Fuel Transportation Readiness for New Nuclear Commercialization

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Introduction

The U.S. nuclear energy sector depends on a safe and reliable nuclear fuel transportation system, one that has moved fuel without incident across every phase of the fuel cycle for over half a century. While it is a system built deliberately through careful federal regulation, industry practice, and decades of operational experience, its governing framework reflects the requirements of conventional reactors and their fuel. **As new nuclear reactor technologies move toward commercialization, modernizing that framework from its current prescriptive requirements to include more flexible, performance-based alternatives will be essential for enabling the next generation of nuclear technologies.**

Current regulations will require adjustments to meet the demands of new reactor technologies. Many new reactors will require fuel at higher enrichments and in different forms than conventional fuel. Others are intended to be transported as complete, pre-fueled units, which will require a more adaptive approach to how reactors are evaluated and certified for transport.

Proactively adapting the U.S. fuel transportation system to the demands of these new fuels and reactor types is necessary for successful reactor deployment. As part of broader regulatory modernization, the Nuclear Regulatory Commission is actively updating its transportation regulations, providing an opportunity to develop performance-based pathways that enable innovation. Sustaining that momentum alongside commercialization timelines will ultimately determine whether new reactors are delivered on time and on budget to address increasing U.S. energy demand.

Main Takeaways

- Safe and secure transportation of both fresh and spent fuel is necessary to protect workers, the public, and the environment.
- Current transportation regulations are built around low-enriched uranium (LEU), with U-235 enriched to 3–5%. New reactors will require fuel enriched up to 20%. There are currently no packages optimized for commercial transportation of fuel enriched between 5-20%.
- Proactively adapting existing transportation regulations and package certification requirements is an enabling condition for successful new nuclear reactor commercialization.

Transportation Safety and Regulatory Oversight

The transportation of nuclear materials poses unique hazards compared to fixed facilities due to the inherent risks involved in moving radioactive material or reactors over long distances, and in some cases, under difficult conditions. The U.S. transportation framework dates from the beginning of the nuclear era and has greatly informed international transportation requirements. A fundamental assumption of this framework is that transportation accidents cannot be prevented completely, so radioactive material packaging must survive all expected accident conditions (regardless of probability).

The safety record of U.S. nuclear fuel transportation is maintained through a system of oversight spanning federal agencies, state and local governments, and private industry. At the federal level, the Department of Transportation (DOT), Nuclear Regulatory Commission (NRC), and Department of Energy (DOE) each hold distinct but complementary jurisdiction.

- DOT regulations under 49 CFR 171, 173-177, and 390-397 govern the transportation of radioactive material.[1] These rules cover the verification of package contents, shipper and carrier responsibilities, and the documentation of all radioactive material transport across land, air, and sea. Generally, DOT regulations require that any nuclear material package must meet requirements developed by the NRC or DOE.
- NRC is responsible for determining the safety requirements for fissile material transportation under 10 CFR 71, which focus specifically on the design, testing, qualification, manufacture, use, and maintenance of packages used to transport fissile material (i.e., fuel). Additionally, 10 CFR 73 subpart E outlines security requirements during transit, which includes routing requirements and physical protection measures.
- DOE manages the transportation of materials and fuel through DOE-owned facilities and national laboratories. It is also responsible for the long-term disposal of spent fuel, as well as its eventual transportation to a permanent repository.
- In practice, current transportation package requirements across DOT, NRC, and DOE are harmonized to the same safety requirements, although the relevant regulator remains responsible for reviewing and approving packages under its jurisdictions.

State, local, and tribal governments operate within this federal framework and have their own specific authorities. Under DOT routing regulations (49 CFR 397.103), state routing agencies may select preferred highway routes for radioactive material shipments to minimize the risk of accidents. Tribal governments also hold the same routing authority under DOT's HM-164 rule for shipments crossing reservation lands. For any spent fuel shipments, licensees must coordinate with the relevant city, county, and tribal governments. Each may have their own routing requirements, notification protocols, and conditions for transit. Effective oversight by, and coordination across, all these entities has allowed the industry to maintain its strong safety record.

Packaging

Packages used to transport spent nuclear fuel are containment systems designed with multiple layers of protection and are fundamental to fuel transportation safety. Typically, an inner vessel holds the fuel itself, while an outer overpack provides structural and thermal protection and radiation shielding. These layers are designed to withstand even the most severe accident conditions.

The NRC's regulations under 10 CFR Part 71 govern package certification, the process by which the NRC approves a package design for use in commercial nuclear fuel transportation. Packages are classified based on the quantity and type of material being transported. Type A fissile (AF) packages designed for lower-radioactivity materials must demonstrate they can

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[1] Specific DOT modal regulations are found in 49 CFR Part 174, subparts A through D and K (rail); 49 CFR Part 175 (air); 49 CFR part 176, subparts A through F and M (vessel); and 49 CFR part 177 and parts 390 through 397 (public highway).

withstand the routine hazards of transport. Type B fissile (BF) packages are required for higher-radioactivity materials, including spent fuel, and are evaluated against a more demanding testing sequence. In addition to testing under normal conditions, Type B packages must demonstrate they can withstand severe, hypothetical accident conditions through the following sequential tests:

a) Free drop – the package is dropped 30 feet onto an unyielding surface;
b) Puncture – the package is dropped 40 inches onto a steel bar;
c) Thermal – the package is fully engulfed in a 1475°F fire for 30 minutes; and,
d) Water immersion – the package must withstand the pressure of 50 feet of water.

Figure 1:Simplified representation of accident condition tests for Type B packages. *Source: NRC*

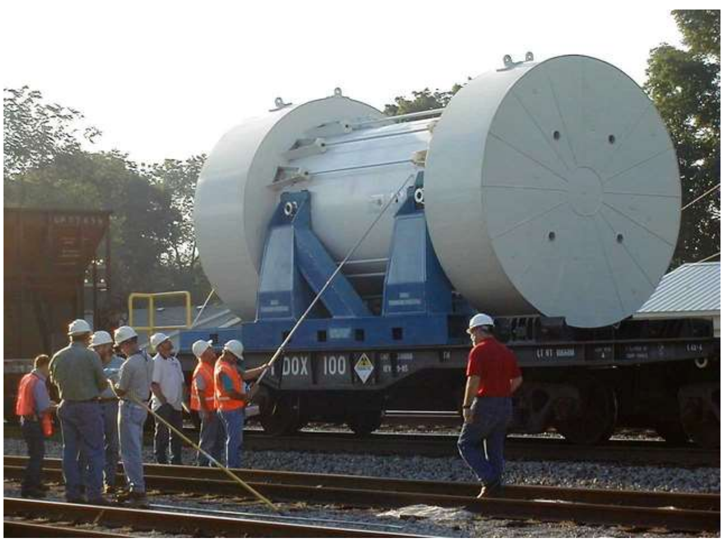

Figure 2: A railcar is used to transport a Type BF spent fuel package. Source: Idaho National Laboratory

Certification is a resource- and time-intensive process. Review timelines vary depending on the complexity of the package design and the quality of the application. Certification can take a year or more, and the testing data required to engineer a new package can take additional years to develop. In addition to NRC certification, the nuclear industry has also adopted the American Society of Mechanical Engineers' Nuclear Quality Assurance-1 (NQA-1) certification program. NQA-1 certification can legitimize a package's safety; however, the administrative expertise, components, and materials needed to achieve this certification are expensive, and can serve as a barrier to entry for a new company's package development.

Type AF and BF packages must also remain subcritical to be certified, meaning the material inside cannot maintain a self-sustaining fission chain reaction during transport. Higher enrichment increases the concentration of fissile material, which raises the probability of an unintended chain reaction. This requires package designs with stricter criticality controls than existing LEU-certified packages were designed to meet. As a result, there are a limited number of transportation packages certified by the NRC for nuclear material enriched between 5% and 20% (high-assay low enriched uranium or HALEU).[2] While these packages

[2] Certified HALEU transportation packages currently include Orano's Versa-Pac and NAC International's OPTIMUS-L packages. While these packages are not optimized for commercial-scale fuel transportation, they are currently being used in place of certifying new, higher capacity packages for the time being.

could be adapted to transport larger fuel quantities, they are not currently capable of supporting efficient or economical commercial-scale fuel transportation.

The DOE and industry have recognized this and are working to close the gap. In December 2025, DOE announced $11 million in awards to five companies to develop and license more transportation packages for fuel enriched up to 20%. Industry is also moving independently. NANO Nuclear and its partner Gesellschaft für Nuklear-Service mbH (GNS) are developing an optimized HALEU transportation package that initial evaluations have indicated can meet 10 CFR Part 71 certification requirements.[3] NANO Nuclear plans to formally engage with the NRC to pursue certification as the next step; however, because package certification can take years, efforts such as these will need to continue in parallel with reactor commercialization along similar timelines.

New Nuclear Reactor Fuel Transportation

Historically, fuel shipments have consisted primarily of low-enriched ceramic uranium fuel pellets, but many new reactor designs will use fuel at higher enrichments and in forms other than conventional LEU. For some of these advanced fuel forms, the criticality safety data needed for commercial-scale package certification is still being developed. Existing regulations must be revisited for this reason, and each fuel type will need to be evaluated on its own terms. These evaluations will affect whether new reactor fuel moves efficiently through the transportation system as more new reactors come online.

For example, molten salt and metallic fuels pose distinct handling and packaging considerations. Each has different chemical requirements and material interactions that existing package designs were not built to address. The NRC is conducting comprehensive research into both fuel types to ensure its framework is ready to certify their packages for transportation. By evaluating a fuel type's decay heat, gamma and neutron emission, and material performance while stored and during transport, the NRC can determine whether existing regulations are compatible with their technical requirements.[4] The Commission's early assessments suggest that existing regulations could be adapted, although specific technical challenges are still being evaluated.

Not all advanced fuel types will introduce additional complexity. Fuels like TRISO are designed with inherent safety features that could actually pose lower risks than conventional LEU during transport, even when spent.[5] Identifying which fuel types qualify for less strict packaging criteria will be an important part of developing efficient and effective transportation regulations. It will allow developers, licensees, and regulators to plan accordingly and avoid uncertainty that could slow commercialization timelines.

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[3] "Nano Nuclear Energy Advances Development of Optimized HALEU Transportation System with Global Nuclear Logistics Leader GNS." NANO Nuclear Energy, March 16, 2026.
[4] Reed, W., et al. *NRC Research Activities in Spent Fuel Storage and Management of Advanced Reactor Fuels for Advanced Reactors* U.S. Nuclear Regulatory Commission, United States of America.
[5] TRSIO or TRi-structural ISOtropic particles are made of a uranium, carbon and oxygen fuel kernel encapsuled by three layers of carbon- and ceramic-based materials that prevent the release of radioactive fission products. They can be fabricated into pellets called "pebbles" for use in either high-temperature gas or molten salt-cooled reactors. https://www.energy.gov/ne/articles/triso-particles-most-robust-nuclear-fuel-earth.

Each agency's regulatory framework is actively evolving, and reactor developers will need to track and engage with parallel rulemakings as they commercialize. The NRC is comprehensively revising its regulations under Executive Order 14300, with the final rule governing transportation expected by April 2027.[6] The DOT's Pipeline and Hazardous Materials Safety Administration recently finalized its HM-265 rulemaking, intended to improve the safety and efficiency of hazardous materials transportation by highway, rail, and vessel more broadly. Because the DOT's updates address the full scope of hazardous materials rather than new nuclear fuel specifically, they do not account for the unique characteristics of new reactor fuel types.

As the NRC moves toward finalizing nuclear-specific transportation requirements, DOT will need to ensure its carrier and route regulations remain compatible with those requirements. Maintaining coordination between the two agencies will reduce the risk of any inconsistencies between rules that could affect developers and carriers trying to simultaneously navigate both sets of requirements.

> **Recommendation:** The NRC should coordinate with DOT as it completes its advanced fuel evaluations, sharing its findings to ensure DOT's carrier and routing requirements account for the unique characteristics of each fuel type.

Mobile Microreactor Transportation

Mobile microreactors present new considerations for packaging certification and transportation licensing. Microreactor designs like Radiant Nuclear's Kaleidos and Westinghouse's eVinci are intended to be deployed, relocated, and redeployed as complete, pre-fueled units. Under 10 CFR 71, there is no dedicated framework for the transportation of these reactors. The criteria in Part 71 were established for shipping fissile material in dedicated packages, not transporting an entire reactor vessel containing its fuel load.

Microreactors can be considered a package under Part 71. This means they can be evaluated under the certification criteria for Type AF and BF material packages. Developers can choose between two paths depending on the reactor's size and fuel load. They can apply for exemption under 10 CFR 71.12, using a risk-informed methodology to demonstrate that a shipment meets necessary safety criteria without satisfying every package design requirement. They can also certify the reactor as a package under 10 CFR 71 by incorporating packaging criteria directly into the reactor's design. The exemption pathway could prove useful for initial deployments but is not designed for high-volume applications. The second pathway is more scalable and economical for large-scale manufacturing but poses complex and costly engineering constraints.

Project PELE, the initial military transportable microreactor program, helped inform early efforts to understand how existing regulatory pathways apply to mobile reactors. A 2024 Pacific Northwest National Laboratory study commissioned by the DoD assessed the most viable transportation pathway for a transportable nuclear power plant containing irradiated fuel. The study concluded that existing Part 71 requirements could not be fully met by a

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[6] The proposed rule, "Modernizing Package Certification Requirements", was published and opened for comment July 27, 2026. The comment period ended August 26, 2026. NIA's public comment can be found here.

transportable reactor package, and that the 10 CFR 71.12 exemption pathway was the most practical route for initial shipments.[7] It illustrated both the utility and the limitations of existing pathways, while also reinforcing the case for a more adaptable regulation.

Regulations governing mobile reactor transportation are actively evolving. In May 2026, the NRC proposed 10 CFR Part 57, a risk-informed, performance-based framework for the licensing of microreactors. The proposed rule would allow applicants to use a risk methodology for evaluating normal and accident transportation conditions where existing Part 71 requirements cannot be met, directly addressing the classification gap that may require developers to seek exemptions under the current framework. The Part 57 proposal was developed under the NRC's mandate from the ADVANCE Act of 2024. The Act directed the NRC to establish licensing strategies for microreactors, explicitly including the transportation of pre-fueled units. How quickly Part 57 is finalized and implemented will affect whether the regulatory framework is ready when mobile reactors are.

Transportation Logistics

Beyond regulation, moving new fuel types and mobile microreactors will also require operational assets like large- to super-load commercial carriers, permitted routes, qualified drivers, and specialized handling equipment. Building this infrastructure takes years and significant investment, and as more reactors are manufactured, demand for these services will grow. The DOE’s Motor Carrier Evaluation Program (MCEP) records and monitors a list of carriers that DOE/NNSA field offices and contractors can use to ship their radioactive materials and hazardous wastes; however, the number of entities currently qualified and equipped to transport these materials is limited. If that capacity does not develop alongside reactor commercialization, fuel cannot be transported regardless of whether regulatory and packaging questions have been resolved.

The Atlas railcar system illustrates how existing infrastructure could be adapted. Atlas was developed by DOE over ten years and cost approximately $33 million. It was designed to transport spent fuel shipments weighing up to 480,000 pounds at the highest safety standards. Its weight capacity and safety credentials are promising for adapting to mobile reactor configurations, but its purpose as a spent fuel-specific transportation vessel means it may require modification and recertification before it could serve that function.

Adapting existing infrastructure does not happen quickly, nor does qualifying a larger workforce or expanding the number of carriers to meet commercial-scale demand. Logistics infrastructure is part of the nuclear fuel transportation system and, like regulations and packaging, will need to develop on a timeline consistent with reactor commercialization.

> **Recommendation:** DOT and DOE should evaluate opportunities to encourage growth and innovation in transportation logistics. This should include working with industry to align carrier qualification, infrastructure, and workforce development with reactor commercialization timelines.

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[7] Coles G.A., et al. 2024. Development and Demonstration of a Risk Assessment Approach for Approval of a Transportation Package of a Transportable Nuclear Power Plant for Domestic Highway Shipment. Richland, WA: Pacific Northwest National Laboratory.

Conclusion

Transportation readiness is a condition for successful nuclear energy commercialization. Fuel transportation has historically been a well-managed part of the nuclear fuel cycle, supported by rigorous oversight and coordination across federal agencies, state and local governments, and private industry. That same coordination is essential as new reactor designs move from demonstration to commercialization.

The transportation system and the regulations governing it must evolve together, and no single entity can drive that evolution alone. DOE's HALEU packaging awards, NRC rulemaking, and the industry's integration of transportation planning into reactor design are meaningful steps toward meeting the demands of future new reactor deployment.

Adapting transportation and packaging regulations to meet the requirements of new reactor fuel types and designs takes time. NRC rulemaking under EO 14300, federal investment in developing HALEU packages, and industry engagement reflect a growing recognition of that reality. Sustaining that momentum will ultimately determine whether transportation effectively supports advanced reactor commercialization or constrains it.