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Draft Summary Report on Irradiated Fuel Handling and Management for LOTUS

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REVISION LOG

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CONTENTS

FIGURES

TABLES

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ACRONYMS

ARD	Advanced Reactor Development
BGS	Boston Government Services, LLC
D&D	Deactivation and Decommissioning
DOE	U. S. Department of Energy
HFEF	Hot Fuels Examination Facility
IFSSF	Irradiated Fuel Salt Storage Facility
ISC	Irradiated Salt Container
INL	Idaho National Laboratory
IPT	Integrated Project Team
LOTUS	Laboratory for Operation and Testing in the United States
LTC	Light Transfer Cask
MFC	Materials and Fuels Complex
MISC	Multi-Irradiated Salt Cannister
NRIC	National Reactor Innovation Center
OC	Outer Container
PIDAS	Perimeter Intrusion Detection and Assessment System
ZPPR	Zero Power Physics Reactor

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BACKGROUND

The National Reactor Innovation Center (NRIC) has conceptualized the design of the Laboratory for Operation and Testing in the United States (LOTUS) test bed to provide the United States Department of Energy (DOE) with the infrastructure necessary to make advanced reactor designs available for commercial developers. LOTUS will provide a test bed to developers with the capabilities of supporting a wide range of experiment design possibilities. Upon completion of the developers' operations and experiments within the test bed, the irradiated fuel, reactor components, and other experiment materials must be removed.

Idaho National Laboratory (INL) possesses significant capabilities for radioactive material handling such as casks, carts, and forklifts. However, given the unique environment presented by the NRIC-LOTUS test bed, located inside the Zero Power Physics Reactor (ZPPR) Perimeter Intrusion Detection and Assessment System (PIDAS) area at the Materials and Fuels Complex (MFC) and the complexity of novel removal activities of recently operated reactor experiments through the new proposed access tunnel. The efficacy was not apparent for existing equipment to provide all the needed capability.

To bridge the potential gaps in cask designs, storage, and transportation, NRIC requested the development of trade studies for the transfer, handling, and storage requirements of irradiated fuel salts and other radioactive materials. NRIC directed Boston Government Services, LLC (BGS) to perform the trade studies and develop a report analyzing alternatives. In addition to the BGS reports, the Idaho National Lab's (INL), provided by the first potential user's Advanced Reactor Development (ARD) team, prepared a feasibility study for the storage of specific irradiated fuel within the existing ZPPR vault.

PURPOSE

This summary report is intended to present the trade studies, options, and alternatives that were investigated. The maturity level of LOTUS, the reactor, fuel salt containers, gloveboxes, and reactor testing campaign and concept of operations were not at a level sufficient to base critical decisions on. This report is not intended to present a final recommendation. The final recommendations for fuel storage location, transport, handling equipment, and operations will be made in FY 2024 and will be based on known materials, test campaign requirements, funding, and final analysis of the fuel and equipment to be used.

DISCUSSION

BGS provided the report, Irradiated Fuel Salt Storage Facility (IFSSF), Requirements Collection, and Trade Study [Ref. (a)], which considered the alternatives of constructing the following: 1) an indoor IFSSF with an open vault area as seen in Figure 1 and Figure 2, 2), an indoor IFSSF with an multi-canister containing cask storage vault as seen in Figure 3, or 3), and a IFSSF outdoor overpack storage area with multi-cannister containing casks as seen in Figure 4.

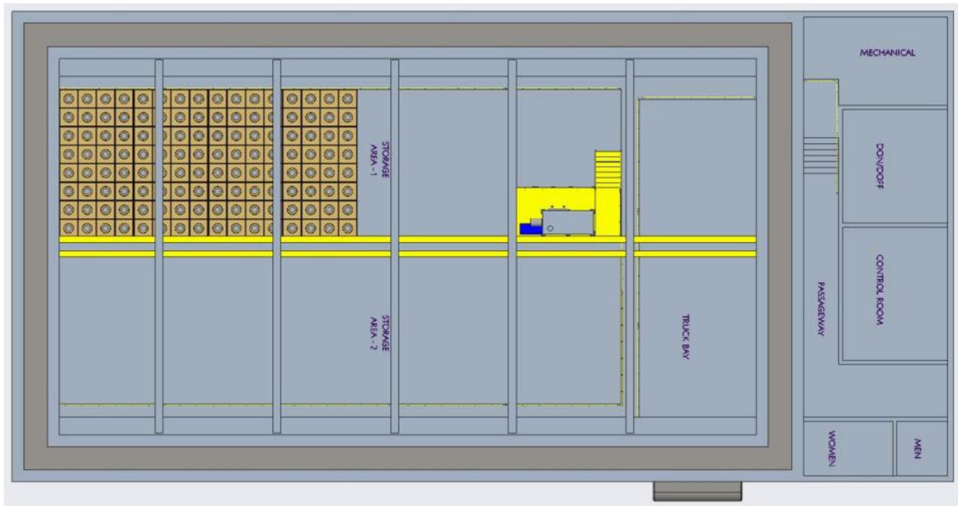

Figure 1. Plan view indoor IFSSF with an open vault concept.

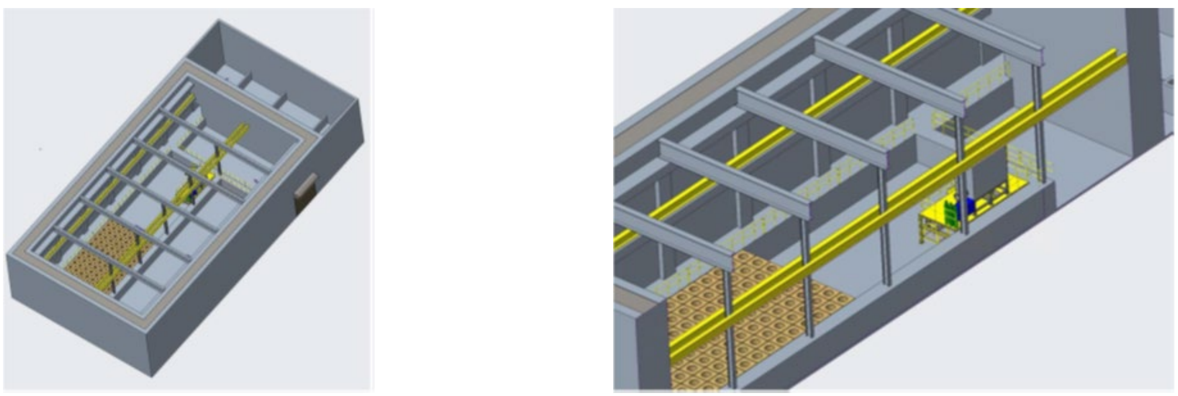

Figure 2. Isometric views, indoor IFSSF with an open vault concept.

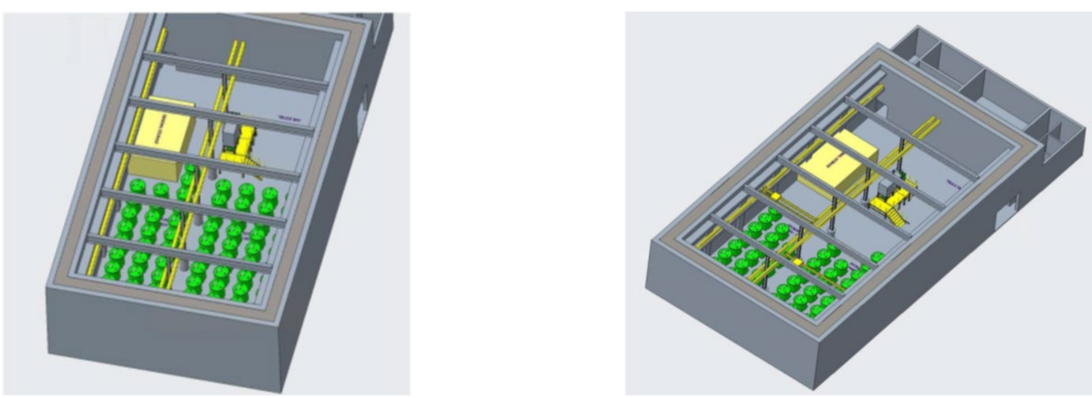

Figure 3. Isometric views, indoor IFSSF with multi-cannister cask concept.

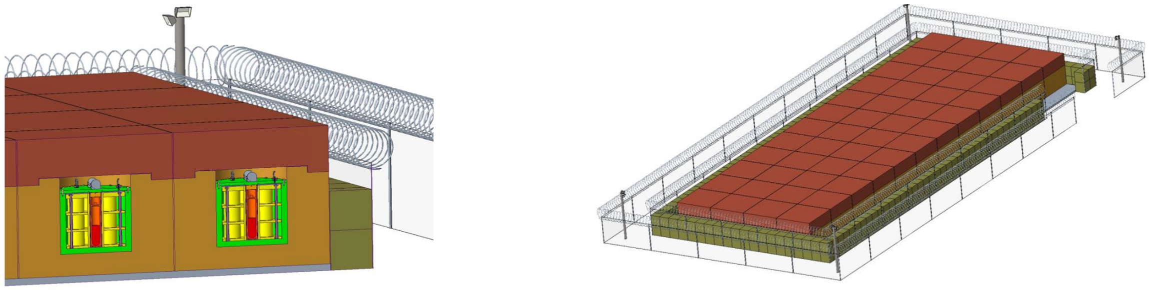

Figure 4. Isometric views, outdoor IFSSF with multi-cannister cask overpack concept.

The report suggests that the IFSSF Indoor alternatives should be further investigation. The IFSSF indoor open vault takes advantage of existing INL transporters and casks, but primarily provides an alternative that was designed to take advantage of the irradiated salt container (ISC) and considers the low-burnup constraints of the initial reactor demonstration. The outdoor overpack with multi-canister cask is not recommended as an alternative because of operational complexities, limited storage, high costs, and security concerns.

The second BGS report, Removal of Irradiated Fuel and Other Radioactive Materials Evaluations and Trade Study for NRIC-LOTUS Test Bed [Ref. (b)], provides details for the efforts to ensure that, after each reactor demonstration, deactivation and decommissioning (D&D) of the reactors can be accomplished within the NRIC-LOTUS test bed envelope (special limits) and LOTUS operations, security, and safety requirements. Further, it is anticipated that the approaches for defueling, storage, and transportation methods reviewed by BGS are applicable to other liquid-fueled molten salt reactors.

Preparations for irradiated fuel removal will begin with loading the ISC, as performed by the reactor developer, from the fuel transfer glove box and placing it into the desired cask for transfer to the storage facility. The three cask designs investigated by BGS are based on a preliminary ISC design by the initial reactor developer:

1) The Hot Fuels Examination Facility (HFEF)-5 Cask—bottom loaded—is the baseline option as originally conceived by the NRIC-LOTUS test bed Integrated Project Team (IPT). This transfer cask will relocate an ISC that has been placed inside an outer container (OC) to an indoor open vault IFSSF. The OC, which comprises the storage unit, is transferred from the fuel transfer glovebox to the HFEF-5 Cask in a transfer pig that remains inside the NRIC-LOTUS test bed containment.

2) The bottom loaded, light transfer cask (LTC) is a new design and is an alternative to the HFEF-5 Cask for transferring an ISC that has been placed inside an OC to an indoor open vault IFSSF. Since the OC is the same as that for the HFEF-5 Cask, no transfer pig is required. The loaded LTC is light enough to be lifted by the NRIC-LOTUS test bed polar crane and short enough that it can be docked below the fuel transfer glovebox for direct loading. The size and weight of the loaded LTC are such that five LTCs can be assembled on a locking pallet system and removed by a forklift one at time as can be seen in *Figure 5*.

3) The Multi-Irradiated Salt Cannister (MISC) transfer and storage cask is a new design, a smaller version, and top loaded of the dry storage casks concepts used for commercial light-water reactor spent fuel storage. It serves for both transfer operations and long-term storage of the ISCs. In place of a vault, the MISC is stored in a secure building on a slab at grade or in a concrete and steel overpack that provides impact and theft resistance

comparable to a secure building. The primary advantage of the MISC is the ability to remove seven ISCs from NRIC-LOTUS test bed cell in a single transfer. The loaded weight must remain under the 20-ton capability of proposed forklifts. The MISC can be seen against the LTC in Figure 6.

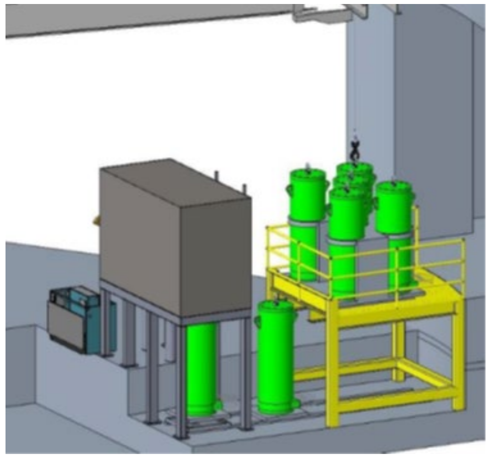

Figure 5. Lightweight transfer cask (LTC) bundled for transport.

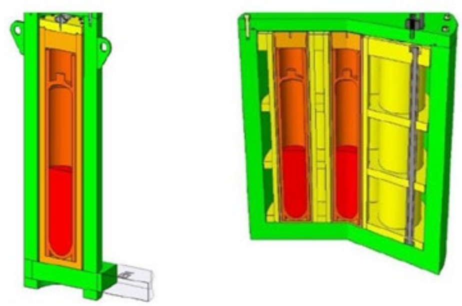

Figure 6. Lightweight storage cask (left) against multi-cannister storage cask (right).

All three operational approaches evaluated are considered feasible, including the HFEF-5, for fuel removal and transfer to the IFSSF. Based on the ultimate IFSSF design selected, the LTC design would be more compatible with a vault design whereas the MISC would be the choice for a newly designed IFSSF to take advantage of its transfer and storage capabilities.

Material handling alternatives were considered for the fuel salts, flush salts, large (> five tons) reactor components, and other smaller components or materials. The alternatives analysis included forklift, gantry crane, wheeled cart on rails (pulled or pushed by a tug vehicle), self-powered wheeled cart on rails, self-powered cart with tires and no rails, air pallet systems, and hydraulic skidding system.

Low Profile, 20-ton Forklift

The use of forklifts were evaluated for staging, transferring items in and out of the test bed, and for loading items into transfer packages or containers. The use of forklifts may be the simplest transfer alternative, but it is not the safest option due to the potential for driver error or equipment failure scenarios. Further challenges include the size constraints of the NRIC-LOTUS test bed tunnel and cell area once the reactor has been installed. Prior planning for an acceptable loading and unloading area must be conducted using the overhead 5-ton polar crane for packaging of equipment within the NRIC-LOTUS test bed cell. The forklift provides advantages such as easily operated, compatibility with several existing packages, and equipment that have been designed to be used with forklifts.

Railed Gantry Crane

The gantry crane option requires rails embedded in the floor of the tunnel leading into the cell of the NRIC-LOTUS test bed. These embedded rails should be designed such that other material handling equipment may use the tunnel as needed. The rails would be placed at the maximum width possible and be extended into the test bed allowing transfer of items from inside the NRIC-LOTUS test bed yard into the cell. Lifting containers would be conducted from overhead. Irregular items with unevenly distributed loads would require lifting at both ends or at all four corners to keep loads steady. And for flexibility and simplicity, a second separate gantry crane that could operate synchronously is envisioned. The use of two gantry cranes adds complexity and cost. However, since the gantry crane(s) can lower containers all the way to the NRIC-LOTUS test bed floor, a second crane would allow for more flexibility in container and material heights that can be loaded. It is assumed that the gantry crane(s) could handle significantly heavier loads than the existing polar crane.

Wheeled Cart on Rails

The wheeled carts on rails can be self-propelled or pushed/towed by a vehicle. The system would use embedded rails like the gantry crane. The rails can extend over the test bed floor and be lowered using a jack system, which would significantly enhance the headroom for loading larger objects. Assuming containers are filled loaded from above, the cart design should provide the lowest profile possible for the intended loads. The head room restrictions for this option are similar to those presented by the forklift option. There are minimal differences between a self-propelled cart and a cart pushed by a vehicle.

Wheeled Cart on Tires

There are similar advantages and disadvantages to the wheeled cart with tires and wheeled cart on rails (self-powered or pushed/pulled by a vehicle). One additional benefit is that, like a forklift, it can be used to move other items to other MFC locations outside of the tunnel. Within the tunnel itself, the wheeled cart with tires has an additional disadvantage of being more accident prone, again much like the forklift.

Air Pallet Systems

Air pallet systems use low friction surfaces to transfer very heavy loads. To operate, they require very flat, smooth surfaces, and a source of compressed air to fill pressurized air bags with holes that provide the air cushion that "floats" the load. Any gaps in the tunnel floor (e.g., at doorways) would have to be temporarily covered and sealed to allow operation of an air pallet system. Again, a platform at the end of the tunnel inside the test bed would be required to transfer items into the cell. A self-propelled, compact battery-operated vehicle can push or pull the pallet providing the necessary force to move loads. Capital and operating cost for the air pallet system could be higher than the alternatives discussed previously. The air pallet system shares similar advantages and disadvantages as the wheeled-cart alternatives.

Hydraulic Skidding System

The hydraulic skidding system, like the wheeled-cart on-rails alternative, is composed of a series of skid beams moved by hydraulic push-pull cylinders traveling over a pre-constructed track. The skid tracks would be extended into the test bed on a platform to allow transfer of items into the cell. High-pressure hydraulic fluid is used to push or pull the load. This requires a hydraulic system where hoses are attached and must move with the load like the air pallet air hose. One disadvantage is that unless there is a source of high-pressure hydraulic fluid in each chamber it is not possible to open or close the tunnel doors during transit.

The preferred alternative for transport system for each type of material can be seen in Table 1.

Table 1. Material transfer preferred alternative methods.

	Materials for Removal				
Material handling Alternative	**HFEF-5 Cask Or Single LTC**	**Multi-Canister Cask Or Multiple LTC in a Rack**	**Highly Radioactive Components**	**Large/Heavy components exceeding 5 tons**	**Small/Lighter components not exceeding 5 tons**
Low-Profile Forklift	✔	✔	✔	✘	✔
Railed Hydraulic Lift Gantry System	✔	✔	✔	✔	✔
Wheeled Cart on Rails (Pushed, Pulled, Self-propelled)	✘	✔	✔	✔	✔
Wheeled Cart without rails (Self-Propelled)	✘	✔	✔	✔	✔
Air Pallet	✘	✔	✔	✔	✔
Hydraulic Skidding System	✘	✔	✔	✔	✔
✔ This is a viable material-handling alternative for this material type ✘ This is not a viable material-handling alternative for this material type					

The first potential user's ARD project team provided an investigation of the feasibility for storing the irradiated specific fuel salt, which will remain under the Department of Energy's ownership following reactor experimentation and must be managed and stored in a compliant manner, within existing INL facilities until the Department of Energy determines there is no future programmatic or research need for the material. This investigation concentrated primarily on the existing vault within the ZPPR facility and the specific fuel salt that is currently the only planned experiment within NRIC-LOTUS test bed.

The first potential user's ARD project team proposes that the irradiated fuel salt be stored in a configuration that facilitates easy retrieval for programmatic reuse at INL facilities, future uranium recovery activities, or eventual direct disposition in a future deep geologic repository, without the need for repackaging. Long-term management of the irradiated fuel salt will depend on the future application of this material and will be managed in a fashion comparable to similar materials being stored at INL.

It has been determined by the first potential user's ARD project team that storage of the irradiated fuel salt in the ZPPR vault is technically feasible under a preliminary design level of understanding and assumptions. Before all hazards and impacts involved can be understood, further design consideration is required. Among the more significant benefits of using the ZPPR vault are (1) utilizing an existing vault that meets all necessary security requirements for storing specific fuel quantities; (2) proximity to the NRIC-LOTUS test bed, with an internal transfer path to the facility; and (3) a possible elimination of the need to down-blend the irradiated fuel.

A conceptual design plan view of how to store the irradiated salt containers is also provided below in *Figure 7*.

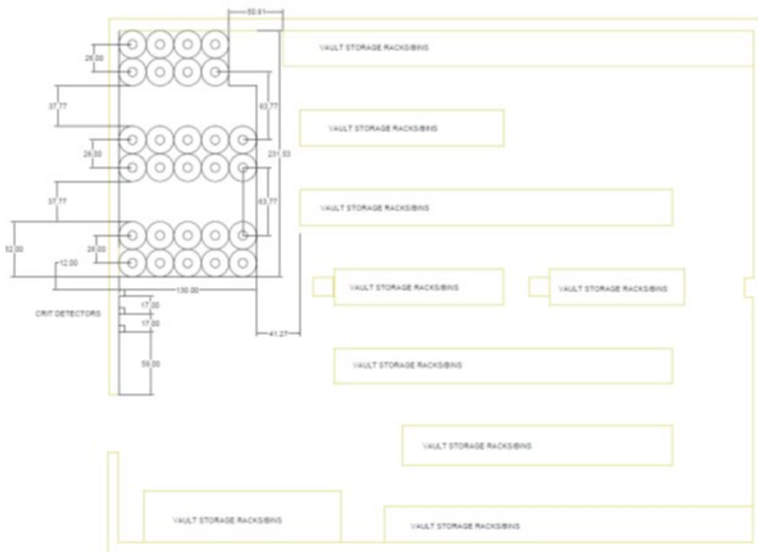

Figure 7. ZPPR vault plan view.

Rough order of magnitude (ROM) cost analysis of the alternatives were provided by BGS and the first potential user's ARD project team show that the costs associated with the IFSSF vary from $14.6 million being the relative cost associated for repurposing of the existing ZPPR vault, $53.8 million for the use of a new facility with an indoor open vault concept, $60.8 million for a new indoor facility using the MISC storage system, and $24.7 million for outdoor storage area with multi cannister overpacks. These cost estimates, conducted in 2021 United States dollars, do not include the cost of ISCs, Battelle Energy Alliance personnel costs, or management reserves. These third-party engineering estimates also do not account for changing economic conditions and INL processes and procedures. Recent similar sized projects at INL, like the Sample Preparation Lab project, cost in the $150 - $200 million range.

NEXT STEPS

The NRIC-LOTUS test bed IPT will continue to update the trade study analysis periodically to include changes and impacts from the maturation of the reactor design, testing campaign, and potential chemical and thermophysical analyses of the HEU salts envisioned for use. A significant change in a critical parameter may invalidate one or more of the investigated solutions or suggest a new option not viable previously. Additional options may be uncovered and reviewed against the current set to determine their overall acceptability. The draft summary report expected in FY2024 will review, analyze, and make recommendations for each of the covered areas of the report. The NRIC-LOTUS test bed IPT in collaboration with their developer partners will work together to propose an appropriate solution in the future.

REFERENCES

(a) Boston Government Services, LLC. 2022. "Irradiated Fuel Salt Storage Facility Requirements Collection and Trade Study." INL/RPT-23-74090, Idaho National Laboratory.

(b) Boston Government Services, LLC. 2022. "Removal of Irradiated Fuel and Other Radioactive Materials: Options and Trade Studies for LOTUS Test Bed." INL/RPT-23-74088, Idaho National Laboratory.

APPENDIX A IRRADIATED FUEL SALT STORAGE FACILITY REQUIREMENTS COLLECTION AND TRADE STUDY

APPENDIX B REMOVAL OF IRRADIATED FUEL AND OTHER RADIOACTIVE MATERIALS: OPTIONS AND TRADE STUDIES FOR LOTUS TEST BED