detailed training program. The personnel should be trained on the following on a regular basis, as appropriate for their assigned roles and responsibilities:

- Incident assessment techniques, using radiological monitoring instruments if appropriate;
- Criticality safety assessment;

- Determination and practical implementation of protective actions and other response actions;
- Use of protective clothing and equipment;
- Collection of contaminated material;
- Sealing techniques for leaking packages;
- Repacking of damaged packages;
- Dose estimation and dose reconstruction.

Additional requirements contained is SSG-65 include:

- The representatives of the appropriate governmental authorities should receive training on the national emergency arrangements, the national transport safety regulations, and the roles and responsibilities of different authorities and organizations in responding to an emergency. These governmental authorities should have access to information about existing emergency response plans and the organizations that may be involved, as well as information about communication procedures and dealing with representatives of the news media.
- A debriefing session should be performed as soon as possible after each drill, exercise and emergency. The emergency workers involved should take part in this debriefing session. Their reports and experiences should be documented and evaluated. The conclusions and lessons should be used to improve the emergency plans.

As part of the development of this report, the 2024 Naval Spent Nuclear Fuel Transportation Accident Demonstration with the Shoshone-Bannock Tribes and the State of Idaho was attended. This demonstration took place on September 18, 2024.

A summary of the transportation accident demonstration is as follows:

- An M-290 Naval spent nuclear fuel transportation cask enroute from Huntington Ingalls Industries - Newport News Shipbuilding in Newport News, Virginia to the Naval Reactors Facility on the Idaho National Laboratory (INL) in Scoville, Idaho is moving through the Fort Hall Reservation on Union Pacific Railroad. The shipment is being escorted by three Naval Nuclear Propulsion Program (NNPP) Shipment Couriers.
- As the train is passing through the Sheepskin Road railroad crossing, a mechanical truck collides with the M-290 transportation cask railcar. The truck strikes the railcar transporting the M-290 transportation cask. As a result of the collision, the truck is thrown aside but remains upright and comes to a stop adjacent to the tracks. Nobody exits the truck. Damage from the collision results in the truck developing a diesel fuel leak. The railcar remains upright, but the rear wheels of the railcar are derailed.
- The train comes to an emergency stop while the NNPP Shipment Couriers and train crew make accident notifications in accordance with established procedures. A Fort Hall Police Officer located near the accident scene immediately responds and begins to assess the injured truck driver. One of the NNPP Shipment Couriers assists in attending to the driver. The third NNPP Shipment Courier establishes an industrial safety boundary around the derailed railcar and conducts radiological surveys to confirm there is no change in the radiological condition or integrity of the M-290 transportation cask as a result of the collision.

- Tribal and local emergency responders (police, fire, and ambulance) and Union Pacific personnel arrive on scene. Response and recovery operations are conducted in accordance with each organization's established procedures. The Fort Hall Fire and Emergency Medical Services (EMS) Department Chief establishes a Unified Command structure and serves as Incident Commander.
- Local reporters report to the Tribal Office of Emergency Management and inquire about the event. The Shoshone-Bannock Tribes Public Information Officer briefs the media.
- Fort Hall Fire and EMS and Idaho State Police perform radiological surveys of the M-290 transportation cask to validate that there is no radiological concern. Based on the results of the radiological surveys, the Fort Hall Fire and EMS Department Incident Commander, Idaho Department of Environmental Quality, and Idaho State EMS Communications Center confirms there are no radiological concerns for the public.
- The Fort Hall Fire and EMS Department Incident Commander determines the scene is stable and turns the scene over to the Fort Hall Police Department, Idaho State Police, and Union Pacific personnel to continue the accident investigation and provide security while Union Pacific re-rails the railcar.

Figure 25 shows the M-290 transportation cask on its railcar and the Rail Escort Vehicle, Figure 26 shows the mechanical truck at the grade crossing after the accident, and Figure 27 shows the Shipment Couriers and Idaho State Police performing radiation surveys.

Figure 25. M-290 Transportation Cask on Its Railcar and Rail Escort Vehicle

Figure 26. Mechanical Truck at Railroad Crossing After Accident

Figure 27. Shipment Couriers and Idaho State Police Performing Radiation Surveys

The lessons learned from the exercise included:

- For an accident on the Fort Hall Reservation, the lead Public information Officer will likely choose to brief the media from a remote location.
    - Shipment couriers must ensure that the Incident Command and lead Public Information Officer receive shipping paperwork and Naval Spent Fuel Shipment Fact Sheet as soon as possible.
    - Provide the lead Public Information Officer’s contact Information to Bettis Emergency Control Center to support establishing a virtual Joint Information Center.
    - A public Information officer from the Naval Reactors Facility Transportation Emergency Response Team Advance Phase One Team will report to the remote location to provide on-site support to the lead Public Information Officer.

- NNPP completed two additional demonstration runs of an actual spent fuel shipment train consist (with an empty M-290 transportation cask) using new rail escort vehicle.
    - Provided shipment couriers with additional real-world, hands-on experience and familiarization before using the rail escort vehicle for an actual loaded shipment.
- With the presence of an NNPP site in Idaho (Naval Reactors Facility) and the role of the Bettis Laboratory, as the lead Emergency Control Center for an NNPP rail shipment accidents, the NNPP has a better understanding of how the two sites would work together to ensure effective communications with the Stale of Idaho and the Shoshone-Bannock Tribes in the unlikely event of an accident involving a Naval spent fuel shipment.

The transportation emergency planning challenges associated with microreactor exercises and drills is the lack of detail on how microreactors may be shipped, where they might be deployed, and how they might be returned to a factory or depot; the need for transportation planning guidance for microreactors; and the need for training for emergency responders along transport routes; microreactor radiation dose rates; the performance of microreactors during transportation accidents; and the lack of specific Emergency Response Guides for microreactors. Many of these transportation emergency planning challenges will diminish as the microreactor industry matures.

6.4 State Perspectives and External Engagement Activities

This section discusses State and Tribal perspectives on microreactor transportation emergency planning challenges and describes other microreactor transportation external engagement activities.

6.4.1 State Perspectives

As part of the development of this report, discussions were held with State and Tribal emergency management staff to elicit their thoughts on the challenges associated with microreactor transportation planning. These discussions took place at the Waste Management 2023 Conference, held February 26 – March 2, 2023, in Phoenix, Arizona, and at the NTSF Annual Meeting, held May 22 – 25, 2023 in St. Louis, Missouri. Appendix A contains the presentation used at the NTSF Annual Meeting.

The following items were observations made by these staff.

- There is a need to better understand how microreactors may be shipped, where they might be deployed, and how they might be returned to a factory or depot.
- Emergency facilities and equipment are already strained.
- Police escorts should be used for microreactor shipments.
- CVSA Level VI inspections should be conducted. The CVSA Level VI inspection protocol may have to be modified to account for increased radiation dose rate potential associated with microreactors. CVSA Level VI inspections may be conducted at each State border (CVSA 2024).
- An on-board radiation detection system may be useful to detect conditions that could be hazardous to the escorts.

- A larger “bubble” (exclusion zone) around microreactor shipments may be required.
- It might be useful to transport a microreactor at night to avoid traffic congestion. It might also be useful to avoid transporting over long weekends or during special events, for the same reason.
- It may be useful for transport routes to avoid rivers and gorges.
- Rolling road closures to limit highway access should be considered.
- Emergency pullouts (i.e., safe havens) for the microreactor along transport routes should be identified. These locations should provide sufficient space to secure the microreactor, be away from people, and have a large perimeter. Contingency radiation monitoring at these emergency pullouts should be considered.
- Training for emergency responders along transport routes should be provided.
- Transportation emergency response planning should consider the presence of radioactive and non-radioactive hazardous materials.
- A dry run microreactor shipment should be conducted prior to the transport of a microreactor containing irradiated fuel.
- Would dedicated trains be used to transport microreactors by rail?
- Placing air space restrictions over the microreactor during transport should be considered.
- A specific Emergency Response Guide may be required for microreactors. This would likely require that a Design Basis Transportation Accident be defined.
- There is a need for transportation planning guidance for microreactors. Potential areas include:
    - Assignment of responsibility
    - Emergency response organization
    - Emergency classification system
    - Notification methods and procedures
    - Emergency communications
    - Public education and information
    - Emergency facilities and equipment.
- It might be advantageous to have emergency response personnel accompany the microreactor shipment.

6.4.2 External Engagement Activities

In order to gather further information on the challenges associated with microreactor transportation planning and to further socialize the risk-informed microreactor transportation package approval process, additional external engagement activities were conducted. These activities included the following presentations:

- Transportation of Microreactors, Nuclear Energy Tribal Working Group, September 26-27, 2023.

- Transportation of Microreactors, Western Interstate Energy Board, High Level Radioactive Waste Committee and WIPP Transportation Technical Advisory Group, Fall 2023 Meeting, Idaho Falls, Idaho, November 8-9, 2023.
- Transportation of Microreactors, INMM 37th Spent Fuel Management Seminar, Alexandria, Virginia, January 17-18, 2024.
- Transport of Unirradiated and Irradiated Advanced Reactor Fuels, Conflicts and Synergies for Transportation/Packaging 3S by Design for Advanced Reactors, Waste Management 2024 Conference, March 10-14, 2023, Phoenix, Arizona.
- Microreactor Transportation Emergency Planning Challenges, International Conference on the Management of Spent Fuel from Nuclear Power Reactors: Meeting the Moment, June 10-14, 2024, Vienna, Austria.
- Transport of Unirradiated and Irradiated Advanced Reactor Fuels, National Transportation Stakeholders Forum Annual 2024 Meeting, Denver, Colorado, June 3-6, 2024.

Appendix B-G contain the presentations used at these external engagement activities.

Participants at these meetings reiterated the need to better understand how microreactors may be shipped, where they might be deployed, and how they might be returned to a factory or depot; the need for transportation planning guidance for microreactors; and the need for training for emergency responders along transport routes. Participants were also interested in understanding how transportation planning guidance would differ among transportation modes (i.e., highway, rail, ship, and barge).

6.5 Implications of East Palestine, Ohio Derailment for Transportation Emergency Response Planning

This section provides background for and discusses potential implications of the East Palestine, Ohio derailment for transportation emergency response planning. The background is largely taken from the National Transportation Safety Board (NTSB) (NTSB 2023) and the Congressional Research Service (CRS 2023).[1]

6.5.1 Background on East Palestine Derailment

On February 3, 2023, at about 8:54 p.m. local time, eastbound Norfolk Southern Railway (NS) general merchandise freight train 32N derailed 38 railcars on main track one of the NS Fort Wayne Line of the Keystone Division in East Palestine,[2] Ohio. The derailed equipment included 11 tank cars carrying hazardous materials that subsequently ignited, fueling fires that damaged an additional 12 non-derailed railcars. First responders implemented a one-mile evacuation zone surrounding the derailment site that affected up to 2,000 residents. There were no reported fatalities or injuries. At the time of the accident, visibility conditions were dark and clear; the temperature was 10°F and there was no precipitation.

Train 32N comprised of two head-end locomotives, 149 railcars, and one distributed power locomotive located between railcars 109 and 110. The consist included 20 placarded hazardous

[1] https://data.ntsb.gov/Docket?ProjectID=106864
[2] Pronounced "Palesteen."

materials tank cars transporting combustible liquids, flammable liquids, and flammable gas, including vinyl chloride.[1,2] Train 32N was traveling about 47 mph at the time of the derailment, which was less than the maximum authorized timetable speed of 50 mph. Train movements near the derailment site are authorized by cab signals and wayside signal indications with an overlaid positive train control system and are coordinated by the NS Cleveland East train dispatcher located in Atlanta, Georgia. The positive train control system was enabled and operating at the time of the derailment.

Train 32N was operating with a dynamic brake application as the train passed a wayside defect detector on the east side of Palestine, Ohio, at milepost (MP) 49.81.[3] The wayside defect detector, or hot bearing detector (HBD), transmitted a critical audible alarm message instructing the crew to slow and stop the train to inspect a hot axle. The train engineer increased the dynamic brake application to further slow and stop the train. During this deceleration, an automatic emergency brake application initiated and train 32N came to a stop.[4]

On the Fort Wayne Line of the Keystone Division, NS has equipped their rail network with HBD systems to assess the temperature conditions of wheel bearings while enroute. The function of the HBD is to detect overheated bearings and provide audible real-time warnings to train crews. Train 32N passed three HBD systems on its trip before the derailment. At MP 79.9, the suspect bearing from the twenty-third car had a recorded temperature of 38°F above ambient temperature. When train 32N passed the next HBD at MP 69.01, the bearing’s recorded temperature was 103°F above ambient. The third HBD, at MP 49.81, recorded the suspect bearing’s temperature at 253°F above ambient. NS has established the following HBD alarm thresholds (above ambient temperature) and criteria for bearings:

- Between 170°F and 200°F, warm bearing (non-critical); stop and inspect.
- A difference between bearings on the same axle greater than or equal to 115°F (non-critical); stop and inspect.
- Greater than 200°F (critical); set out railcar.

After the train stopped, the crew observed fire and smoke and notified the Cleveland East dispatcher of a possible derailment. With dispatcher authorization, the crew applied handbrakes to the two railcars at the head of the train, uncoupled the head-end locomotives, and moved the locomotives about one mile from the uncoupled railcars. Responders arrived at the derailment site and began response efforts.

On February 5, responders mitigated the fire, but five derailed DOT-105 specification tank cars (railcars 28 – 31 and 55) carrying 115,580 gallons of vinyl chloride continued to concern authorities because the temperature inside one tank car was still rising. This increase in temperature suggested that the vinyl chloride was undergoing a polymerization reaction, which

[1] Vinyl chloride is a flammable petrochemical used in the manufacture of polymer polyvinyl chloride, or PVC. When exposed to heat, vinyl chloride can undergo a rapid polymerization reaction—an exothermic chemical process that can pose an explosion hazard.
[2] Residues of some hazardous materials are considered flammable liquids; in this case, two placarded tank cars contained benzene residue.
[3] On a diesel-electric locomotive, dynamic braking uses electric traction motors as generators, slowing the train and dissipating mechanical energy as heat.
[4] An automatic emergency brake application is the full application of a train’s main air brakes. An automatic emergency brake application can occur when a train experiences a separation that disconnects the air brake hoses between railcars.

could pose an explosion hazard. Responders scheduled a controlled venting of the five vinyl chloride tank cars to release and burn the vinyl chloride, expanded the evacuation zone to a one-mile by two-mile area and dug ditches to contain released vinyl chloride liquid while it vaporized and burned. The controlled venting began about 4:40 p.m. on February 6, and continued for several hours.

The controlled venting required the evacuation of many residents in and around East Palestine due to potential airborne exposure to toxic combustion byproducts. Once cleared to return to their homes, some residents complained of respiratory illnesses and the deaths of wild and domesticated animals.

The NTSB issued its final report on the East Palestine derailment on June 25, 2024. A corrected version of this report was reissued on July 23, 2024. In its final report (NTSB 2024), NTSB found that the probable cause of the derailment was an overheated wheel bearing.

The Federal Railroad Administration (FRA) issued its final report on July 19, 2024. FRA also found that the derailment was caused by a roller bearing that failed due to overheating (FRA 2024).

On March 4, 2023, a second NS train derailed in Springfield, Ohio. No hazardous materials were involved in this derailment.

Media coverage of the East Palestine derailment has, in general, been negative. The examples below are from the *New York Times* but are representative of the media coverage.

- After the Ohio Train Derailment: Evacuations, Toxic Chemicals and Water Worries. *New York Times*, February 13, 2023.
- Health and Environmental Fears Remain After Ohio Derailment and Inferno. *New York Times*, February 14, 2023.
- In Ohio Town Where Train Derailed, Anxiety and Distrust Are Running Deep. *New York Times*, February 15, 2023.
- ‘We’re Scared, Too’: Ohio Residents Press for Answers on Train Derailment at Meeting. *New York Times*, February 15, 2023.
- Ohio Residents Demand Answers on Train Derailment. *New York Times*, February 16, 2023.
- ‘Chernobyl 2.0’? Ohio Train Derailment Spurs Wild Speculation. *New York Times*, February 16, 2023.
- Federal Officials Send Help After Ohio Derailment, but Residents’ Frustrations Persist. *New York Times*, February 16, 2023.
- Many in East Palestine, Skeptical of Official Tests, Seek Out Their Own. *New York Times,* February 19, 2023.
- After Chemical Burn, Farm Owners Worry About a Cherished Way of Life. *New York Times*, February 22, 2023.
- In Town Where Train Derailed, Lawyers Are Signing Up Clients in Droves. *New York Times, February* 24, 2023.

- Canada Saw a Deadly Derailment. A Decade Later, Little Has Changed. *New York Times*, February 24, 2023.
- 'Evacuate Us!' Fear and Anxiety Boil Over as Residents Confront Train Company on Derailment. *New York Times*, March 2, 2023.
- Ohio Attorney General Sues Norfolk Southern Over Derailment. *New York Times*, March 14, 2023.
- Weeks After Ohio Train Derailment, Health Concerns Mount. *New York Times*, March 20, 2023.
- After the Ohio Train Derailment: Evacuations, Toxic Chemicals and Water Worries. *New York Times*, June 23, 2023.
- One Family's Toxic Train Wreck Ordeal: Illness, Exile and Debt. *New York Times*, August 21, 2023.
- Norfolk Southern Settles Derailment Suit for $600 Million. *New York Times*, April 9, 2024.
- Norfolk Southern to Pay $310 Million for East Palestine Accident. *New York Times*, May 23, 2024.
- Safety Agency Faults Norfolk Southern for 'Vent and Burn' After 2023 Derailment. *New York Times*, June 25, 2024.

6.5.2 Rail Safety Legislation

This section discusses rail safety legislation proposed as a result of the East Palestine derailment.

6.5.2.1 S. 576 and H.R. 1674

In response to the East Palestine derailment, the Railway Safety Act of 2023 (S. 576 and H.R. 1674) was introduced in 2023. S. 576 and H.R. 1674 address safety requirements for rail carriers and trains transporting hazardous materials. Specific requirements contained in the bills include:[1]

- The DOT must issue safety regulations for trains carrying hazardous materials to require that rail carriers or shippers (1) provide State emergency response commissioners with advanced notice and information about the hazardous materials; (2) reduce blocked rail crossings; and (3) comply with certain requirements regarding train length and weight specifications, track standards, speed restrictions, and response plans.
- DOT must also establish requirements for wayside defect detectors. These are used by railway systems alongside the tracks to detect defects and failures (e.g., wheel bearing failures). Current federal regulations do not require their use, but federal guidance does address their placement and use. Under the bill, DOT must issue regulations establishing requirements for the installation, repair, testing, maintenance, and operation of wayside defect detectors for each rail carrier operating a train carrying hazardous materials.

[1] See the S. 576 and H.R. 1674 summaries at https://www.congress.gov/bill/118th-congress/senate-bill/576 and https://www.congress.gov/bill/118th-congress/house-bill/1674.

The bills also:

- Increase the maximum fines DOT may impose on rail carriers for violating safety regulations,
- Require DOT to update rail car inspection regulations and audit the federal inspection program,
- Require a minimum two-person crew for certain freight trains,
- Phase out certain railroad tank cars by May 1, 2025 (four years sooner than required under current law),
- Expand training for local first responders,
- Impose a new fee on certain rail carriers, and
- Provide funding for research and development to improve railway safety.

6.5.2.2 H.R. 8996

In July 2024, the Railroad Safety Enhancement Act of 2024 (H.R. 8996) was introduced. H.R. 8996 is proposed bipartisan legislation that would add resources and regulations for new safety mandates for rail shippers. H.R. 8996 incorporates S. 576 discussed above.

Key provisions of H.R. 8996 address safety requirements for hazardous materials transport by rail, train length and weight regulations, blocked grade crossings, penalties, tank car phase-outs, technology research and development, and emergency response assistance:

- Enhances safety requirements for trains transporting hazardous materials, including establishing speed limits, tank car standards, and emergency planning requirements for Class I railroads.
- Requires the Secretary of Transportation to review safety regulations related to train length and weight to ensure the safe transportation of goods and passengers by rail.
- Directs the Secretary to conduct a study on blocked highway-rail grade crossings and provide recommendations to prevent or reduce such occurrences.
- Increases penalties for violations of rail safety regulations.
- Phases out the use of certain older tank cars (DOT 111 tank cars) for transporting certain flammable liquids.
- Provides funding for research and development of rail safety technologies, including defect detectors and technologies to prevent derailments of trains transporting hazardous materials.
- Establishes a program to provide emergency financial assistance to communities responding to significant hazardous materials transportation incidents.

Telematics will provide shippers and tank car owners with real-time visibility into the rail network. These devices will also monitor the railcar asset's health and provide valuable data to prevent incidents. H.R. 8996 authorizes $10 million annually for an FRA pilot program to develop onboard sensors, and look to the future capabilities of these sensors, including real-time visibility, wheel/bearing/hand brake/hatch, and temperature readings. H.R. 8996 also authorizes $100 million annually for the FRA to establish a grant program for railcar manufacturers to install onboard freight railcar telematics systems and gateway devices. The program will prioritize new freight railcars, as this is the easiest installation time and these cars have the longest lifespan, and tank cars carrying hazardous materials. FRA is required to issue a report on the number of railcars with onboard telematics due to these funds.

The Confidential Close Call Reporting System (C3RS) is run by an independent third party, the National Aeronautics and Space Administration. H.R. 8996 requires all Class 1 railroads and Amtrak to enroll in C3RS for two years. This will allow railroads and their employees to report close calls, unsafe incidents, and share information industry-wide on best practices without fear of reprisal from management. It also prevents FRA enforcement for events reported.

Highway-rail crossings are the most dangerous part of America's rail network, in part because this is where our nation's highway and rail systems meet. Removing as many rail crossings as possible will help reduce deaths and relieve congestion in the rail network. H.R. 8996 authorizes an additional $1 billion for the Railroad Crossing Elimination Grant Program.

The ASKRAIL app is a mobile application used by first responders in collaboration with Class 1 railroads. It allows first responders to access accurate data about which hazardous materials a railcar is carrying so they can make informed decisions on how to respond to incidents. First responders must have accurate information about what they expect they will be fighting when reaching a scene. H.R. 8996 requires the State Department of Transportations' eligible for specific grants to notify first responders in their state about the existence of the app and to certify to the FRA they have completed this requirement. Because derailments often occur in remote and isolated areas, service for the application can be unreliable. H.R. 8996 also creates the ASKRAIL Connectivity Pilot Program and authorizes $25 million per year. The pilot program creates a competitive bidding process to provide service in areas along the national rail network in most need of connectivity.

6.5.3 Potential Implications for Microreactor Transportation Emergency Response Planning

The implications of the East Palestine derailment for microreactors containing unirradiated or irradiated fuel being shipped by rail are likely to be limited because the regulatory requirements for the transport of fissile material and SNF are already significantly greater than the regulatory requirements for the transport of other hazardous materials. For example, S. 576 and H.R. 1674 would require advance notification of State officials and advance notification of state and Tribal officials is already required for SNF shipments (see 10 CFR 71.97).

Railroad industry requirements for the shipment of SNF also exceed those established for other hazardous material. For example, AAR Standard S-2043, "Performance Specification for Trains Used to Carry High-Level Radioactive Material" applies to trains carrying SNF (AAR 2024a). This would include microreactors containing their irradiated fuel. This standard requires the continuous monitoring of 11 safety-related parameters to detect defect conditions that, if not addressed with a stop for inspection, may result in a derailment. One requirement of AAR Standard S-2043 that relates to prevention of wheel bearing failure is addressed by using temperature sensors on each of the wheels on each railcar in the train. Each sensor constantly reports bearing temperatures to a computer display in the rail escort vehicle[1] that is monitored by the escorts in the rail escort vehicle. Both warning and stop condition temperature thresholds for bearing defects are being established to detect a defective wheel bearing in advance of its

[1] It is likely that a rail escort vehicle containing security escorts and other equipment would be present in a train transporting a microreactor.

failure. The difference between personnel on the train monitoring bearing temperatures and periodic railroad wayside detection systems is the immediate detection when the temperature exceeds the prescribed threshold and alert notification to the escorts, locomotive crew, and the movement control center.

AAR Standard S-2043 would not apply to microreactors containing their unirradiated fuel being shipped by rail. However, application of AAR Standard S-2043 to unirradiated microreactors shipments by rail may be a condition of NRC transportation package approval. Likewise, advance notification of State and Tribal officials may also be required as a condition of transportation package approval for unirradiated microreactors shipments by rail.

While the East Palestine derailment is not likely to increase the regulatory requirements for the transport of microreactors by rail, the derailment has resulted in the increased scrutiny of transporting of hazardous materials by rail by the public, Tribal, State, and federal agencies, and the U.S. Congress. This increased scrutiny could negatively affect the transport of radioactive material by rail and specifically the transport of microreactors.

7.0 Conclusions

Transporting microreactors containing irradiated fuel pose unique transportation emergency response planning challenges. Many challenges are because of the unique aspects of microreactor designs and because State and Tribal emergency responders along potential truck and rail routes are likely to be unfamiliar with microreactor transport.

These challenges are organized into cross-cutting emergency response challenges and specific transportation emergency response challenges. Cross-cutting emergency response planning challenges include:

- The need to revise the emergency response guidebook to provide a guide that is specific to microreactors. This guide may have to be design- and fuel-type specific.
- The use of a risk informed process for microreactor transportation package approval. The specific issue identified is that a microreactor containing irradiated fuel may not meet the 10 mrem/h at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441, and it may require a stand-off distance of approximately 30 meters to obtain a dose rate of 10 mrem/h, depending on the amount of shielding and storage time before transport. This could have implications for transportation emergency response planning if external package dose rates keep responders and recovery crews from meeting necessary objectives for recovery and mitigation.
- Managing the interface between safety and security for microreactor shipments.

Specific transportation emergency response planning challenges were identified by comparing microreactor characteristics to the contents of typical transportation emergency response plans. These challenges include:

- Assignment of Responsibility
- Emergency Response Organization
- Emergency Response Support and Resources
- Emergency Classification System/Emergency Action Levels
- Notification Methods and Procedures
- Emergency Communications
- Public Education and Information
- Emergency Facilities and Equipment
- Accident Assessment
- Protective Response
- Radiological Exposure Control
- Medical and Public Health Support
- Recovery, Reentry, and Post-Accident Operations
- Exercises and Drills
- Radiological Emergency Response Training

Several additional challenges were also identified:

- The use of hazardous materials in microreactor designs. Two specific hazardous materials are discussed: beryllium and sodium. The presence of these hazardous materials could require emergency response jurisdictions to have specialized equipment that may not be part of the standard capabilities of many jurisdictions.
- The need to conduct external engagement prior to transporting a microreactor containing irradiated fuel. This is a planning challenge because a microreactor containing irradiated fuel has not been shipped in the United States, and State and Tribal emergency responders along potential truck and rail routes are likely to be unfamiliar with microreactor transport. This engagement could take 2 – 3 years.
- The potential need to conduct emergency response training along transport routes as a compensatory measure required in the NRC transportation certificate of compliance for the microreactor.
- The potential need to develop transportation accident recovery plans as a compensatory measure required in the NRC transportation certificate of compliance for the microreactor.

Shipment of microreactors containing their irradiated fuel by vessel and air are likely to pose additional transportation emergency planning challenges.

Recommended future activities regarding microreactor transportation emergency planning include:

- Establishing a national response center for tracking movement and coordination between microreactor stakeholders and impacted jurisdictions.
- Developing a standard for microreactor transportation accident training, detection, and response equipment and concept of operations or procedures.
- Establishing standards for situational awareness requirements for microreactor in transition.
- Developing operational protocols for how to respond to microreactor accidents.
- Developing a whole community approach for the management of microreactor transportation, sitting and acceptance of microreactors.
- Identifying interagency offices involved in the development, deployment, operations, and recovery of microreactors and the associated radiological material.
- Identifying gaps, challenges, and issues with impacted jurisdiction common capabilities and abilities to respond to a potential microreactor transportation accident.
- Developing a series of pilot training and exercises to include tabletop exercises and drills.
- Developing a report on critical planning and operational issues related to the concept of operations for a microreactor transportation accident.
- Developing a cost benefit analysis identifying the cost of resources for implementing safe and secure transportation of microreactors.

8.0 References

10 CFR Part 50. 2024. “Domestic Licensing of Production and Utilization Facilities.” *Code of Federal Regulations.* Available at https://www.govinfo.gov/app/collection/cfr/2024

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10 CFR Part 72. 2024. “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste.” *Code of Federal Regulations.* Available at https://www.govinfo.gov/app/collection/cfr/2024

10 CFR Part 73. 2024. “Physical Protection of Plants and Materials.” *Code of Federal Regulations.* Available at https://www.govinfo.gov/app/collection/cfr/2024

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Appendix A – 2023 NTSF Annual Meeting Microreactor Presentation

09/28/2024

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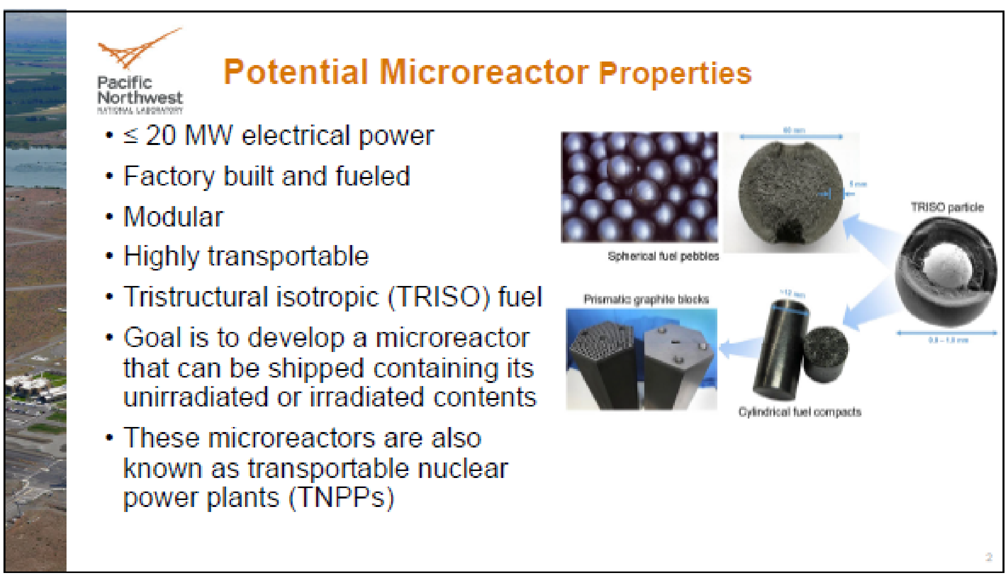

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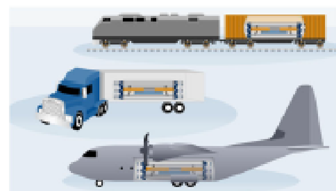
09/28/2024

Microreactor Transportation

- Current microreactor concepts are to transport the microreactor containing its unirradiated or irradiated fuel
- A microreactor with its unirradiated or irradiated contents is unlikely to meet the entire suite of NRC regulatory requirements in 10 CFR Part 71
- A risk-informed process will likely be used for NRC transportation package approval
  - Demonstrate equivalent safety and that risk to the public is low
  - This will require the use of compensatory measures



Source: GAO. | GAO-20-388SP

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Purpose

- In general, the transportation emergency response community is not familiar with microreactors or the concept of transporting a microreactor containing its irradiated fuel
- The purpose of this discussion is to obtain State and Tribal perspectives on the potential emergency planning challenges associated with the transportation of a microreactor containing its irradiated fuel
- The challenges may differ from shipments of spent nuclear fuel in Type B transportation casks (the current paradigm)
- Some challenges are likely to be mode-specific (i.e., different for shipment by truck, rail, air, and vessel)
- Some challenges will be design-specific, e.g., presence of other hazardous materials

4

2

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Assumptions

- The microreactor shipment would be a commercial shipment and would receive transportation package approval from the NRC using a risk-informed process
- Transport would be by truck or rail
  - Transport by air and vessel are not being evaluated at this time
- The microreactor containing its irradiated fuel would contain a highway route-controlled quantity of radioactive material (i.e., > 3000 A_2)
  - For truck shipments this means that a CVSA Level VI inspection and safety permit would be required (see 49 CFR 385 and 49 CFR 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
- The microreactor would be fueled by LEU or HALEU (not HEU)
- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars

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5

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Areas Examined In Identifying Microreactor Transportation Emergency Planning Challenges

• Assignment of Responsibility	• Accident Assessment
• Emergency Response Organization	• Protective Response
• Emergency Response Support and Resources	• Radiological Exposure Control
• Emergency Classification System	• Medical and Public Health Support
• Notification Methods and Procedures	• Recovery, Reentry, and Post-Accident Operations
• Emergency Communications	• Exercises and Drills
• Public Education and Information	• Radiological Emergency Response Training
• Emergency Facilities and Equipment	• Responsibility for the Planning Effort: Development, Periodic Review, and Distribution of Emergency Plans

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6

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Potential Compensatory Measures (I)

- Microreactors containing irradiated fuel shipped by highway would be highway route-controlled quantities (HRCQ) (> 3000 A_2) shipments and would need to meet the routing requirements in 49 CFR Part 397
  - The use of interstates, beltways around cities, state identified preferred routes could be considered as compensatory measures
- Microreactors will likely be overweight/overdimension and will require state permitting when transported by highway
  - Specific heavy haul truck or superload permit requirements could be considered as compensatory measures

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Potential Compensatory Measures (II)

- Other potential compensatory measures include:
  - Increased exclusion zone around the microreactor because of possible radiation dose rate increase
  - Real time health/fitness onboard monitoring/diagnostics of reactor package
  - Escorting of the reactor forward and aft for the entire route
  - Rolling road closures
  - Travel at reduced speeds
  - Choosing a route that avoids bodies of water (balanced by quality of road)
  - Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic)
  - Judicious use of time-of-day and day-of-week restrictions
  - Avoid shipping during severe weather
  - Conduct training for emergency responders along the route

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Potential Challenges

- Managing the interface between safety and security for microreactor shipments
- Revise the Emergency Response Guidebook to provide a Guide that is specific to microreactors. This guide may have to be design- and fuel-type specific
- Use of hazardous materials in microreactor designs. Two are being discussed— beryllium and sodium. These hazardous materials could require emergency response jurisdictions to have specialized equipment that may not be part of their standard capabilities
- Conducting external engagement prior to transporting a microreactor containing its irradiated fuel. A microreactor containing its irradiated fuel has not been shipped in the U.S., and State and Tribal emergency responders along potential routes are likely to be unfamiliar with microreactor transport. This engagement could take 2 to 3 years
- Need to conduct emergency response training and create accident recovery plans

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Thank you

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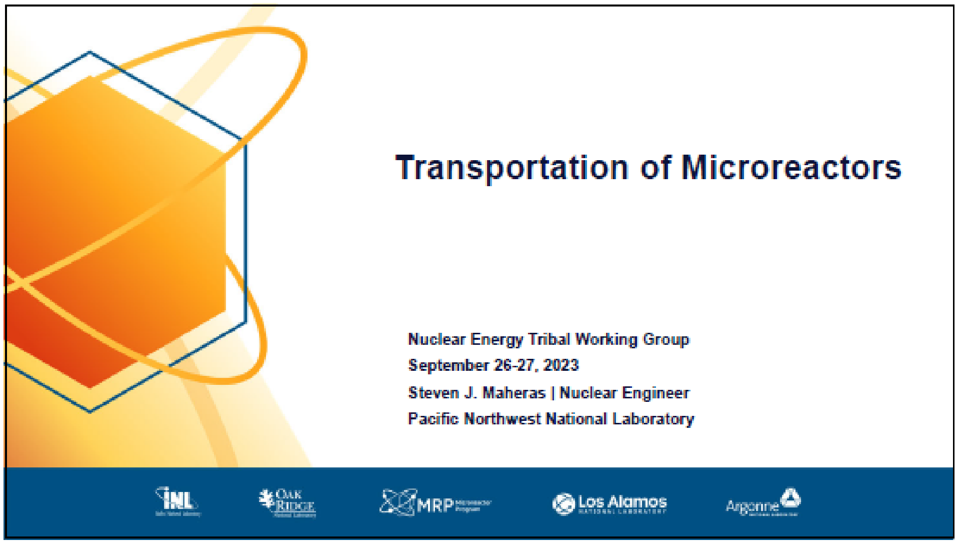
Appendix B – 2023 Nuclear Energy Tribal Working Group Microreactor Presentation

09/27/2024



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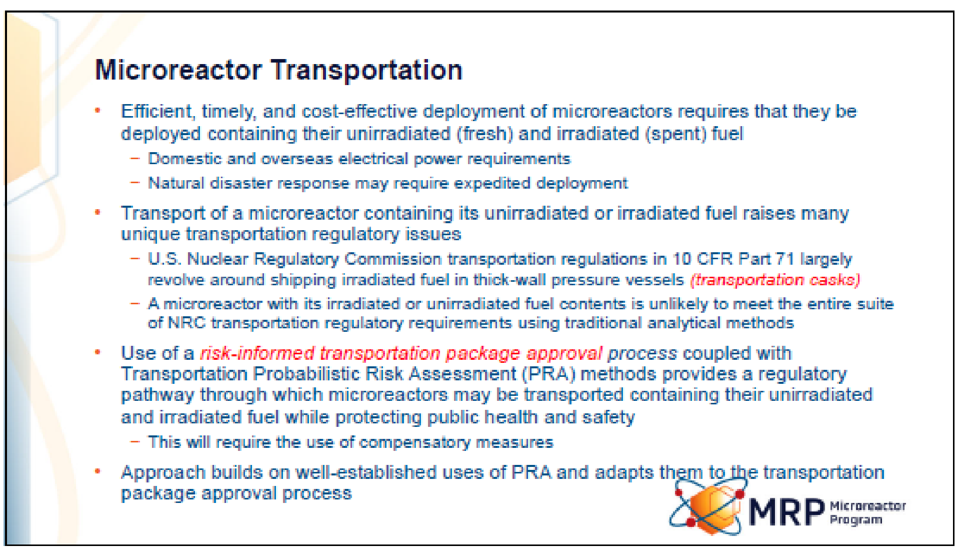

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1

Current Transportation Approach

- The microreactor shipment would be a commercial shipment and would receive transportation package approval from the NRC using a risk-informed process
- Strategy is Crawl-Walk-Run
  - Concentrate on highway transport first
  - Then other surface modes (rail and barge/ship) – evaluation of transport by vessel has just started
  - Finally air transport
- The microreactor containing its irradiated fuel would contain a *highway route-controlled quantity of radioactive material (HRCQ)*
  - For truck shipments this means that a Commercial Vehicle Safety Alliance (CVSA) Level VI inspection and safety permit would be required (see 49 CFR 385 and 49 CFR 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
- The microreactor would be fueled by LEU or HALEU (not HEU)
- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars
  - S-2043 was developed for railcars specifically containing irradiated fuel

LEU= Low Enriched Uranium (< 5 % U-235)
HALEU= High Assay Low Enriched Uranium (5-20 % U-235)
HEU= High Enriched Uranium (> 20% U-235)

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3

Use of Hazardous Materials in Microreactors

- Beryllium-containing materials are currently being investigated for use in microreactors as replacements for graphite as a neutron moderator (Cheng et al., 2022)
- Beryllium is a hazardous material and if these beryllium-containing materials were incorporated into a microreactor, the presence of these materials would have to be considered in the transportation emergency response planning for these specific microreactors
- Sodium-containing heat pipes are being investigated for use in some microreactors, such as the Westinghouse eVinci microreactor
- Sodium is a hazardous material and the presence of sodium would have to be considered in the transportation emergency response planning for these microreactors, specifically in two areas:
  - The ability of sodium in combination with water to exacerbate releases of radioactive material during a transportation accident, and
  - The need to modify transportation accident fire-fighting guidelines if sodium was present

Source: Cheng B., E. M. Duchnowski, D. J. Sprouster, L. L. Snead, N. R. Brown, and J. R. Trelewicz. 2022. "Ceramic Composite Moderators as Replacements for Graphite in High Temperature Microreactors." Journal of Nuclear Materials. Volume 563.

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4

09/27/2024

Transport of Microreactors Will Likely Require a New Emergency Response Guide to Aid Transportation Emergency Responders

- The DOT Pipeline and Hazardous Materials Safety Administration *Emergency Response Guidebook (ERG)* provides first responders with a manual to help deal with hazardous materials transportation accidents during the critical first 30 minutes after the accident
- Emergency responders are trained to use the shipping papers, numbered placard, or orange panel number to determine which emergency response guide to use in responding to a transportation accident
- The emergency response guides were not developed based on transportation accidents involving microreactors containing irradiated fuel
- The ERG would have to be expanded to include a guide that is specific to microreactor transportation accidents
- The guide may have to be fuel-type specific because of the differences in potential releases from different microreactor fuel types
- The guide may also have to be modified to account for the presence of hazardous materials such as beryllium or sodium

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5

It is likely that NRC will require compensatory measures a condition of transportation package approval

- Potential compensatory measures include:
  - 49 CFR Part 397 transportation routing requirements
    - The use of interstates, beltways around cities, state identified preferred routes could be considered as compensatory measures
  - Microreactors will likely be overweight/overdimension and will require state permitting when transported by highway
    - Specific heavy haul truck or superload permit requirements could be considered as compensatory measures
  - A transportation accident recovery plan may also be required as a condition of transportation package approval

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3

Other Potential Compensatory Measures Include

- Increased exclusion zone around the microreactor because of possible radiation dose rate increase
- Real time health/fitness onboard monitoring/diagnostics of reactor package
- Escorting of the reactor forward and aft for the entire route
- Rolling road closures
- Travel at reduced speeds
- Choosing a route that avoids bodies of water (balanced by quality of road)
- Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic)
- Judicious use of time-of-day and day-of-week restrictions
- Avoid shipping during severe weather
- Conduct training for emergency responders along the route

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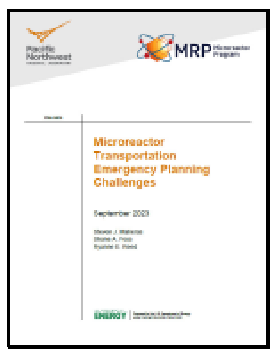
7

Microreactor Transportation Emergency Response Planning Challenges

- The DOE-NE Microreactor Program is working to identify potential microreactor transportation emergency response planning challenges
- DOE's National Transportation Stakeholders Forum has been used to obtain input from the Tribes and States on these potential challenges
- Potential challenges initially identified include:
  - Managing the interface between safety and security for microreactor shipments
  - Revising the Emergency Response Guidebook to provide a Guide that is specific to microreactors. This guide may have to be design- and fuel-type specific
  - Use of hazardous materials in microreactor designs. Two are being discussed— beryllium and sodium. These hazardous materials could require emergency response jurisdictions to have specialized equipment that may not be part of their standard capabilities
  - Conducting external engagement prior to transporting a microreactor containing its irradiated fuel. A microreactor containing its irradiated fuel has not been shipped in the U.S., and State and Tribal emergency responders along potential routes are likely to be unfamiliar with microreactor transport. This engagement could take 2 to 3 years
  - Need to conduct emergency response training and create transportation accident recovery plans



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Appendix C – 2023 Western Interstate Energy Board Meeting Microreactor Presentation

09/27/2024

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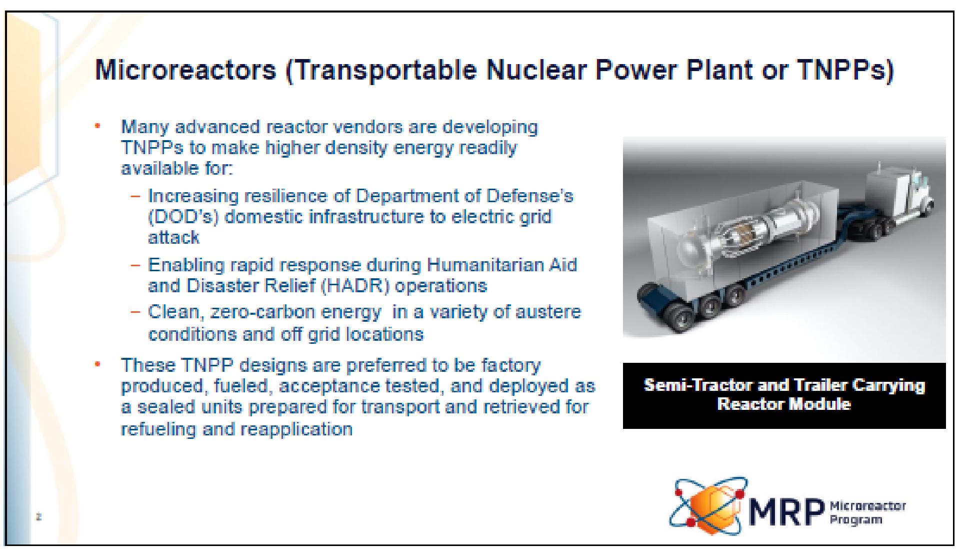

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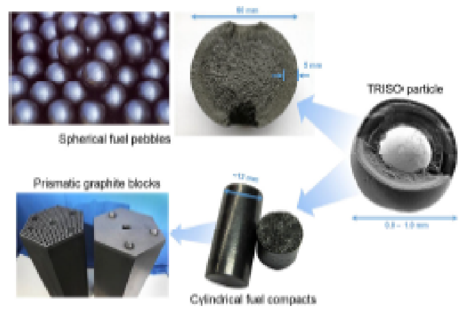
1

09/27/2024

Properties of these TNPPs/Microreactors

- ≤ 20 MW electrical power
- Factory built and fueled
- Modular
- Highly transportable
- Most designs use tri-structural isotropic (TRISO) fuel
  - Pebbles
  - Compacts
- Most designs are high-temperature gas-cooled reactors



3

Microreactor Transportation

- Efficient, timely, and cost-effective deployment of microreactors requires that they be deployed containing their unirradiated (fresh) and irradiated (spent) fuel
- Transport of a microreactor containing its unirradiated or irradiated fuel raises many unique transportation regulatory issues
  - U.S. Nuclear Regulatory Commission transportation regulations in 10 CFR Part 71 largely revolve around shipping irradiated fuel in thick-wall pressure vessels *(transportation casks)*
  - A microreactor with its irradiated or unirradiated fuel contents is unlikely to meet the entire suite of NRC transportation regulatory requirements using traditional analytical methods
- Use of a *risk-informed transportation package approval process* coupled with Transportation Probabilistic Risk Assessment (PRA) methods provides a regulatory pathway through which microreactors may be transported containing their unirradiated and irradiated fuel while protecting public health and safety
  - This will require the use of compensatory measures
- Approach builds on well-established uses of PRA and adapts them to the transportation package approval process

4

2

Basis for the Proposed Regulatory Approach

- If Fissile Material or Type B package postulated Hypothetical Accident Conditions (HAC) requirements (10 CFR 71.73) cannot be directly met, then other package approval options are possible:
  - 10 CFR 71.41(c) Alternative Environmental and Test Conditions (10-160B and 8-120B Transportation Casks)
  - 10 CFR 71.41(d) Special Package Authorization (West Valley Melter Package)
  - 10 CFR 71.12 Exemption (Trojan Reactor Vessel)
- Approval of transporting the Trojan Reactor Vessel up the Columbia River and on the Hanford Site was based on compensatory actions as it could not be fully tested.
- Preferred initial pathway identified is the Exemption Process that allows compensatory actions to protect the basis of exemption if acceptable risk is demonstrated
  - Can apply to more than a single shipment unlike Special Package Authorization
  - Flexibility in deviating from deterministic requirements compared to Alternative Environmental and Test Conditions

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5

Reasoning Behind the Selection of this Regulatory Approval Pathway

- Quantitative risk analysis approaches such as Probabilistic Risk Assessment (PRA) are used in risk-informed regulatory approaches:
  - PRAs have been conducted since the 1970s for nuclear reactors (e.g., see WASH-1400) and used since the 2000s for risk informed licensing applications.
  - PRA has also been used to assess:
    - Dry cask storage systems at a nuclear power plants (see NUREG-1864)
    - Transportation of spent nuclear fuel (SNF), most notably in NUREG/CR-4829, NUREG/CR-6672, and NUREG-2125
- Proposed to NRC as an aid in developing a near-term approval pathway to drive Advanced Factory-Produced TNPP development and deployment
- Bridges the gap between the current regulatory framework (thick-wall steel vessel based) and the level of robustness of current proposed TNPP technology
- Provides buffer time for strategic regulatory considerations and possible rule making to more so accommodate advanced, transportable, microreactor conventions

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6

09/27/2024

Elements of Transportation Probabilistic Risk Assessment (PRA)

- Characterization of the TNPP radioactive material inventory
  - Gaseous and nongaseous fission products retained within the TRISO
  - Fission products that have diffused from the TRISO fuel and are held up in the compact and other core structures,
  - Fission products and gases that have diffused from the TRISO fuel and have condensed or plated-out in the reactor containment boundary
- Identification of TNPP safety functions
  - Typically includes the safety functions that are normally evaluated for transportation packages
  - Criticality safety, radiation shielding, containment of radioactive material, and heat removal
- Identification and development of TNPP transportation accident scenarios
  - Use of hazard analysis to identify hazardous conditions and make qualitative estimates of their risk that are then used to develop TNPP transportation accident scenarios
  - Determine the TNPP transportation accident scenarios to include in the transportation PRA

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7

Elements of Transportation PRA

- Development of the TNPP transportation accident scenario likelihoods
  - Specific items considered include collection and analysis of route specific hazards and large truck accident data; route specific spatially derived hazards, development of the likelihoods for vehicle accidents that can occur during transport, and the frequencies developed for each bounding representative accident
- Development of the TNPP transportation accident scenario consequences
  - Radiological consequences of an accident can be the result of direct exposure to radiological material either due to loss of shielding or neutrons from an inadvertent criticality. Direct exposures principally impact receptors in the near vicinity of the accident. These consequences are highly dependent on materials used in the design
  - Radiological consequences can also be the result of material released in the environs impacting a receptor. For these releases, the principal pathway is usually airborne and the dose from inhalation is usually considered to dominate the overall dose. There may be a direct component to this pathway as well.

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4

Elements of Transportation PRA

- Releases from TRISO fuel
  - Based on 5-factor formula
  - Source term= MAR x DR x ARF x RF x LPF
  - Releases from TRISO fuel due to transportation accidents expected to be small but fuel analysis and testing are currently limited and system thermal and impact fragility and testing analysis are currently limited, so initially efforts will use a bounding approach
- Large truck accident rates
  - Total (fatal and non-fatal) large truck (>10,000 lb. gross vehicle weight [GVW]) single-vehicle accidents on all highways (Motor Carrier Management Information System [MCMIS] crash data and Federal Highway Administration [FHWA] mileage data)
  - Fatal accident rates for combination (tractor-trailer) trucks >26,000 lb. GVW on interstate highways (Fatality and Injury Reporting System Tool [FIRST] crash data and FHWA mileage data)
  - Fatal accident rates for combination trucks >26,000 lb. GVW) striking fixed objects on interstate highways (FIRST crash data and FHWA mileage data)
- Route specific spatially derived hazards
  - Soils – the relative hardness was quantified
  - Bridges – presence of underpasses and overpasses were enumerated
  - Rivers and water bodies
  - River and creek crossings

MAR = Material at risk, DR = Damage ratio, ARF = Airborne release fraction, RF = Respirable fraction, LPF = Leak path factor

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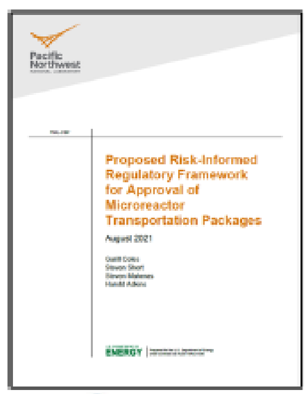
9

Microreactor Background

- Project Pele
  - Project led by the U.S. Department of Defense Strategic Capabilities Office (SCO) to design, build, and demonstrate an advanced prototype mobile nuclear reactor
  - Close collaboration with U.S. Department of Energy, U.S. Nuclear Regulatory Commission (NRC), and others
- BWXT Advanced Technologies, LLC, selected to build and demonstrate a mobile microreactor
- Reactor demonstration will be performed at the Idaho National Laboratory (INL) site


Pacific Northwest

Proposed Risk-Informed Regulatory Framework for Approval of Microreactor Transportation Packages

August 2021

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5

Microreactor Modules

- 1 to 5 MWe, minimum of 3 years of full power operation
- HTGR using HALEU UCO TRISO fuel
- 4 or 5 modules
  - Reactor Module
  - Intermediate Heat Exchanger (IHX) Module
  - Control Module
  - Power Conversion Module
- Reactor Module contains well over 99% of radioactivity (remainder in IHX Module)
- Each module contained in and integral with separate ISO-compliant CONEX containers

Acronyms: MWe – megawatt electric; HTGR – high temperature gas-cooled reactor, HALEU – high-assay low-enriched uranium; UCO – uranium oxycarbide; TRISO – tri-structural isotropic; IHX – intermediate heat exchanger; CONEX – container express

11

MRP Microreactor Program

11

Current Transportation Approach

- The microreactor shipment would be a commercial shipment and would receive transportation package approval from the NRC using a risk-informed process
- Strategy is Crawl-Walk-Run
  - Concentrate on highway transport first
  - Then other surface modes (rail and barge/ship) – evaluation of transport by vessel has just started
  - Eventually air transport
- The microreactor containing its irradiated fuel would contain a *highway route-controlled quantity of radioactive material (HRCQ)*
  - For truck shipments this means that a Commercial Vehicle Safety Alliance (CVSA) Level VI inspection and safety permit would be required (see 49 CFR Part 385 and 49 CFR Part 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
- The microreactor would be fueled by LEU or HALEU (not HEU)
- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars
  - S-2043 was developed for railcars specifically containing irradiated fuel
- Marine shipments would be via a Class INF-3 ship

12

LEU= Low Enriched Uranium (< 5 % U-235)
HALEU= High Assay Low Enriched Uranium (5-20 % U-235)
HEU= High Enriched Uranium (> 20% U-235)

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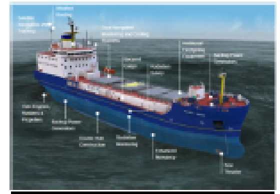
12

Class INF-3 Ship Safety Features

- Double hulls and hull reinforcement to withstand collision damage, with additional strengthening surrounding the holds
- Enhanced buoyancy provided by extensive compartmentalization within the hull, cargo areas, and throughout each ship to ensure the ship will continue to float even in extreme circumstances
- Dual navigation, communications, cargo monitoring, and cooling systems
- Satellite navigation and tracking
- Twin engines, rudders and propellers, with separate machinery and steering gear rooms
- Bow thrusters—single propellers in a duct that runs through the bow—provide optimum maneuverability in ports
- Hold cooling plant located outside of holds for easier maintenance
- Integrated bridge system
- No oil tanks adjacent to the outer hull
- Security features incorporated into the design
- Improved environmental and safety performance
- Advanced fire detection and firefighting systems, including a multi-zone and multi-sensor fire detection system linked to alarms on the bridge, a hold flooding system and spare electrical generators in the bow and stern to ensure that power is available to operate essential systems, such as firefighting equipment, even in extreme circumstances
- Fixed radiation monitors for each hold that are linked to an alert system on the bridge



13

Use of Hazardous Materials in Microreactors

- Beryllium-containing materials are currently being investigated for use in microreactors as replacements for graphite as a neutron moderator (Cheng et al., 2022)
- Beryllium is a hazardous material and if these beryllium-containing materials were incorporated into a microreactor, the presence of these materials would have to be considered in the transportation emergency response planning for these specific microreactors
- Sodium-containing heat pipes are being investigated for use in some microreactors, such as the Westinghouse eVinci microreactor
- Sodium is a hazardous material and the presence of sodium would have to be considered in the transportation emergency response planning for these microreactors, specifically in two areas:
  - The ability of sodium in combination with water to exacerbate releases of radioactive material during a transportation accident, and
  - The need to modify transportation accident fire-fighting guidelines if sodium was present

Source: Cheng B., E. M. Duchnowski, D. J. Sprouster, L. L. Snead, N. R. Brown, and J. R. Trelewicz. 2022. "Ceramic Composite Moderators as Replacements for Graphite in High Temperature Microreactors." Journal of Nuclear Materials. Volume 563.

MRP Microreactor Program

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7

Transport of Microreactors Will Likely Require a New Emergency Response Guide to Aid Transportation Emergency Responders

- The DOT Pipeline and Hazardous Materials Safety Administration *Emergency Response Guidebook (ERG)* provides first responders with a manual to help deal with hazardous materials transportation accidents during the critical first 30 minutes after the accident
- Emergency responders are trained to use the shipping papers, numbered placard, or orange panel number to determine which emergency response guide to use in responding to a transportation accident
- The emergency response guides were not developed based on transportation accidents involving microreactors containing irradiated fuel
- The ERG would have to be expanded to include a guide that is specific to microreactor transportation accidents
- The guide may have to be fuel-type specific because of the differences in potential releases from different microreactor fuel types
- The guide may also have to be modified to account for the presence of hazardous materials such as beryllium or sodium

MRP Microreactor Program

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It is likely that NRC will require compensatory measures as a condition of transportation package approval

- Potential compensatory measures include:
  - 49 CFR Part 397 transportation routing requirements
    - The use of interstates, beltways around cities, state identified preferred routes could be considered as compensatory measures
  - Microreactors will likely be overweight/overdimension and will require state permitting when transported by highway
    - Specific heavy haul truck or superload permit requirements could be considered as compensatory measures
- A transportation accident recovery plan may also be required as a condition of transportation package approval

MRP Microreactor Program

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Other Potential Compensatory Measures Include

- Increased exclusion zone around the microreactor because of possible radiation dose rate increase
- Real time health/fitness onboard monitoring/diagnostics of reactor package
- Escorting of the reactor forward and aft for the entire route
- Rolling road closures
- Travel at reduced speeds
- Choosing a route that avoids bodies of water (balanced by quality of road)
- Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic)
- Judicious use of time-of-day and day-of-week restrictions
- Avoid shipping during severe weather
- Conduct training for emergency responders along the route

MRP Microreactor Program

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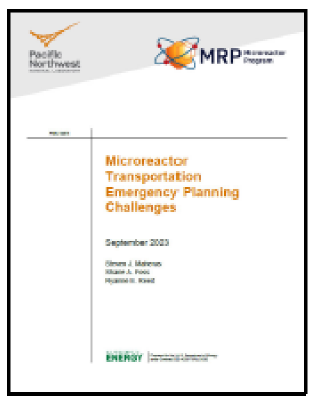
Microreactor Transportation Emergency Response Planning Challenges

- The DOE-NE Microreactor Program is working to identify potential microreactor transportation emergency response planning challenges
- DOE's National Transportation Stakeholders Forum has been used to obtain input from the Tribes and States on these potential challenges



MRP Microreactor Program

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Accomplishments and What's Next

- Discussions with NRC started in August of 2020
- Submitted our methodology report to NRC for review – 11/15/2022
- Received Requests for Additional Information (RAIs) from NRC – 4/19/2023
- Revised methodology report in response to RAIs submitted to NRC – 7/10/2023
- Meeting with Advisory Committee on Reactor Safeguards (ACRS) subcommittee scheduled for 11/17/2023
- Meeting with full ACRS scheduled for 12/06/2023
- At this stage we are not asking for transportation package approval, rather we are asking for the endorsement of the methodology


Development and Application of Risk Assessment Approach for Transportation Package Approval of a Transportable Nuclear Power Plant for Domestic Highway Shipment

November 2022

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Appendix D – 2024 INMM 37th Spent Fuel Management Seminar Microreactor Presentation

09/27/2024

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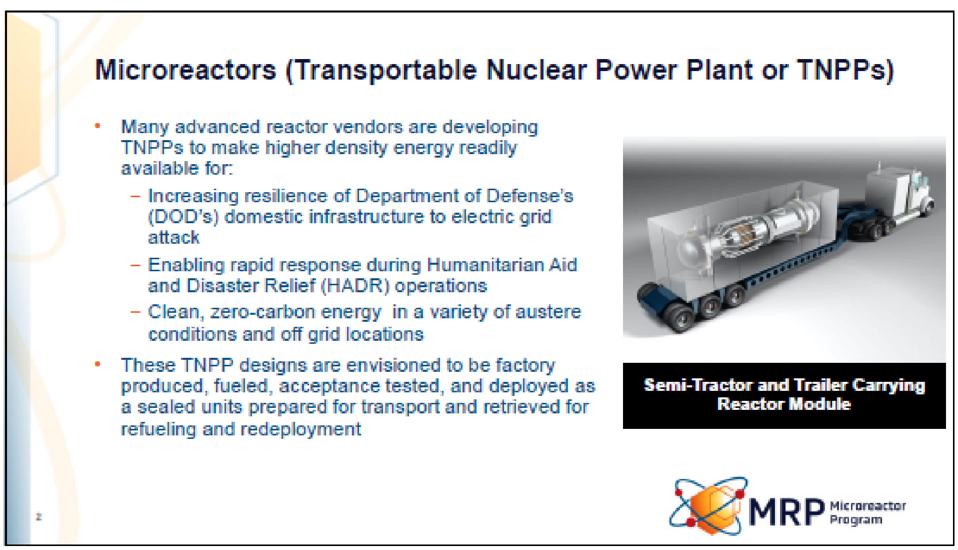

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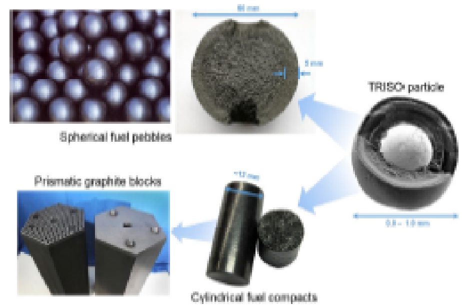
1

Properties of these TNPPs/Microreactors

- ≤ 20 MW electrical power
- Factory built and fueled
- Modular
- Highly transportable
- Most designs use tri-structural isotropic (TRISO) fuel
  - Pebbles
  - Compacts
- Most designs are high-temperature gas-cooled reactors



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3

Microreactor Transportation

- Efficient, timely, and cost-effective deployment of microreactors requires that they be deployed containing their unirradiated (fresh) and irradiated (spent) fuel
- Transport of a microreactor containing its unirradiated or irradiated fuel raises many unique transportation regulatory issues
  - U.S. Nuclear Regulatory Commission transportation regulations in 10 CFR Part 71 largely revolve around shipping irradiated fuel in thick-wall pressure vessels *(transportation casks)*
  - A microreactor with its irradiated or unirradiated fuel contents is unlikely to meet the entire suite of NRC transportation regulatory requirements using traditional analytical methods
- Use of a *risk-informed transportation package approval process* coupled with Transportation Probabilistic Risk Assessment (PRA) methods provides a regulatory pathway through which microreactors may be transported containing their unirradiated and irradiated fuel while protecting public health and safety
  - This will require the use of compensatory measures
- Approach builds on well-established uses of PRA and adapts them to the transportation package approval process

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4

Current Transportation Approach

- The microreactor shipment would be a commercial shipment and would receive transportation package approval from the NRC using a risk-informed process
- Strategy is Crawl-Walk-Run
  - Concentrate on highway transport first
  - Then other surface modes (rail and barge/ship) – evaluation of transport by vessel has just started
  - Eventually air transport
- The microreactor containing its irradiated fuel would contain a *highway route-controlled quantity of radioactive material (HRCQ)*
  - For truck shipments this means that a Commercial Vehicle Safety Alliance (CVSA) Level VI inspection and safety permit would be required (see 49 CFR Part 385 and 49 CFR Part 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
- The microreactor would be fueled by LEU or HALEU (not HEU)
- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars
  - S-2043 was developed for railcars specifically containing irradiated fuel
- Marine shipments would be via a Class INF-3 ship

LEU= Low Enriched Uranium (< 5 % U-235)
HALEU= High Assay Low Enriched Uranium (5-20 % U-235)
HEU= High Enriched Uranium (> 20% U-235)

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Microreactor Transportation Issues

- Factory or depot criticality testing
- Air transport of microreactors
- Transport by vessel – Class INF-3 Ships
- Use of hazardous materials in microreactors
- New Transportation Emergency Response Guide for microreactors
- Potential compensatory measures
- Transportation emergency planning challenges

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09/27/2024

Factory or Depot Testing

- Unirradiated fuel is normally shipped in a Type A Fissile Material (Type AF) package
- If the microreactor undergoes criticality testing at the factory or depot, then sufficient radioactive material could be generated as to require that the microreactor meet Type B Fissile Material (Type BF) package requirements
  - This time is on the order of minutes at full power
- If the microreactor undergoes criticality testing and generates greater than about 0.5 gram of Pu, then the Plutonium Air Shipment Regulations apply (10 CFR 71.64, 71.74, and 71.88)
  - 9-meter drop for Type B packages is equivalent to an impact velocity of about 13 m/s
  - 90 m/s impact velocity for Fissile Material packages shipped by air – about 50 times more energy than the 9-meter drop
  - 129 m/s impact velocity for Pu air shipments – about 100 times more energy than the 9-meter drop
- The issues above could apply if previously irradiated uranium is used as nuclear fuel due to transuranic radionuclide contamination

7

MRP Microreactor Program

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Use of Class INF-3 Ships for Transporting Microreactors

- The International Maritime Organization (IMO) *International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Waste on Board Ships* (INF Code) contains requirements for the design of ships transporting radioactive material
- Irradiated nuclear fuel shipments would require a Class INF-3 ship
  - These ships contain advanced safety features
- There are only three Class INF-3 vessels available for commercial hire, from Pacific Nuclear Transport Limited (PNTL)
  - The PNTL vessels are UK flagged; there are no US flagged INF-3 vessels
  - Sweden and China also have INF-3 vessels


Pacific Heron


Pacific Egret


Pacific Grebe

Classes of INF Ships

Class of INF Ship	Criteria
INF 1	Ships that are certified to carry materials that have an aggregate radioactivity of less than 4,000 TBq (1.1×10^5 Ci).
INF 2	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes that have an aggregate radioactivity less than 2×10^6 TBq (5.4×10^7 Ci) and ships that are certified to carry plutonium that has an aggregate radioactivity less than 2×10^5 TBq (5.4×10^6 Ci).
INF 3	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes, and ships that are certified to carry plutonium that has no restriction on the aggregate radioactivity of the materials.

Characteristics of Pacific Egret, Pacific Grebe, and Pacific Heron

Length	103.92 meters
Beam (Width)	17.25 meters
Draft	6.15 meters
Number of Holds	4
Capacity	20 transportation casks
Design Speed	14 knots
Deadweight	4,916 metric tons
Displacement	9,687 metric tons
Engine	Two diesel engines, each with 3,600 hp
Principle Cargo Carried	Mixed Oxide Fuel Assemblies (Pacific Egret and Pacific Heron) High-Level Waste and Compacted Waste (Pacific Grebe)

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RP Microreactor Program

8

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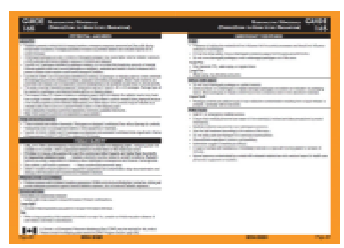

MRP Microreactor Program

10

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MRP Microreactor Program

11

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MRP Microreactor Program

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09/27/2024

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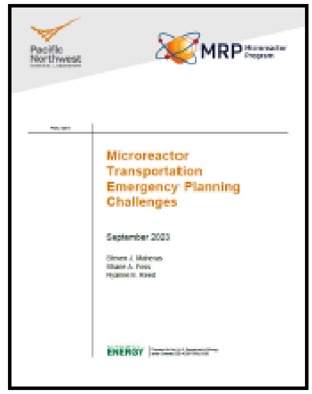

MRP Microreactor Program

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MRP Microreactor Program

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Appendix E – Waste Management 2024 Conference Advanced Reactor and Microreactor Presentation

09/27/2024

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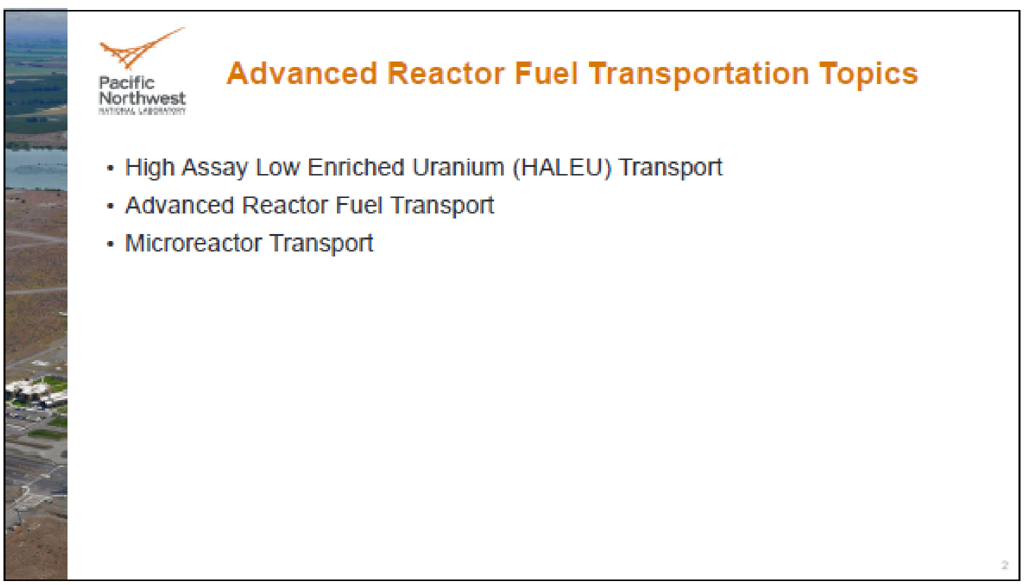

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09/27/2024

High Assay Low Enriched Uranium (HALEU) Transport

- Current nuclear fuel cycle is based on transporting industrial quantities of low enriched (< 5% U-235) uranium
- HALEU is uranium enriched to 5-20% U-235
- A fuel cycle based on HALEU would require transport of industrial quantities of 5-20% enriched uranium among various facilities
- Issue– the availability of transportation packages for this shipping of industrial quantities of HALEU
  - The types of transportation packages required depends on if facilities are collocated and the source of the uranium

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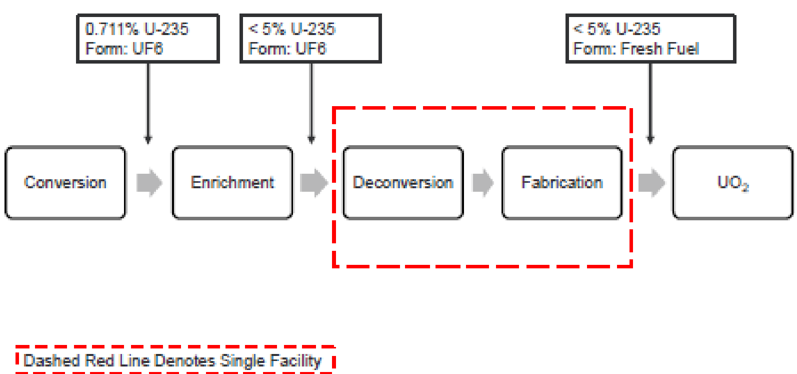
Current Uranium Fuel Cycle



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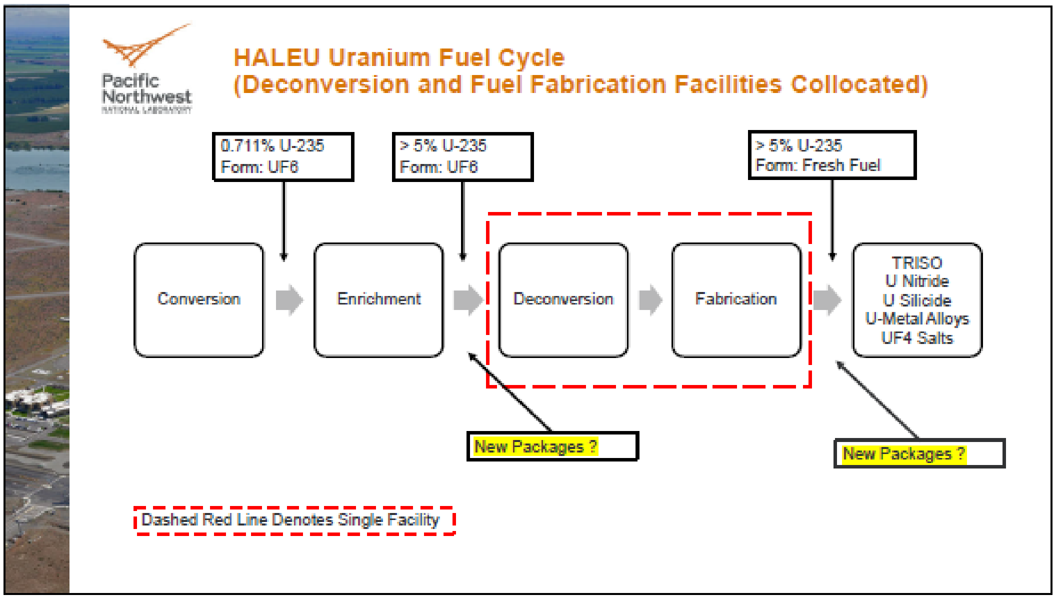

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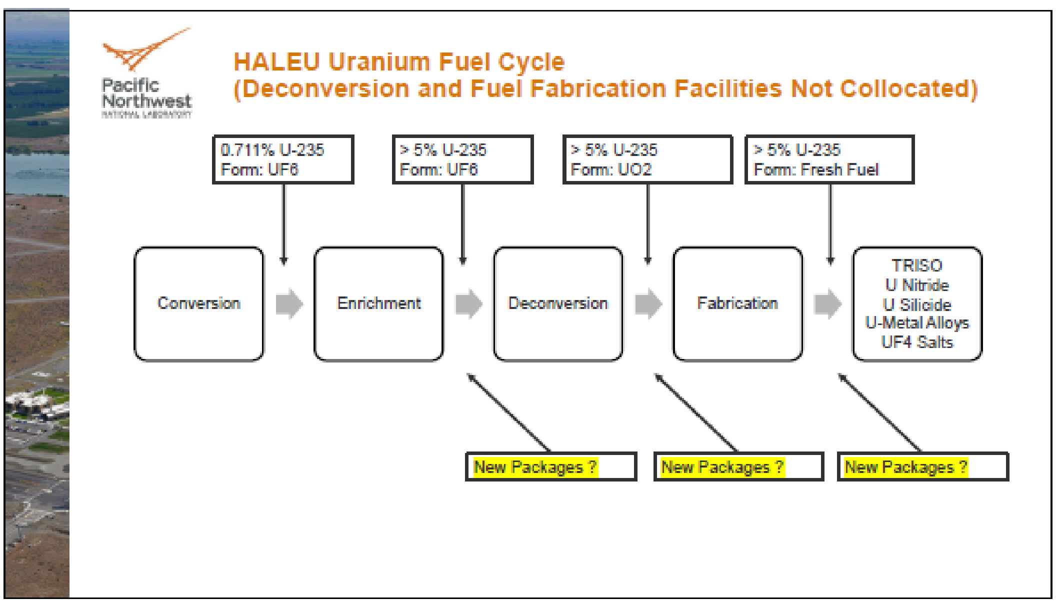

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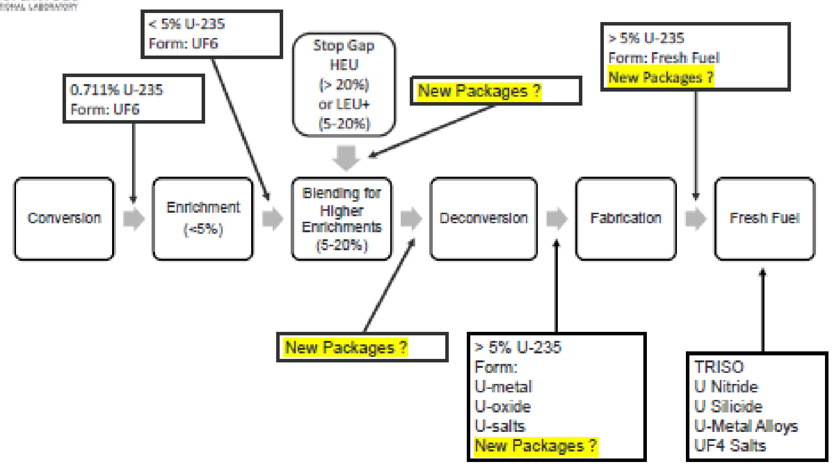
More Transportation Packages Could Be Required If Existing Stocks of Previously Irradiated Uranium (Stop Gap Uranium) Used and Facilities Not Collocated



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Advanced Reactor Fuel Transport

- Advanced Reactor Fuel types represent a range of potential forms:
  - TRISO
  - U-Zr metal alloys
  - UO2
  - FLiBe salts
  - Etc.
- It will be important to understand how these spent fuels and waste will need to be handled, stored, transported, and disposed

Source: Fuel Fabrication Capability Assessment in Support of Advanced Reactor Deployments, PNNL-31226 (2022)

US Advanced Reactor Design Companies

Company	Reactor Name	Reactor Type	MWt	Spectrum	Coolant Type	Temp (°C)	Enr (wt%)	Fuel Type
Advanced Reactor Concepts	ARC-100	Commercial FOAK	260	Fast	Sodium	470	13.5	U-10Zr Metal Alloy
Alpha Tech					Fluoride Salt			Fluoride Based Fuel Salt
Atomics	Nuclear Space Propulsion	NTP system						
Bechtel, GE Hitachi Nuclear Energy, and TerraPower	Versatile Test Reactor (VTR)	Test Reactor	300	Fast	Sodium	500	15	U-20Pu-10Zr Metal Alloy
BWXT	Mobile Nuclear Power Plant (MNPP)	MNPP	(1-10 MWe)	Thermal				TRISO
BWXT	BANR	Commercial FOAK	(1-10 MWe)	Thermal				TRISO
Columbia Basin Consulting	CBCO LFR	Commercial FOAK	250	Fast	Lead Bismuth	500		UO_2 then Metal
Elysium	Molten Chloride Salt Fast Reactor (MCSFR)	Commercial FOAK	110-2700	Fast	Chloride Salt	660		U Pu Na K Cl
Flibe Energy	Liquid Fluoride Thorium Reactor (LFTR)	Commercial FOAK	600	Thermal	Fluoride Salt	650		$2LiF$-BeF_2-$(^{233}U)F_4$
Flibe Energy	Demonstration Reactor	Demonstration	60	Thermal	Fluoride Salt	650		$2LiF$-BeF_2-$(^{233}U)F_4$
Flibe Energy	Test Reactor in Zipper at INL	Test Reactor	0.5	Thermal	Fluoride Salt	650		$2LiF$-BeF_2-$(^{233}U)F_4$
GE Hitachi, USA*	BWRX-300	Commercial FOAK	937.5	Thermal	Light Water	287		UO_2
GE Hitachi, USA*	PRISM	Commercial FOAK	471	Fast	Sodium	500	15	U-26Pu-10Zr Metal Alloy
General Atomics	EM2	Commercial FOAK	500	Fast	Helium Gas	850		
General Atomics	Fast Modular Reactor (FMR)	Demonstration	111	Fast	Helium Gas	850		
General Atomics	Mobile Microreactor	Microreactor (MNPP)						TRISO
Global Energy Research Associates	GERA small modular reactor (SMR)	Commercial FOAK	764	Thermal				Gaseous Pu based
HOLOSGen	HOLOSGen	Microreactor	6-30	Thermal	Helium Gas	760	12	TRISO
Holtec	SMR-160	Commercial FOAK	500	Thermal	Light Water	315		UO_2
Hybrid Power Technologies, LLC	HPR	Commercial FOAK		Thermal	Helium Gas			TRISO
Hydromine	LFR-AS-200	Demonstration	475	Fast	Lead Bismuth	500	19	UO_2-PuO_2
Kairos Power	Hermes	Test Reactor		Thermal	Fluoride Salt	650		TRISO
Kairos Power*	KP-X	Commercial FOAK	320	Thermal	Fluoride Salt	650		TRISO

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US Advanced Reactor Design Companies

Company	Reactor Name	Reactor Type	MWt	Spectrum	Coolant Type	Temp (°C)	enrg (wt%)	Fuel Type
MicroNuclear LLC	MSMR							
Moltex Energy (Canada)	Stable Salt Reactor – Wasteburner (SSR-W)	Commercial FOAK	375	Fast	Chloride Salt	700	Pu	NaCl-PuCl + Actinides
Muons	Mu*Star	Commercial FOAK	500	Thermal	Fluoride Salt	750		Fluoride Based Fuel Salt
Newcore	Newcore molten chloride fast reactor (MCFR)	Demonstration	10	Hybrid	Lead Bismuth			
NuGen LLC	NuGen Engine	Microreactor	(1-3 MWe)	Fast	Helium Gas			TRISO
NuScale*	NuScale Power Module™	Commercial FOAK	(60-484 MWe)	Thermal	Light Water	315	4.95	UO_2
Oklo*	Aurora	Microreactor	4	Fast	Sodium	440		U-10Zr Metal Alloy
Radiant	Radiant	Microreactor	(1.2 MWe)					TRISO
Space Nuclear Power Corp.	Kilopower	Microreactor	4-40 kWt	Fast	Na Heat Pipes	800		U-7.6Mo
StarCore	StarCore	Commercial FOAK	50	Thermal	Helium Gas		15	TRISO
TerraPower, USA	Traveling Wave Reactor–Prototype (TWR-P)	Demonstration	1,475	Fast	Sodium	500	13.75	U-10Zr Metal Alloy
TerraPower and GE	Natrium	Demonstration	840	Fast	Sodium	500	15.75	U-10Zr Metal Alloy
TerraPower, USA	MCFR	Commercial FOAK		Fast	Chloride Salt		U Pu	U Pu Na K Cl
Terrestrial USA	Integral Molten Salt Reactor (IMSR®)	Commercial FOAK	415	Thermal	Fluoride Salt	700	4.95	$LiF-BeF_2-ZrF_4-UF_4$
ThorCon	The Do-able MSR	Commercial FOAK	1114	Thermal	Fluoride Salt	700	19.75	UF_4 and ThF_4
ThorCon	Do-able Prototype	Demonstration		Thermal		700	19.75	
Ultra Safe Nuclear Corporation	MMR Energy System	Microreactor	15	Thermal	Helium	630	19.75	TRISO FCM™ Fuel
Ultra Safe Nuclear Technologies	Nuclear Space Propulsion	NTP system	1	Thermal	Helium	630	19.75	TRISO FCM™ Fuel
Westinghouse	SMR	Commercial FOAK	755	Thermal	Water cooled	340		UO_2
Westinghouse	defense-eVinci	Microreactor (ANPP)	(1-10 MWe)	Thermal	Na Heat Pipes	600	19.75	TRISO
Westinghouse*	eVinci	Microreactor	12.5	Thermal	Na Heat Pipes	600	19.75	Not yet determined
Westinghouse	Lead Fast Reactor (LFR)	Demonstration	1,023	Fast	Lead	650		UO_2 then nitride
X-energy*	Xe-100	Commercial FOAK	200	Thermal	Helium	750	15.5	TRISO

Company	Reactor Name	Reactor Type	MWt	Spectrum	Coolant Type	Temp (°C)	enrg (wt%)	Fuel Type
X-energy	Xe-Mobile	Microreactor (ANPP)	(1-10 MWe)	Thermal	Helium	750	15.5	TRISO

* Vendors submitted Design Certification Application to the U.S. NRC or engaged in Licensing Modernization Project

Key: ARDP Awards; DoD Strategic Capabilities Office Project; NRC Interactions

Source: Fuel Fabrication Capability Assessment in Support of Advanced Reactor Deployments, PNNL-31226 (2022)

9

9

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Microreactor Transportation

- Efficient, timely, and cost-effective deployment of microreactors requires that they be deployed containing their unirradiated and irradiated fuel
  - DoD domestic and overseas electrical power requirements
  - Natural disaster response may require expedited deployment
- Transport of a microreactor containing its unirradiated or irradiated fuel raises many unique regulatory issues
  - U.S. Nuclear Regulatory Commission transportation regulations in 10 CFR Part 71 largely revolve around thick-wall pressure vessels and a microreactor with its irradiated or unirradiated fuel contents is unlikely to meet the entire suite of codified transportation regulatory requirements using traditional analytical methods
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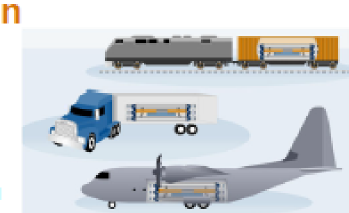

Source: GAO. | GAO-20-380SP

Baseline Application is a Transportable Nuclear Power Plant (TNPP) Package Being Developed for DoD/SCO

- 1 to 5 MWe, minimum of 3 years of full power operation
- HTGR using HALEU UCO TRISO fuel
- 4 or 5 modules
  - Reactor Module
  - IHX Module
  - Control Module
  - Power Conversion Module
- Reactor Module contains well over 99% of radioactivity (remainder in IHX Module)
- Each module contained in and integral with separate ISO-compliant CONEX containers

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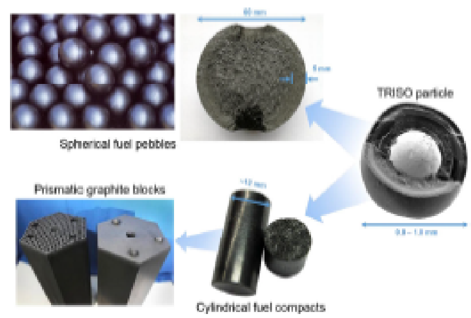
Potential Transportable Microreactor Properties

- ≤ 20 MW electrical power
  - Small modular reactors typically ≤ 300 MW electrical power
- Factory built and fueled
- Modular
- Highly transportable
- Tristructural isotropic (TRISO) fuel
- Goal is to develop a microreactor that can be shipped containing its unirradiated or irradiated contents
- These microreactors are also known as transportable nuclear power plants (TNPPs)



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  - Finally, air transport
- The microreactor containing its irradiated fuel would contain a highway route-controlled quantity of radioactive material (i.e., > 3000 A_2)
  - For truck shipments this means that a CVSA Level VI inspection and safety permit would be required (see 49 CFR 385 and 49 CFR 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
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- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars

12

6

Transport By Vessel

- Based on current microreactor core inventory calculations, a Class INF 3 ship would likely be required to transport a microreactor containing irradiated fuel
- There are only three Class INF 3 ships available for commercial hire from Pacific Nuclear Transport Limited (PNTL)
  - Pacific Egret, Pacific Grebe, and Pacific Heron
  - The PNTL ships are United Kingdom (UK) flagged; there are no United States-flagged Class INF 3 ships

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INF 2	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes that have an aggregate radioactivity less than 2×10^6 TBq (5.4×10^7 Ci) and ships that are certified to carry plutonium that has an aggregate radioactivity less than 2×10^4 TBq (5.4×10^5 Ci).
INF 3	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes, and ships that are certified to carry plutonium that has no restriction on the aggregate radioactivity of the materials.

Characteristics of Pacific Egret, Pacific Grebe, and Pacific Heron

Length	103.92 meters
Beam (Width)	17.25 meters
Draft	6.75 meters
Number of Holds	4
Capacity	20 transportation casks
Design Speed	14 knots
Deadweight	4,916 metric tons
Displacement	9,067 metric tons
Engine	Two diesel engines, each with 3,600 hp
Principle Cargo Carried	Mixed Oxide Fuel Assemblies (Pacific Egret and Pacific Heron) High-Level Waste and Compacted Waste (Pacific Grebe)

INF Code: International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes On Board Ships (see https://www.imo.org/en/OurWork/Safety/Pages/INF-Code.asp)

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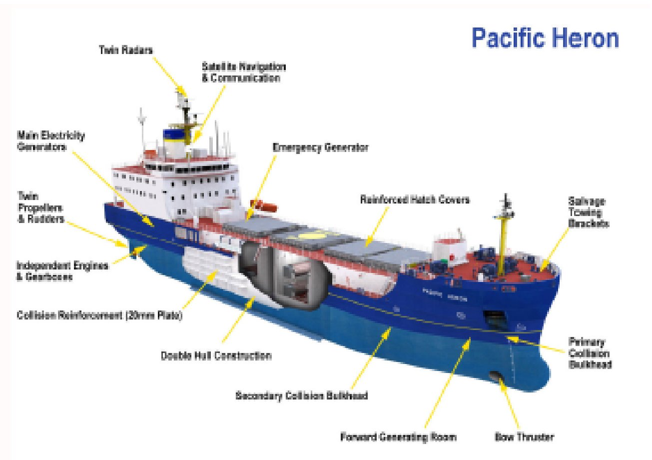
Key Safety Features of Class INF 3 Ships



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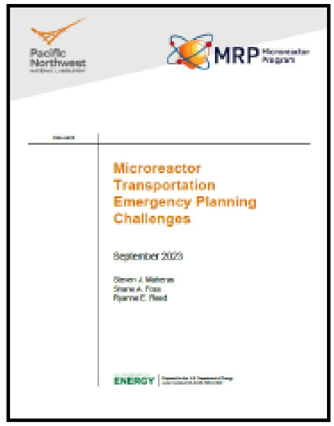
Microreactor Transportation Emergency Planning Challenges

- Evaluating the potential transportation emergency planning challenges associated with transporting microreactors containing their unirradiated or irradiated fuel
  - Microreactor transportation emergency planning challenges organized into cross-cutting challenges and specific transportation emergency response challenges
- Cross-cutting transportation emergency planning challenges
  - Use of hazardous materials in microreactor designs
  - Revisions to the DOT Emergency Response Guidebook
  - Potential compensatory measures
  - External Engagement, Emergency Response Training, and Accident Recovery Plans
- Discussions with States and Tribes also discussed



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Use of Hazardous Materials in Microreactor Designs

- Beryllium-containing materials are currently being investigated for use in microreactors as replacements for graphite as a neutron moderator (Cheng et al., 2022)
- Beryllium is a hazardous material and if these beryllium-containing materials were incorporated into a microreactor, the presence of these materials would have to be considered in the transportation emergency response planning for these specific microreactors
- Sodium-containing heat pipes are being investigated for use in some microreactors
- Sodium is a hazardous material and the presence of sodium would have to be considered in the transportation emergency response planning for these microreactors, specifically in two areas:
  - The ability of sodium in combination with water to exacerbate releases of radioactive material during a transportation accident, and
  - The need to modify transportation accident fire-fighting guidelines if sodium was present

Source: Cheng B., E. M. Duchnowski, D. J. Sprouster, L. L. Snead, N. R. Brown, and J. R. Trelewicz. 2022. "Ceramic Composite Moderators as Replacements for Graphite in High Temperature Microreactors." Journal of Nuclear Materials. Volume 563.

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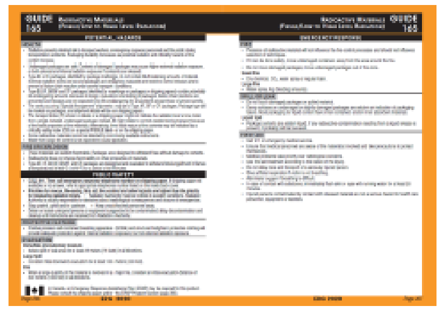
Emergency Response Guidebook (ERG)

- The DOT Pipeline and Hazardous Materials Safety Administration ERG provides first responders with a manual to help deal with hazardous materials transportation accidents during the critical first 30 minutes after the accident
- Emergency responders are trained to use the shipping papers, numbered placard, or orange panel number to determine which emergency response guide to use in responding to the accident
- The emergency response guides were not developed based on transportation accidents involving microreactors containing irradiated fuel
- The ERG would have to be expanded to include a guide that is specific to microreactor transportation accidents
- The guide may have to be fuel-type specific because of the differences in potential releases from different microreactor fuel types
- The guide may also have to be modified to account for the presence of hazardous materials such as beryllium or sodium



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Potential Compensatory Measures

- Microreactors containing irradiated fuel shipped by highway would be a highway route-controlled quantity (HRCQ) (> 3000 A_2) shipments and would need to meet the routing requirements in 49 CFR Part 397
  - The use of interstates, beltways around cities, state identified preferred routes could be considered as compensatory measures
- Microreactors will likely be overweight/overdimension and will require state permitting when transported by highway
  - Specific heavy haul truck or superload permit requirements could be considered as compensatory measures

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Other Potential Compensatory Measures

- Other potential compensatory measures include:
  - Increased exclusion zone around the microreactor during transport because of possible radiation dose rate increase
  - Real time health/fitness onboard monitoring/diagnostics of reactor package
  - Escorting of the reactor forward and aft for the entire route
  - Rolling road closures
  - Travel at reduced speeds
  - Choosing a route that avoids bodies of water (balanced by quality of road)
  - Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic)
  - Judicious use of time-of-day and day-of-week restrictions
  - Avoid shipping during severe weather
  - Conduct training for emergency responders along the route

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Potential Issue Associated with Compensatory Measures

- It is likely that NRC microreactor transportation package approval would be conducted using a risk-informed process and the microreactor containing irradiated fuel may not meet the 10 mrem/hr at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441 and 10 CFR 71.47
- As a result, the microreactor may require a stand-off distance of approximately 30 meters to obtain a dose rate of 10 mrem/hr, depending on the amount of shielding and storage time
- This could have implications for transportation emergency response planning if external package dose rates keep responders and recovery crews from meeting necessary objectives for recovery and mitigation

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External Engagement, Emergency Response Training, and Accident Recovery Plans

- Potential need to conduct external engagement prior to transporting a microreactor containing its irradiated fuel
  - A microreactor containing its irradiated fuel has not been shipped in the U.S., and State and Tribal emergency responders along potential routes are likely to be unfamiliar with microreactor transport
  - This engagement could take 2 to 3 years
- Potential need to conduct emergency response training along transport routes
- Potential need to develop transportation accident recovery plans

21

Discussions with States and Tribes

- In general, the transportation emergency response community is not familiar with microreactors or the concept of transporting a microreactor containing its irradiated fuel
- The purpose of the discussions was to obtain State and Tribal perspectives on the potential emergency planning challenges associated with the transportation of a microreactor containing its irradiated fuel
- The challenges may differ from shipments of spent nuclear fuel in Type B transportation casks (the current paradigm)
- Some challenges are likely to be mode-specific (i.e., different for shipment by truck, rail, air, and vessel)
- Some challenges will be design-specific, e.g., presence of other hazardous materials

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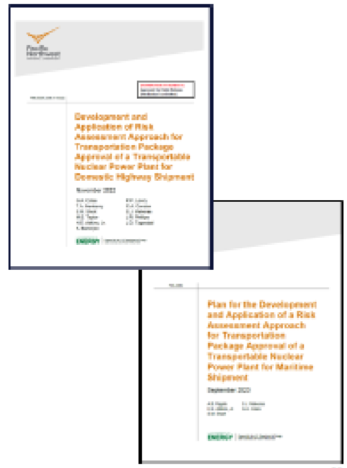
Current Microreactor Transportation Status

- Risk-informed transportation package approval methodology report submitted to NRC (November 2022)
- Requests for Additional Information (RAIs) on the risk-informed transportation package approval methodology report received from NRC (April 2023)
- RAI responses and revised report submitted to NRC (July 2023)
- Presented risk-informed transportation package approval methodology to NRC Advisory Committee on Reactor Safeguards (ACRS)
  - ACRS Subcommittee – November 17, 2023
  - Full ACRS – December 6, 2023
- At this stage we are not asking for transportation package approval, rather we are asking for the endorsement of the methodology
  - Endorsement of methodology by NRC expected Q2-Q3 FY2024
- Also working closely with NRIC on maritime transport of microreactors



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Thank you

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Appendix F – IAEA International Conference on the Management of Spent Fuel from Nuclear Power Reactors Microreactor Presentation

09/27/2024

Microreactor Transportation Emergency Planning Challenges

Steven J. Maheras
Shane A. Foss
Ryanne E. Reed

International Conference on the Management of Spent Fuel from Nuclear Power Reactors: Meeting the Moment

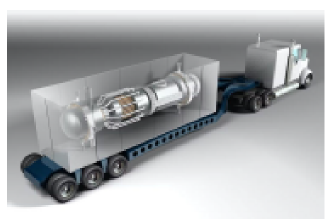
June 10-14, 2024

Vienna, Austria

1

Microreactors (Transportable Nuclear Power Plant or TNPPs)

- Many advanced reactor vendors are developing TNPPs to make higher density energy readily available for:
  - Increasing resilience of U.S. Department of Defense's (DOD's) domestic infrastructure to electric grid attack
  - Enabling rapid response during Humanitarian Aid and Disaster Relief (HADR) operations
  - Clean, zero-carbon energy in a variety of austere conditions and off grid locations
- These TNPP designs are typically factory produced, fueled, acceptance tested, and deployed as a sealed units prepared for transport and retrieved for refueling and reapplication



Semi-Tractor and Trailer Carrying Reactor Module

MRP Microreactor Program

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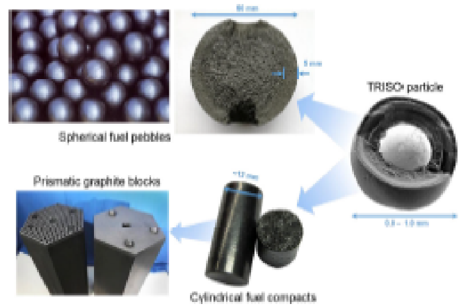
Properties of these TNPPs/Microreactors

- ≤ 20 MW electrical power
- Factory built and fueled
- Modular
- Highly transportable
- Most designs use tri-structural isotropic (TRISO) fuel
  - Pebbles
  - Compacts
- Most designs are high-temperature gas-cooled reactors



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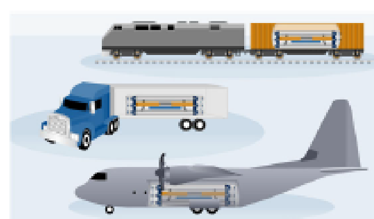
Microreactor Transportation

- Current microreactor concepts are to transport the microreactor containing its unirradiated or irradiated fuel
- A microreactor with its unirradiated or irradiated contents is unlikely to meet the entire suite of regulatory requirements in U.S. Nuclear Regulatory Commission (NRC) transportation regulations (10 CFR Part 71)
- A risk-informed process will likely be used for NRC transportation package approval
  - Demonstrate equivalent safety and that risk to the public is low
  - This will probably require the use of compensatory measures



Source: GAO. | GAO-20-[illegible]

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Current Transportation Approach

- The microreactor shipment would be a commercial shipment and would receive transportation package approval from the NRC using a risk-informed process
- Strategy is Crawl-Walk-Run
  - Concentrate on highway transport first
  - Then other surface modes (rail and barge/ship) – evaluation of transport by vessel has just started
  - Finally air transport
- The microreactor containing its irradiated fuel would contain a *highway route-controlled quantity* of radioactive material (i.e., > 3000 A_2)
  - For truck shipments this means that a Commercial Vehicle Safety Alliance (CVSA) Level VI inspection and safety permit would be required (see 49 CFR 385 and 49 CFR 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
- The microreactor would be fueled by LEU or HALEU (not HEU)
- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars
- Marine shipments would be via a Class INF-3 ship

LEU= Low Enriched Uranium (< 5 % U-235)
HALEU= High Assay Low Enriched Uranium (5-20 % U-235)
HEU= High Enriched Uranium (> 20% U-235)

MRP Microreactor Program

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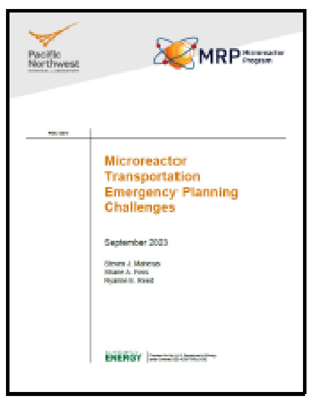
Microreactor Transportation Emergency Response Planning Challenges

- The U.S. Department of Energy Office of Nuclear Energy (DOE-NE) Microreactor Program is working to identify potential microreactor transportation emergency response planning challenges
- The U.S. Department of Energy (DOE) National Transportation Stakeholders Forum has been used to obtain input from the Tribes and States on these potential challenges



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Areas Examined In Identifying Microreactor Transportation Emergency Planning Challenges

• Assignment of Responsibility	• Accident Assessment
• Emergency Response Organization	• Protective Response
• Emergency Response Support and Resources	• Radiological Exposure Control
• Emergency Classification System	• Medical and Public Health Support
• Notification Methods and Procedures	• Recovery, Reentry, and Post-Accident Operations
• Emergency Communications	• Exercises and Drills
• Public Education and Information	• Radiological Emergency Response Training
• Emergency Facilities and Equipment	• Responsibility for the Planning Effort: Development, Periodic Review, and Distribution of Emergency Plans

MRP Microreactor Program

7

Results of Evaluation

- Microreactor transportation emergency planning challenges organized into cross-cutting challenges and specific transportation emergency response challenges
- This presentation will discuss several cross-cutting transportation emergency planning challenges
  - Use of hazardous materials in microreactor designs
  - Revisions to the DOT Emergency Response Guidebook
  - Potential compensatory measures
  - External Engagement, Emergency Response Training, and Accident Recovery Plans
- Discussions with States and Tribes also discussed

MRP Microreactor Program

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Use of Hazardous Materials in Microreactor Designs

- Beryllium-containing materials are currently being investigated for use in microreactors as replacements for graphite as a neutron moderator (Cheng et al., 2022)
- Beryllium is a hazardous material and if these beryllium-containing materials were incorporated into a microreactor, the presence of these materials would have to be considered in the transportation emergency response planning for these specific microreactors
- Sodium-containing heat pipes are being investigated for use in some microreactors
- Sodium is a hazardous material and the presence of sodium would have to be considered in the transportation emergency response planning for these microreactors, specifically in two areas:
  - The ability of sodium in combination with water to exacerbate releases of radioactive material during a transportation accident, and
  - The need to modify transportation accident fire-fighting guidelines if sodium was present

Source: Cheng B., E. M. Duchnowski, D. J. Sprouster, L. L. Snead, N. R. Brown, and J. R. Trelewicz. 2022. "Ceramic Composite Moderators as Replacements for Graphite in High Temperature Microreactors." Journal of Nuclear Materials. Volume 563.

MRP Microreactor Program

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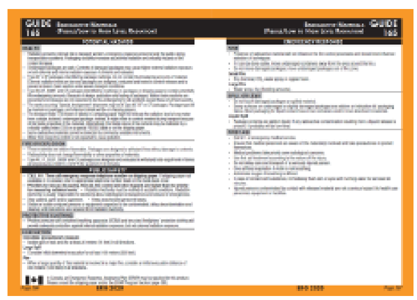
Emergency Response Guidebook (ERG)

- The U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) ERG provides first responders with a manual to help deal with hazardous materials transportation accidents during the critical first 30 minutes after the accident
- Emergency responders are trained to use the shipping papers, numbered placard, or orange panel number to determine which emergency response guide to use in responding to the accident
- The emergency response guides were not developed based on transportation accidents involving microreactors containing irradiated fuel
- The ERG would have to be expanded to include a guide that is specific to microreactor transportation accidents
- The guide may have to be fuel-type specific because of the differences in potential releases from different microreactor fuel types
- The guide may also have to be modified to account for the presence of hazardous materials such as beryllium or sodium



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Potential Compensatory Measures

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  - The use of interstates, beltways around cities, state identified preferred routes could be considered as compensatory measures
- Microreactors will likely be overweight/overdimension and will require state permitting when transported by highway
  - Specific heavy haul truck or superload permit requirements could be considered as compensatory measures

MRP Microreactor Program

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Other Potential Compensatory Measures Could Include

- Increased exclusion zone around the microreactor because of possible radiation dose rate increase
- Real time health/fitness onboard monitoring/diagnostics of reactor package
- Escorting of the reactor forward and aft for the entire route
- Rolling road closures
- Travel at reduced speeds
- Choosing a route that avoids bodies of water (balanced by quality of road)
- Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic)
- Judicious use of time-of-day and day-of-week restrictions
- Avoid shipping during severe weather
- Conduct training for emergency responders along the route

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Potential Issue Associated with Compensatory Measures

- It is likely that NRC microreactor transportation package approval would be conducted using a risk-informed process and the microreactor containing irradiated fuel may not meet the 0.1 mSv/h at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441 and 10 CFR 71.47
- As a result, the microreactor may require a stand-off distance of approximately 30 meters to obtain a dose rate of 0.1 mSv/h, depending on the amount of shielding and storage time
- This could have implications for transportation emergency response planning if external package dose rates keep responders and recovery crews from meeting necessary objectives for recovery and mitigation

MRP Microreactor Program

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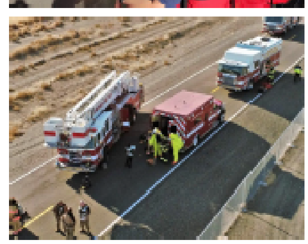
External Engagement, Emergency Response Training, and Accident Recovery Plans

- Would need to conduct external engagement prior to transporting a microreactor containing its irradiated fuel
  - A microreactor containing its irradiated fuel has not been shipped in the U.S., and State and Tribal emergency responders along potential routes are likely to be unfamiliar with microreactor transport
  - This engagement could take 2 to 3 years
- Potential need to conduct emergency response training along transport routes
- Potential need to develop transportation accident recovery plans



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Health Monitoring Information System

- Incorporating a health monitoring instrumentation system into the design of a microreactor would enable data on the status of the microreactor to be collected during its transport
- This data could be used to reduce the risks associated with transporting a microreactor containing irradiated fuel
- Three categories of data to be collected have been identified
  - Reactor Safety – neutron fluence and dose rate, temperature monitoring, vehicle shock and vibration data
  - Shielding – radiation dose rates around reactor and supplemental shielding
  - Radiological Containment – reactor vessel pressure, fission gas activity, intrusion monitors and alarms

15

Discussions with States and Tribes

- In general, the transportation emergency response community is not familiar with microreactors or the concept of transporting a microreactor containing its irradiated fuel
- The purpose of the discussions was to obtain State and Tribal perspectives on the potential emergency planning challenges associated with the transportation of a microreactor containing its irradiated fuel
- The challenges may differ from shipments of spent nuclear fuel in Type B transportation casks (the current paradigm)
- Some challenges are likely to be mode-specific (i.e., different for shipment by truck, rail, air, and vessel)
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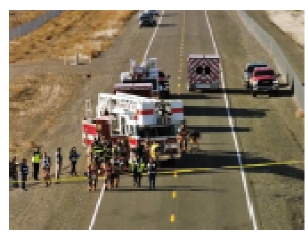

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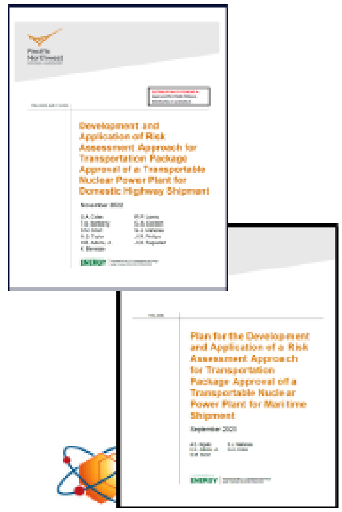
Collaboration Activities

- Working closely with the U.S. Department of Defense (DoD) Strategic Capabilities Office (SCO)
  - Project Pele
  - Presented risk-informed transportation package approval methodology to U.S. Nuclear Regulatory Commission (NRC) Advisory Committee on Reactor Safeguards (ACRS)
    - ACRS Subcommittee – November 17, 2023
    - Full ACRS – December 6, 2023
    - Endorsement of methodology by NRC expected in 2024
- Working closely with U.S. Army Reactor Office (ARO) and the U.S. Army Office of the Chief of Engineers (OCE)
- Working closely with National Reactor Innovation Center (NRIC) on maritime transport of microreactors



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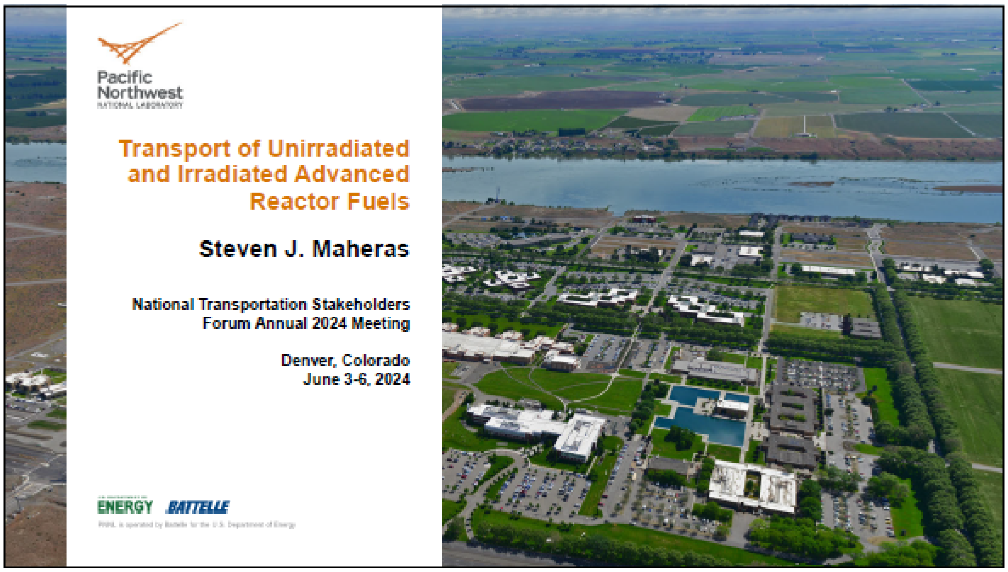
Appendix G – 2024 NTSF Annual Meeting Advanced Reactor and Microreactor Presentation

09/27/2024



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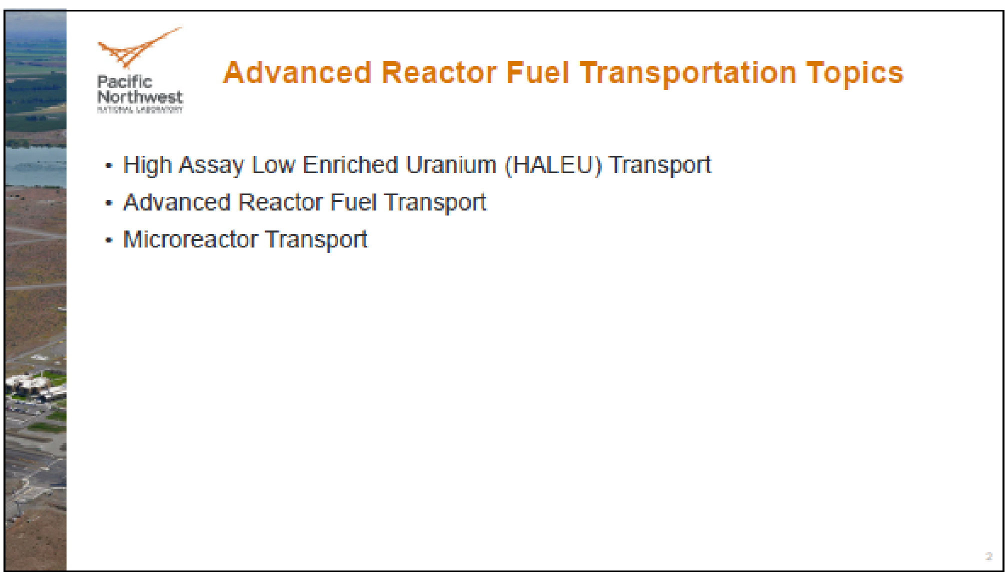

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High Assay Low Enriched Uranium (HALEU) Transport

- Current nuclear fuel cycle is based on transporting industrial quantities of low enriched (< 5% U-235) uranium
- HALEU is uranium enriched to 5-20% U-235
  - HALEU allows for smaller reactor designs, longer core lives, increased fuel efficiency, and less waste
  - HALEU made from recycling government owned highly enriched uranium (HEU) and downblending to HALEU or using gas centrifuges to enrich uranium to higher percentages of U-235
- A fuel cycle based on HALEU would require transport of industrial quantities of 5-20% enriched uranium among various facilities
- Issue – the availability of transportation packages for this shipping of industrial quantities of HALEU
  - The types of transportation packages required depends on if facilities are collocated and the source of the uranium

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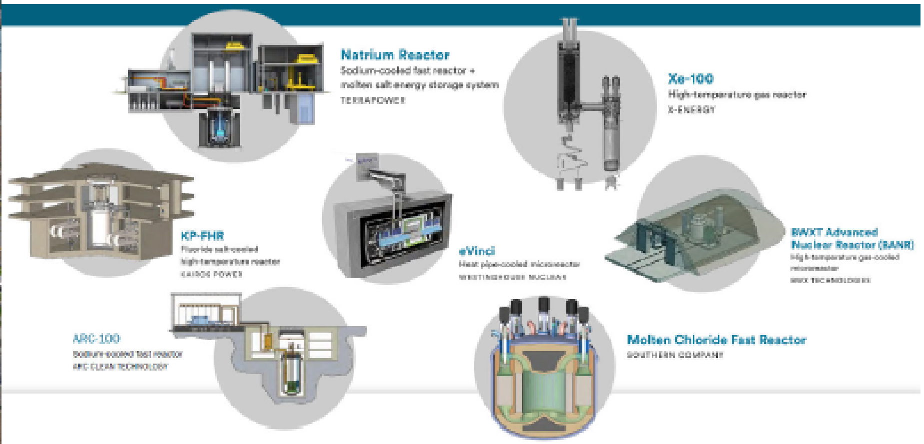
Several Advanced Reactors Need HALEU Fuel



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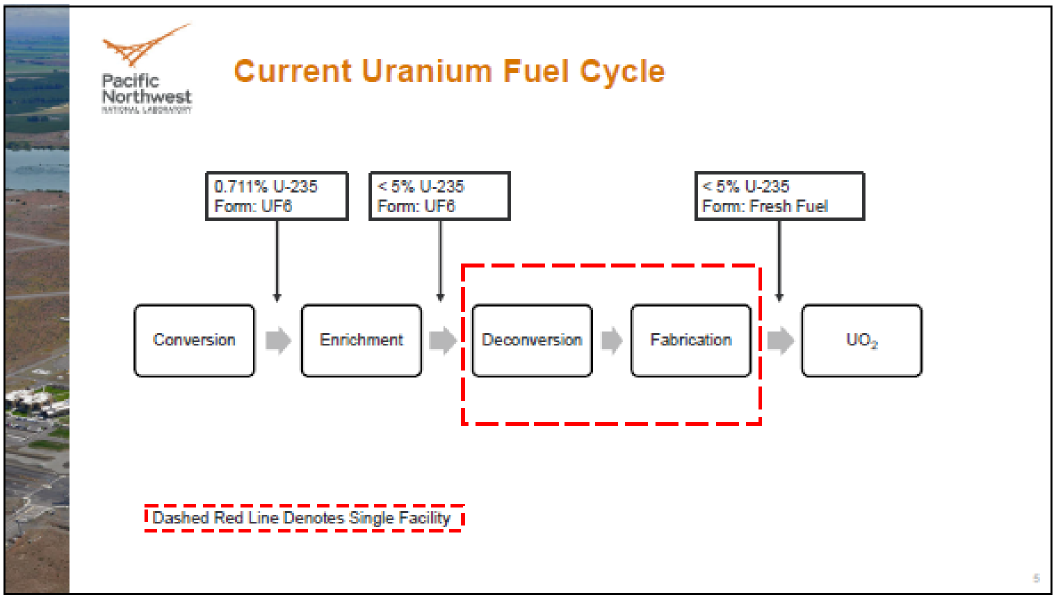

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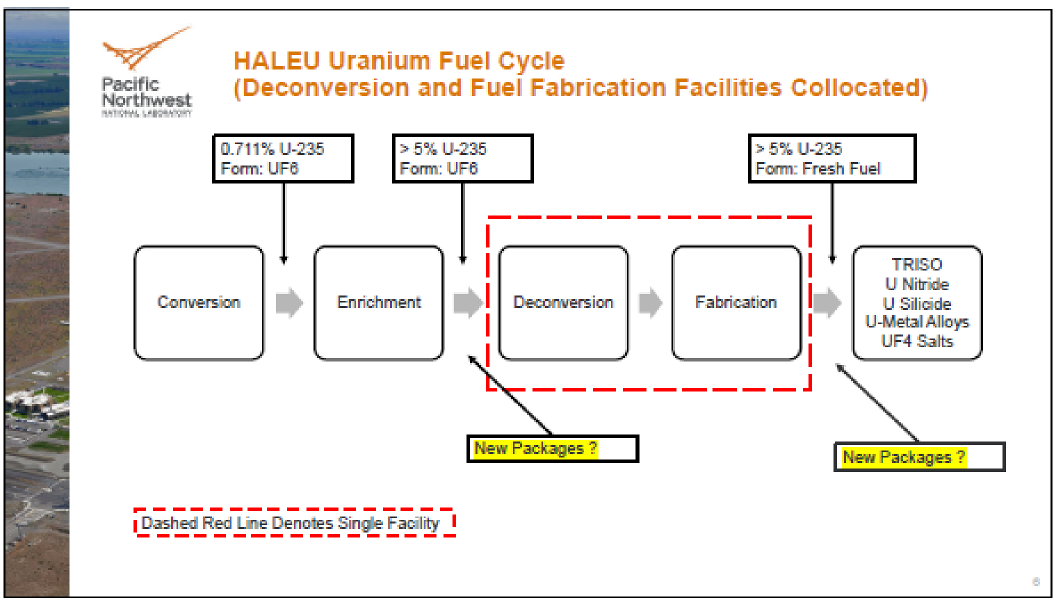

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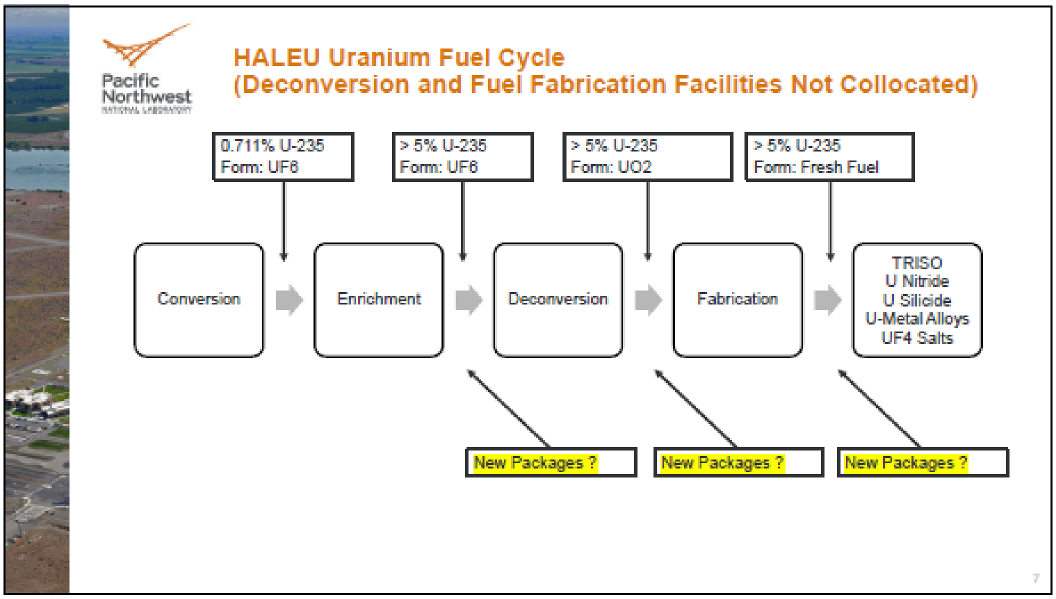
Pacific Northwest
HALEU Uranium Fuel Cycle
(Deconversion and Fuel Fabrication Facilities Not Collocated)
0.711% U-235
Form: UF6
> 5% U-235
Form: UF6
> 5% U-235
Form: UO2
> 5% U-235
Form: Fresh Fuel
Conversion
Enrichment
Deconversion
Fabrication
TRISO
U Nitride
U Silicide
U-Metal Alloys
UF4 Salts
New Packages ?
New Packages ?
New Packages ?

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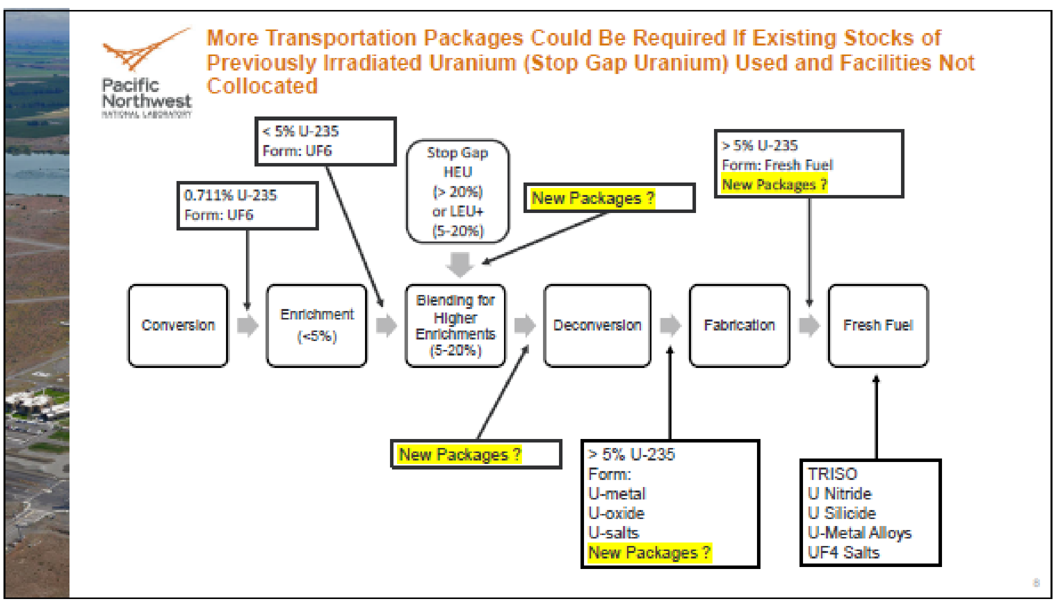
Pacific Northwest
More Transportation Packages Could Be Required If Existing Stocks of Previously Irradiated Uranium (Stop Gap Uranium) Used and Facilities Not Collocated
< 5% U-235
Form: UF6
Stop Gap
HEU
(> 20%)
or LEU+
(5-20%)
New Packages ?
> 5% U-235
Form: Fresh Fuel
New Packages ?
0.711% U-235
Form: UF6
Conversion
Enrichment
(<5%)
Blending for
Higher
Enrichments
(5-20%)
Deconversion
Fabrication
Fresh Fuel
New Packages ?
> 5% U-235
Form:
U-metal
U-oxide
U-salts
New Packages ?
TRISO
U Nitride
U Silicide
U-Metal Alloys
UF4 Salts

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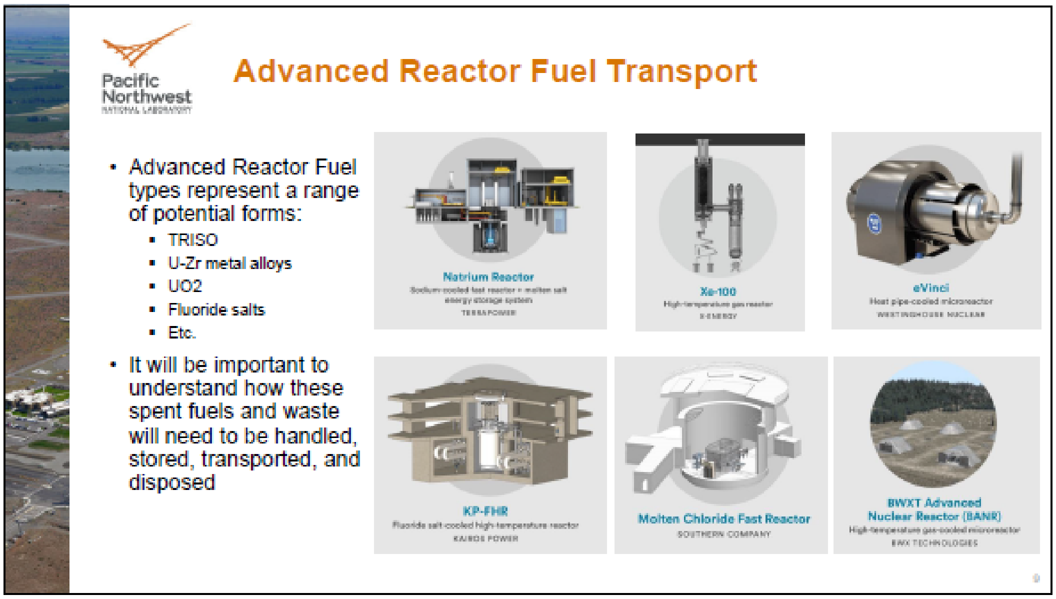

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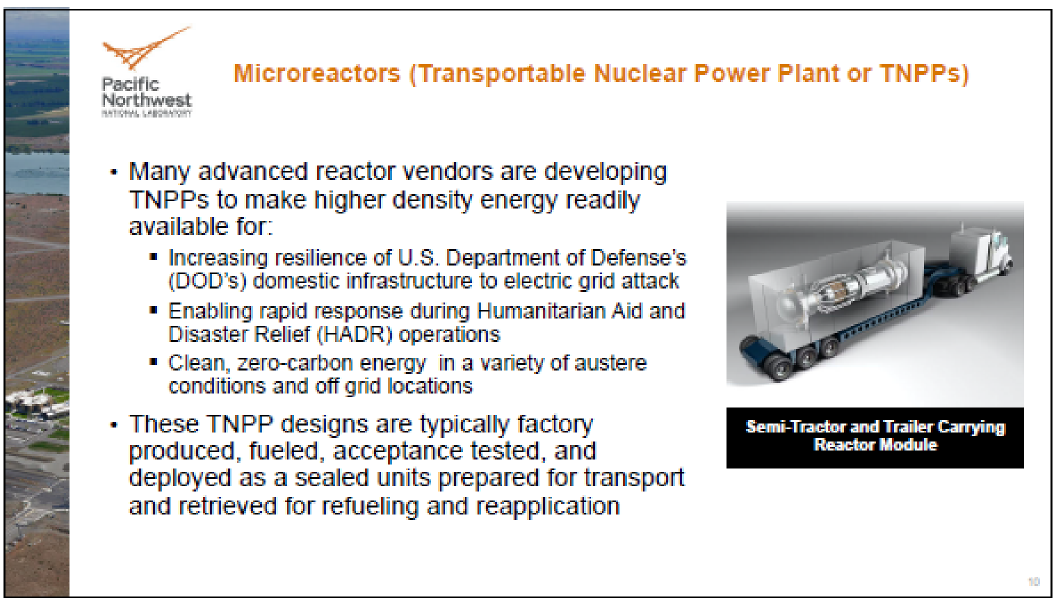

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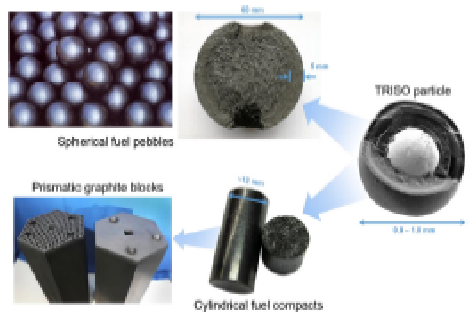
Properties of these TNPPs/Microreactors

- ≤ 20 MW electrical power
  - Small modular reactors typically ≤ 300 MW electrical power
- Factory built and fueled
- Modular
- Highly transportable
- Tristructural isotropic (TRISO) fuel
  - Pebbles
  - Compacts
- Most designs are high-temperature gas-cooled reactors



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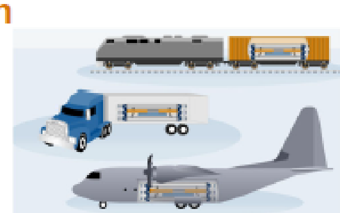
Microreactor Transportation

- Microreactor concepts are typically to transport the microreactor containing its unirradiated or irradiated fuel
- A microreactor with its unirradiated or irradiated contents is unlikely to meet the entire suite of regulatory requirements in U.S. Nuclear Regulatory Commission (NRC) transportation regulations (10 CFR Part 71)
- A risk-informed process will likely be used for NRC transportation package approval
  - Demonstrate equivalent safety and that risk to the public is low
  - This will probably require the use of compensatory measures



Source: GAO. | GAO-20-380SP

12

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Current Transportation Approach

- The microreactor shipment would be a commercial shipment and would receive transportation package approval from the NRC using a risk-informed process
- Strategy is Crawl-Walk-Run
  - Concentrate on highway transport first
  - Then other surface modes (rail and barge/ship) – evaluation of transport by vessel has just started
  - Finally, air transport
- The microreactor containing its irradiated fuel would contain a *highway route-controlled quantity of radioactive material* (i.e., > 3000 A_2)
  - For truck shipments this means that a CVSA Level VI inspection and safety permit would be required (see 49 CFR 385 and 49 CFR 397)
  - For rail shipments this means that the transportation planning requirements in 49 CFR 172.820 would apply
- The microreactor would be fueled by LEU or HALEU (not HEU)
- For rail shipments, transport would be via Association of American Railroads (AAR) Standard S-2043 railcars
- Marine shipments would be via a Class INF-3 ship

LEU= Low Enriched Uranium (< 5 % U-235)
HALEU= High Assay Low Enriched Uranium (5-20 % U-235)
HEU= High Enriched Uranium (> 20% U-235)

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Transport By Vessel

- Based on current microreactor core inventory calculations, a Class INF-3 ship would likely be required to transport a microreactor containing irradiated fuel
- There are only three Class INF 3 ships available for commercial hire from Pacific Nuclear Transport Limited (PNTL)
  - Pacific Egret, Pacific Grebe, and Pacific Heron
  - The PNTL ships are United Kingdom (UK) flagged; there are no United States-flagged Class INF 3 ships

Classes of INF Ships

Class of INF Ship	Criteria
INF 1	Ships that are certified to carry materials that have an aggregate radioactivity of less than 4,000 TBq (1.1×10^5 Ci).
INF 2	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes that have an aggregate radioactivity less than 2×10^6 TBq (5.4×10^7 Ci) and ships that are certified to carry plutonium that has an aggregate radioactivity less than 2×10^5 TBq (5.4×10^6 Ci).
INF 3	Ships that are certified to carry irradiated nuclear fuel or high-level radioactive wastes, and ships that are certified to carry plutonium that has no restriction on the aggregate radioactivity of the materials.

Characteristics of Pacific Egret, Pacific Grebe, and Pacific Heron

Length	103.92 meters
Beam (Width)	17.25 meters
Draft	6.75 meters
Number of Holds	4
Capacity	20 transportation casks
Design Speed	14 knots
Deadweight	4,916 metric tons
Displacement	9,667 metric tons
Engine	Two diesel engines, each with 3,600 hp
Principle Cargo Carried	Mixed Oxide Fuel Assemblies (Pacific Egret and Pacific Heron) High-Level Waste and Compacted Waste (Pacific Grebe)

INF Code: International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes On Board Ships (see https://www.imo.org/en/OurWork/Safety/Pages/INF-Code.asp)

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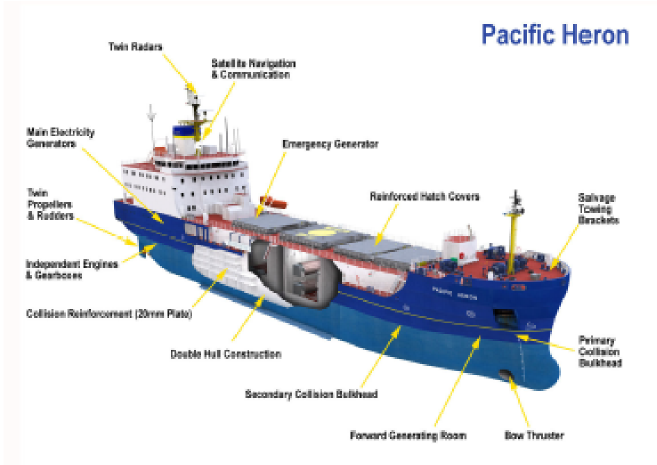
Key Safety Features of Class INF 3 Ships



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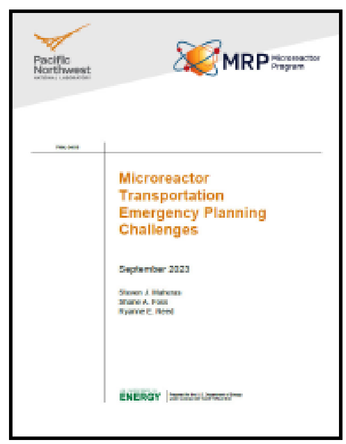
Microreactor Transportation Emergency Planning Challenges

- The U.S. Department of Energy Office of Nuclear Energy (DOE-NE) Microreactor Program is working to identify potential microreactor transportation emergency response planning challenges
- The U.S. Department of Energy (DOE) National Transportation Stakeholders Forum has been used to obtain input from the Tribes and States on these potential challenges



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Results of Evaluation

- Microreactor transportation emergency planning challenges organized into cross-cutting challenges and specific transportation emergency response challenges
- This presentation will discuss several cross-cutting transportation emergency planning challenges
  - Use of hazardous materials in microreactor designs
  - Revisions to the DOT Emergency Response Guidebook
  - Potential compensatory measures
  - External Engagement, Emergency Response Training, and Accident Recovery Plans
- Discussions with States and Tribes also discussed

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Use of Hazardous Materials in Microreactor Designs

- Beryllium-containing materials are currently being investigated for use in microreactors as replacements for graphite as a neutron moderator (Cheng et al., 2022)
- Beryllium is a hazardous material and if these beryllium-containing materials were incorporated into a microreactor, the presence of these materials would have to be considered in the transportation emergency response planning for these specific microreactors
- Sodium-containing heat pipes are being investigated for use in some microreactors
- Sodium is a hazardous material and the presence of sodium would have to be considered in the transportation emergency response planning for these microreactors, specifically in two areas:
  - The ability of sodium in combination with water to exacerbate releases of radioactive material during a transportation accident, and
  - The need to modify transportation accident fire-fighting guidelines if sodium was present

Source: Cheng B., E. M. Duchnowski, D. J. Sprouster, L. L. Snead, N. R. Brown, and J. R. Trelewicz. 2022. "Ceramic Composite Moderators as Replacements for Graphite in High Temperature Microreactors." Journal of Nuclear Materials. Volume 563.

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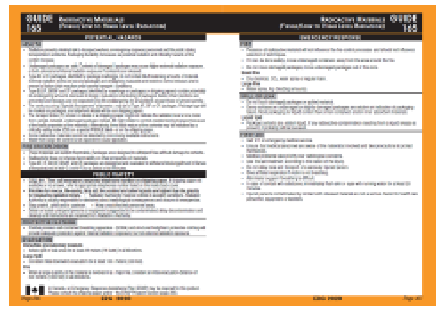
Emergency Response Guidebook (ERG)

- The U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) ERG provides first responders with a manual to help deal with hazardous materials transportation accidents during the critical first 30 minutes after the accident
- Emergency responders are trained to use the shipping papers, numbered placard, or orange panel number to determine which emergency response guide to use in responding to the accident
- The emergency response guides were not developed based on transportation accidents involving microreactors containing irradiated fuel
- The ERG would have to be expanded to include a guide that is specific to microreactor transportation accidents
- The guide may have to be fuel-type specific because of the differences in potential releases from different microreactor fuel types
- The guide may also have to be modified to account for the presence of hazardous materials such as beryllium or sodium



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Potential Compensatory Measures

- Microreactors containing irradiated fuel shipped by highway would be a highway route-controlled quantity (HRCQ) (> 3000 A_2) shipments and would need to meet the routing requirements in 49 CFR Part 397
  - The use of interstates, beltways around cities, state identified preferred routes could be considered as compensatory measures
- Microreactors will likely be overweight/overdimension and will require state permitting when transported by highway
  - Specific heavy haul truck or superload permit requirements could be considered as compensatory measures

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Other Potential Compensatory Measures

- Other potential compensatory measures include:
  - Increased exclusion zone around the microreactor during transport because of possible radiation dose rate increase
  - Real time health/fitness onboard monitoring/diagnostics of reactor package
  - Escorting of the reactor forward and aft for the entire route
  - Rolling road closures
  - Travel at reduced speeds
  - Choosing a route that avoids bodies of water (balanced by quality of road)
  - Controls for bridges over bodies of water (bridge inspection, speed reduction, close bridge to other traffic)
  - Judicious use of time-of-day and day-of-week restrictions
  - Avoid shipping during severe weather
  - Conduct training for emergency responders along the route

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Potential Issue Associated with Compensatory Measures

- It is likely that NRC microreactor transportation package approval would be conducted using a risk-informed process and the microreactor containing irradiated fuel may not meet the 10 mrem/hr at 2 meters from the conveyance dose rate limit contained in 49 CFR 173.441 and 10 CFR 71.47
- As a result, the microreactor may require a stand-off distance of approximately 30 meters to obtain a dose rate of 10 mrem/hr, depending on the amount of shielding and storage time
- This could have implications for transportation emergency response planning if external package dose rates keep responders and recovery crews from meeting necessary objectives for recovery and mitigation

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External Engagement, Emergency Response Training, and Accident Recovery Plans

- Would need to conduct external engagement prior to transporting a microreactor containing its irradiated fuel
  - A microreactor containing its irradiated fuel has not been shipped in the U.S., and State and Tribal emergency responders along potential routes are likely to be unfamiliar with microreactor transport
  - This engagement could take 2 to 3 years
- Potential need to conduct emergency response training along transport routes
- Potential need to develop transportation accident recovery plans

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Health Monitoring Information System

- Incorporating a health monitoring instrumentation system into the design of a microreactor would enable data on the status of the microreactor to be collected during its transport
- This data could be used to reduce the risks associated with transporting a microreactor containing irradiated fuel
- Three categories of data to be collected have been identified
  - Reactor Safety – neutron fluence and dose rate, temperature monitoring, vehicle shock and vibration data
  - Shielding – radiation dose rates around reactor and supplemental shielding
  - Radiological Containment – reactor vessel pressure, fission gas activity, intrusion monitors and alarms

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Discussions with States and Tribes

- In general, the transportation emergency response community is not familiar with microreactors or the concept of transporting a microreactor containing its irradiated fuel
- The purpose of the discussions was to obtain State and Tribal perspectives on the potential emergency planning challenges associated with the transportation of a microreactor containing its irradiated fuel
- The challenges may differ from shipments of spent nuclear fuel in Type B transportation casks (the current paradigm)
- Some challenges are likely to be mode-specific (i.e., different for shipment by truck, rail, air, and vessel)
- Some challenges will be design-specific, e.g., presence of other hazardous materials

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Collaboration Activities

- Working closely with the U.S. Department of Defense (DoD) Strategic Capabilities Office (SCO)
  - Project Pele
  - Presented risk-informed transportation package approval methodology to U.S. Nuclear Regulatory Commission (NRC) Advisory Committee on Reactor Safeguards (ACRS)
    - ✓ ACRS Subcommittee – November 17, 2023
    - ✓ Full ACRS – December 6, 2023
    - ✓ Endorsement of methodology by NRC expected in 2024
- Working closely with U.S. Army Reactor Office (ARO) and the U.S. Army Office of the Chief of Engineers (OCE)
- Working closely with National Reactor Innovation Center (NRIC) on maritime transport of microreactors

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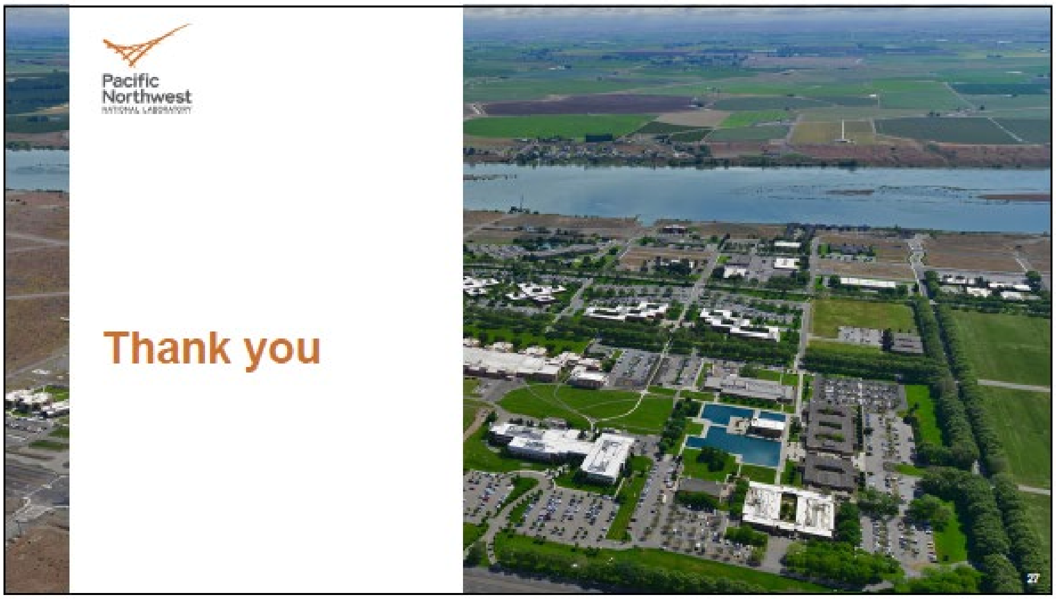

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