Engineering a future for TRISO waste

With a new generation of reactor technologies on the cusp of commercial deployment a new regulatory-ready, globally deployable canister solution is essential to keep pace.

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A new generation of nuclear reactors is gaining traction, driven not only by energy policy but also by powerful new end-users like tech giants Google, Microsoft, and Amazon. Google's agreement with Kairos Power in October 2024 kickstarted the trend, soon followed by Amazon, Microsoft, Meta, and others forming similar partnerships. But while reactor innovation is accelerating, one critical piece of the puzzle remains unsolved: how to manage and dispose of the new types of waste these reactors will generate.

Enter Project PUCK – a collaboration between Deep Isolation and Kairos Power. Funded by the US Department of Energy's Small Business Innovation Research (SBIR) programme, Project PUCK (Performance Validation of the Universal Canister System for Kairos Power) has delivered a first-of-its-kind solution for the safe storage, transport, and disposal of the TRISO (tri-structural isotropic) fuel used in high-temperature gas reactors. The timing is critical: in May President Trump signed four Executive Orders launching a national mission to accelerate deployment of advanced nuclear with an explicit focus on waste.

Tackling a new generation of waste

Deep Isolation's Universal Canister System (UCS) is engineered to safely store, transport, and dispose of advanced reactor waste in both traditional mined repositories and novel deep borehole configurations. The UCS was designed, prototyped, and tested with support from the US Department of Energy's Advanced Research Projects Agency–Energy (ARPA-E) through a multi-year project involving Deep Isolation, NAC International, UC Berkeley, and Lawrence Berkeley National Laboratory. That effort focused on identifying key waste streams from advanced reactors, including TRISO spent fuel, and creating a canister system capable of safely managing them through all stages of the back-end fuel cycle. It also established universal waste acceptance criteria and conducted extensive safety and performance modelling across repository types.

Building on that foundation, Deep Isolation launched Project PUCK to validate the technical and economic viability of the UCS for real-world advanced reactor waste management – specifically, TRISO spent fuel from Kairos Power's Fluoride Salt-Cooled High-Temperature Reactor (KP-FHR).

The Universal Canister System

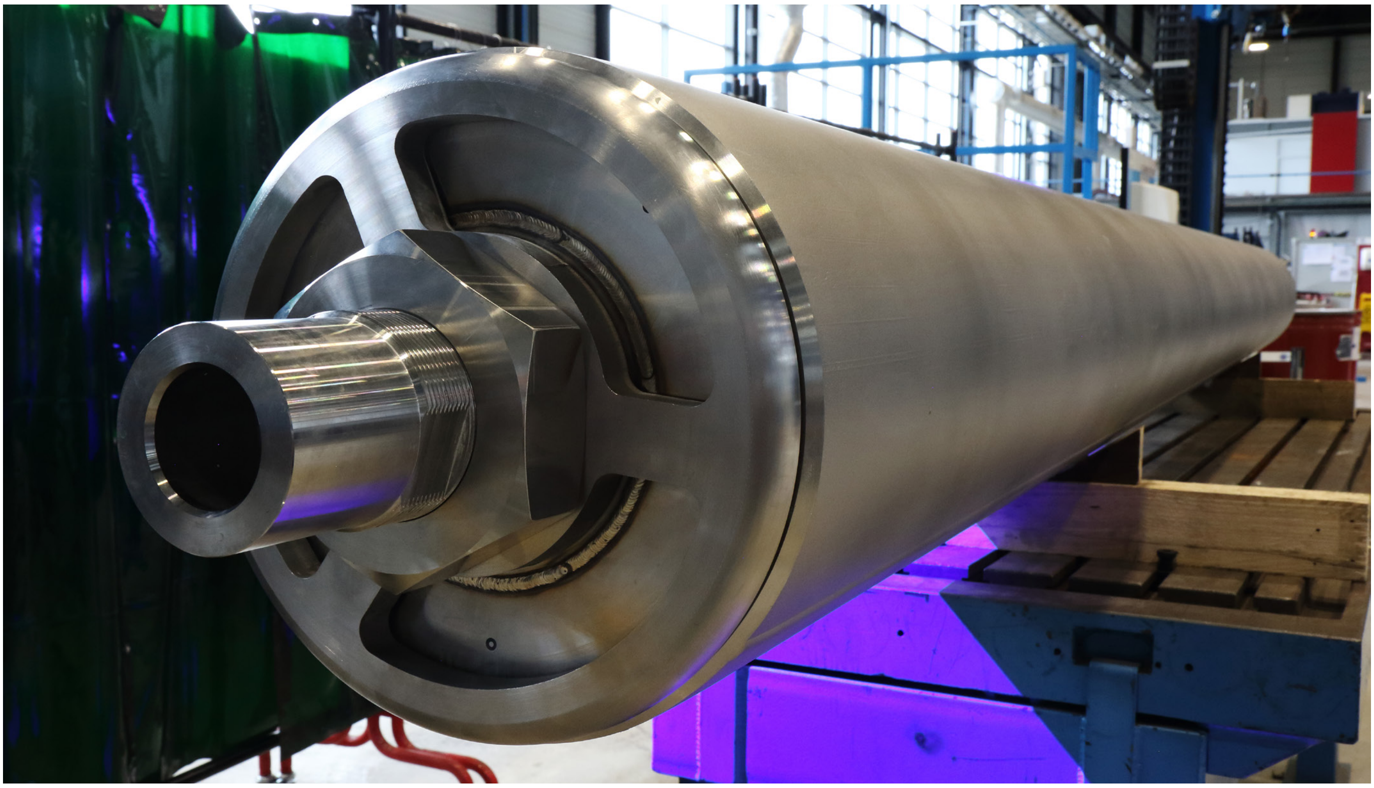
The UCS is a triple-purpose container that integrates storage, transportation, and geologic disposal into a single robust package. It accommodates a wide range of advanced reactor waste forms, including TRISO fuel in various configurations (pebbles, cylindrical compacts, and prismatic assemblies), lanthanide borosilicate (LaBS) glass with high waste-loading capacity, and intact halide salts from molten salt reactors.

Derived from Deep Isolation's intellectual property originally developed for the disposal of spent fuel from conventional pressurised water reactors (PWRs), the expanded UCS includes a family of canisters in varying sizes to accommodate a range of waste types and disposal depths – all enabling a unified approach across various reactor technologies, and all keeping costs down by re-using core standardised features. Three main canister classes have been developed, varying in diameter, wall thickness, and volumetric capacity, yet compatible with both deep borehole and mined repository disposal. Standard design features include a corrosion-resistant stainless-steel shell, closure lid system, and lift adapter assemblies compatible with oil and gas handling infrastructure. The UCS is designed to be interoperable with NAC International's MAGNASTOR® and MAGNATRAN® systems, enabling near-term deployment within established licensing frameworks.

Project PUCK included comprehensive assessments of the UCS's technical performance and cost implications when paired with TRISO spent fuel. Analyses evaluated structural, thermal, shielding, and criticality performance for a UCS loaded with TRISO fuel. Safety and performance assessment models were used to evaluate repository performance of TRISO in each UCS class across multiple configurations including mined repository in shale, horizontal borehole repository in shale, and vertical borehole repository in crystalline basement rock. The results confirmed that the UCS design meets the requirements for safe handling and long-term isolation of TRISO waste in both mined and borehole repositories.

A separate techno-economic analysis applied Deep Isolation's cost modeling framework to assess lifecycle disposal costs. Key insights included:

- TRISO waste's graphite matrix increases disposal volume compared to conventional PWR spent fuel. This increase potentially raises disposal costs by 37 100%.
- Volume reduction strategies – such as removing the graphite coating and consolidating TRISO pebbles into particulate form could reduce disposal costs by 18-23%, albeit with added complexity.
- Co-locating borehole repositories with reactors or waste-generating sites can cut total costs by up to 40% by minimising transport and infrastructure requirements.



Above: **Deep Isolation's prototype canister**

- Importantly, the assessments verified that UCS-loaded TRISO waste meets long-term safety criteria in deep geologic disposal environments.

Impact of the UCS

Project PUCK concluded with a validated demonstration that the UCS is both a technically sound and commercially promising solution for advanced reactor waste. The project showed that the UCS is fully compatible with the unique characteristics of TRISO, particularly its heat generation profile and radiological properties. Safety was demonstrated through rigorous analysis that modelled performance across multiple disposal environments, offering strong validation. Also important were the economic insights. The project confirmed that integrated planning of waste packaging, transportation, and disposal – enabled by the UCS – can yield meaningful cost savings. This includes clear cost benefits for co-locating waste repositories with generating facilities, and the potential to further optimise costs through strategic canister design refinements.

Another significant outcome is the UCS's compatibility with already licensed storage and transport systems. This interoperability positions UCS for immediate use, avoiding delays that typically arise with regulatory uncertainty or incompatibility.

As a next step, Deep Isolation and its partners are working to advance the UCS from technical validation to full-scale demonstration. Plans are underway for an end-to-end system demonstration, featuring emplacement and retrieval of multiple UCS canisters in a prototypic deep borehole environment, with full surface handling equipment and operations. This effort will be conducted in collaboration with the multi-national, non-profit Deep Borehole Demonstration Center and other strategic partners, with the goal of showcasing the full readiness of the disposal technology and building public and regulatory confidence. By simulating real-world operational conditions, this will bridge the gap between design validation and commercial deployment, further strengthening the case for the UCS as an integrated back-end solution for advanced reactors.

Taken together, these outcomes show the UCS can play a foundational role in supporting the safe commercialisation of next-generation reactors, while reinforcing public and regulatory confidence in nuclear energy as a credible and sustainable component of the future energy mix.

Toward scalable, integrated solutions

Although Project PUCK focused on TRISO fuel from a single vendor, the implications are much broader. The UCS is inherently designed with versatility in mind, making it well-suited to scale across a diverse set of advanced reactor designs. Moreover, early integration of disposal considerations into reactor planning offers tangible benefits. Aligning facility designs with waste handling, canister loading, transport, and disposal logistics from the outset enables more cost-effective, sustainable deployment of next-generation nuclear technologies.

By accommodating diverse waste forms and repository types, the UCS supports a portfolio-based strategy that adapts to regional geology, community preferences, and reactor deployment scenarios.

As the world races to deploy next-generation reactors, effective waste solutions are not optional – they are essential for licensing, public trust, and commercial viability. Project PUCK shows that disposal pathways for advanced fuels like TRISO are not only technically viable, but economically rational. By building waste readiness into the framework of reactor deployment, the UCS offers a scalable route to long term waste security.

This is more than an engineering breakthrough. With nuclear waste now recognised as a national strategic priority by the White House, the UCS is poised to anchor a new generation of disposal solutions to keep pace with the AI era and beyond. ■