

From Analog to Digital: Enabling the Next Generation of Nuclear Material Transport Packaging

The U.S. Department of Energy's National Nuclear Security Administration (DOE/NNSA) has worked cooperatively with global partners to advance proliferation-resistant fuel cycle technologies and nuclear material management since its inception, successfully removing or confirming the disposition of more than 7.3 metric tons of weapons-usable nuclear material from 49 countries and Taiwan. This experience working within existing regulatory frameworks, combined with deep expertise in advanced modeling and simulation used to maintain the safety, security, and reliability of the U.S. nuclear weapons stockpile for decades, provides unique insight into both current limitations and transformative opportunities in nuclear material packaging.

As the United States rapidly expands nuclear energy deployment, demand is surging for advanced fuels with higher fissile contents in quantities that dwarf previous requirements. Yet while the technologies and processes underpinning the nuclear renaissance have evolved dramatically, the lifecycle for nuclear material packaging remains stubbornly analog. The resulting global framework for testing, licensing, and validation of nuclear material packages has proven robust and safe, but comes at the cost of flexibility, speed, and sustainability.

Current practice for the design of new packages predominantly relies on physical testing protocols despite IAEA regulations (TS-R-1, paragraph 701(d)) and national frameworks (e.g 10 CFR 71.41(a)) permitting computational methods. This analog approach, combined with limited business volume, has created a fragile supply chain with high innovation risks and significant inefficiencies. Meanwhile, cutting-edge modeling and simulation capabilities—already proven in stockpile applications—can model atomic-level processes in three dimensions at nanosecond timescales with high fidelity, and advanced manufacturing techniques have proven their value in nuclear applications.

Drawing on lessons learned from decades of DOE/NNSA's nuclear material management and advanced simulation experience, this paper examines how a comprehensive digital framework could revolutionize nuclear material packaging by integrating computer-aided design, advanced simulation, and new manufacturing techniques. We propose specific opportunities for government to 1) catalyze innovation while maintaining safety standards and reducing regulatory burdens, and 2) demonstrate how this integrated approach can extend from design and testing through fabrication to deliver high-reliability packages efficiently and consistently. The result: alignment between government and industry to better meet growing nuclear packaging demands for decades to come.

Country or International Organization

Instructions

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