INL/RPT-23-74566
Revision 0

# Identification and Evaluation for Fueling of NRIC DOME Reactors Report

September 2022

*M3RC-23IN0203027 - Identification and Evaluation for Fueling of NRIC DOME Reactors Report*

Todd Sherman - Nuclear Facility Engineer
*Author*

Aaron Balsmeier - NRIC Chief Engineer
*Approver*

Chance Price - Technical Program Manager
*Project Manager*

Philip Schoonover - NRIC Senior Program Manager
*Sponsor*

*INL is a U.S. Department of Energy National Laboratory operated by Battelle Energy Alliance, LLC.*

# DISCLAIMER

# REVISION LOG

| Revision No. | Date | Affected Pages | Description |
|---|---|---|---|
| 0 | 09/15/2023 | All | Initial Issuance |
| | | | |
| | | | |
| | | | |

*Page intentionally left blank*

# ABSTRACT, SUMMARY, AND FOREWORD

The National Reactor Innovation Center (NRIC) has designed a testbed for advanced microreactor experiments that enables and encourages technology developers to bring advanced designs closer to commercial availability. The test bed, Demonstration of Microreactor Experiments (DOME), will be used to facilitate much of the operation experimentation process of each advanced microreactor including fueling and operational power experiments. This report identifies and evaluates the options for initial fueling of the microreactors in DOME. This report also discusses the optional locations that were considered for the initial fueling of microreactors; namely the Transient Reactor Test (TREAT) reactor building and an unspecified temporary location. But various logistical and construction issues essentially eliminated these other options from further consideration. A brief discussion in this report outlines potential equipment and protocol associated with fueling in DOME.

*Page intentionally left blank*

# CONTENTS



# FIGURES

*Page intentionally left blank*

# ACRONYMS

| | |
|---|---|
| DOME | Demonstration of Microreactor Experiments |
| INL | Idaho National Laboratory |
| NRIC | National Reactor Innovation Center |
| TREAT | Transient Reactor Test |
| TRISO | tristructural isotropic |

*Page intentionally left blank*

# NRIC DOME

## 1. DESCRIPTION

The evaluation of the initial fueling process of the demonstration reactors in the Demonstration of Microreactor Experiments (DOME) facility includes an initial set of functional requirements, graphical views of major equipment items, and narrative descriptions of the fueling operations. A preconceptual fueling design report provides an analysis of alternatives for locations and methods to support the installation of new, unirradiated fuel into demonstration reactors. This report evaluates the preconceptual design for initial fueling of a demonstration reactor in DOME.

## 2. BACKGROUND

In addition to providing the structures needed to house the demonstration reactors, the National Reactor Innovation Center (NRIC) will also support the initial fueling of the demonstration reactors, as these reactors will be transported to Idaho National Laboratory (INL) unfueled.

Based on initial vendor interactions, the reactor modules planned for DOME should fit inside a standard high-cube cargo container, with interior dimensions of 15 feet (4.6 m) wide, 29 feet (8.8 m) long, and 13 feet (4 m) high inside. The reactors currently planning to test in DOME will either be a high-temperature gas reactor or cooled by fully sealed sodium-heat pipes. These reactors are anticipated to use tristructural isotropic (TRISO) fuel with high-assay low-enriched uranium. TRISO fuel particles are generally formed into cylindrical compacts arranged within larger prismatic graphite blocks to make up the fuel loading. A general image of a prismatic block fuel system is shown in Figure 1.

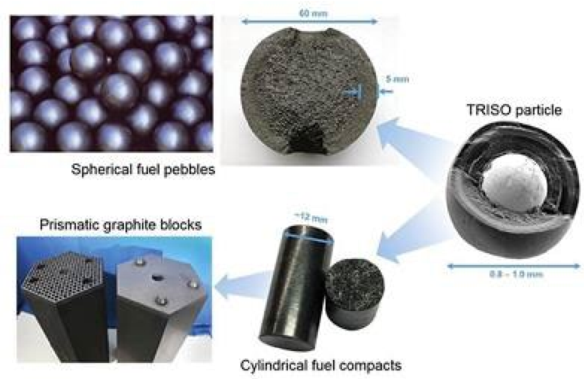


Figure 1: Generic TRISO prismatic block fuel system.

Individual fuel shipments will arrive in separate shipping containers from the reactor module. Fuel could feasibly arrive to INL as individual cylindrical compacts that would require further assembly into prismatic graphite blocks or as preassembled fuel modules, depending on the allowable shipping configurations. In any case, INL will be required to provide the facilities and some equipment to support the initial fueling and reactor assembly of demonstration reactors.

## 3. FUELING DESIGN

A fueling facility is needed for the initial fueling of DOME demonstration reactors. This facility requires the ingress and egress of reactor modules, new fuel modules, and other demonstrator equipment. The DOME preconceptual fueling report considered the following options for the fueling facility: the DOME containment, the Transient Reactor Test (TREAT) reactor building, and an unspecified temporary location.

Independent of which fueling facility is selected, two primary work areas are required to support initial fueling operations: a new fuel preparation area and a reactor fueling work area. The new fuel preparation area provides space to receive new fuel shipping containers, perform receipt inspections on the new fuel modules, and store the new fuel modules in lockers until they are ready to be loaded into the reactor vessel. The reactor fueling work area provides work platforms to allow worker access at various elevations around the container and provides a cleanliness barrier to prevent foreign materials from entering the reactor during assembly. Fueling activities require the use of specific tools, such as tensioners, fuel lifting attachments, and welding equipment. These specific tools are expected to be provided by the demonstrators, while the facility is expected to provide a crane for use in fueling operations.

## 3.1 Fueling Operations in DOME Containment

See Figure 2 for a depiction of the fuel preparation and reactor fueling work areas if the DOME containment is used as the fueling facility.

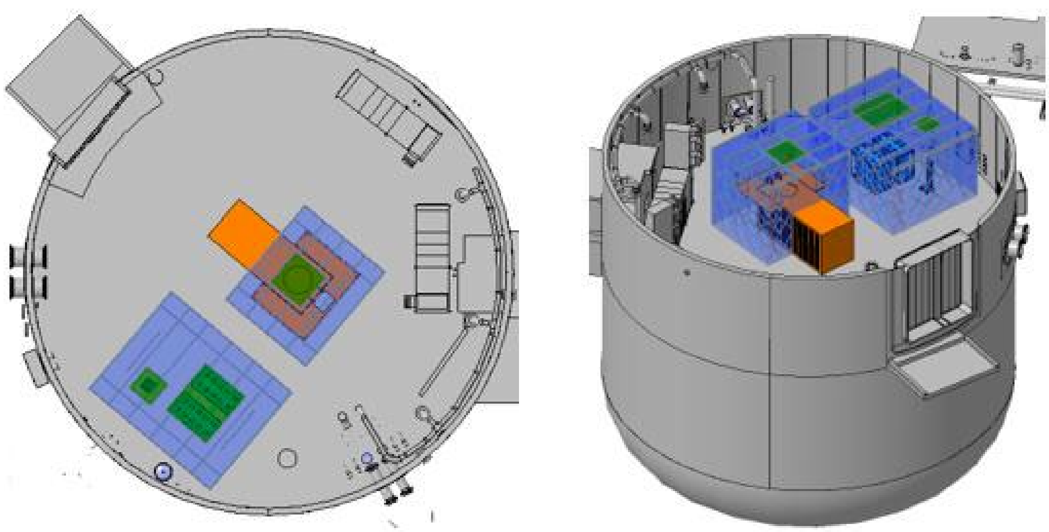

Figure 2: Fuel preparation and reactor fueling areas for fueling in the DOME containment.

Advantages and disadvantages of performing initial fueling operations in the DOME facility are:

### 3.1.1 Advantages

- Demonstration reactors will not need to be transferred to another location after the initial fueling operation is complete.
- The DOME containment is a nuclear work facility that offers confinement and containment capabilities in the event of an accident.
- Unplanned work stoppages will not affect other INL facility operations.

### 3.1.2 Disadvantages

- The size of the initial fueling work envelope will limit the number of other operations that can occur in parallel such as setting up auxiliary systems.
- The DOME containment does not currently have a functional crane, so reactor assembly operations would either require the polar crane to be returned to service or a new crane purchased or rented.

## 3.2 Fueling Operations in the TREAT Reactor Building

The TREAT reactor building south high bay area is serviced by an existing 60-ton bridge crane with maximum hook height of 61 feet. This bridge crane also has a 10-ton auxiliary hoist, with a hook height of 64 feet.

Advantages and disadvantages of performing initial fueling operations in the TREAT facility are:

### 3.2.1 Advantages

- It allows for parallel facility preparations to occur in DOME containment.
- The existing operational bridge crane can support fuel installation and reactor assembly.
- The large process floor has room to establish initial fueling work areas.

### 3.2.2 Disadvantages

- There is an increased risk to TREAT mission deliverables due to unplanned work stoppages or accidents with potential for radiological release.
- There is a schedule risk requiring close coordination with TREAT and Microreactor Applications Research Validation and Evaluation (MARVEL) operations taking place in the TREAT reactor building.
- The TREAT facility safety report needs to be revised to account for additional fuel handling operations.
- Additional analyses are required to evaluate hypothetical accident conditions for transporting fueled demonstration reactors on the INL site.
- There is an increased risk of damage to reactor systems prior to reactor operations (e.g., unintended damage during movement that could either cause a safety issue or preclude testing from being performed).

## 3.3 Fueling Operations at a Temporary Location

Initial fueling operations can be performed at an unspecified temporary location in the vicinity of the Materials and Fuels Complex. This option requires the procurement of a mobile fuel handling crane and pouring a large concrete pad to support the reactor Conex containers and mobile fuel handling crane. A temporary structure (e.g., prefabricated steel building or Herculite tent) would be established around the concrete pad to provide weather protection for initial fueling operations.

Advantages and disadvantages of performing DOME initial fueling operations at a temporary location are:

### 3.3.1 Advantages

- It allows for parallel facility preparations to occur in the DOME containment.
- It is designed to mitigate the space constraints in the DOME containment.

### 3.3.2 Disadvantages

- There are additional acquisition costs for a concrete pad, mobile crane, and temporary tent.
- A temporary tent is a less robust structure for fuel security.
- A concrete pad and temporary tent may still drive the need for an environmental impact statement.
- Additional analyses are required to evaluate hypothetical accident conditions for transporting fueled demonstration reactors on the INL site.
- There is an increased risk of damage to reactor systems prior to reactor operations (e.g., unintended damage during movement that could either cause a safety issue or preclude testing from being performed).

## 3.4 Recommendation for Initial Fueling Location

Considering the advantages and disadvantages of each initial fueling facility option, the DOME containment is the preferred location for initial fueling operations. One of the main benefits of performing initial fueling operations in DOME is that it cuts down on the number of shipments of fueled demonstration reactors on the INL site. Moreover, the transportation of fueled reactors on the INL site remains an open analytical challenge. Some reactor vendors that expressed interest in testing in the DOME facility do not intend to produce mobile reactors. Requiring such vendors to incorporate transportation features into their designs may make testing in DOME a less desirable option. While performing initial fueling operations in DOME will occupy a significant amount of facility space and could impede parallel operations, all of these impedances will be under the direct purview of the NRIC program. This is a direct benefit over TREAT, where there would be competing priorities among a variety of independent programs.

## 3.5 Fuel Handling Crane

A crane may be required to support initial fueling operations, installing individual fuel modules, and installing other heavy equipment such as the reactor closure heads. When an overhead crane is being used to lift heavy components over fuel, any drop accidents could potentially cause a release of radioactivity. The Nuclear Regulatory Commission has licensed commercial reactors on the basis that the safe handling of critical loads can be accomplished by adding safety features to the crane itself, by adding safety features to the structures over which critical loads are lifted, or by implementing a combination of the two strategies. When the safe handling of fuel or reactor heavy equipment is based on the crane itself, special design requirements are typically imposed to ensure that a single failure will not result in a loss of the capability to retain the load. Various fuel handling operations could be performed with a smaller mobile crane if single failure-proof features can be provided.

## 3.6 Major Fueling Equipment

The preconceptual fueling report identifies various pieces of generic equipment that are expected to be needed to complete fueling operations for the various reactor deigns and configurations:

- Reactor fueling work platforms (see Figure 3)
- Fuel shipping containers
- New fuel inspection stand (see Figure 4)
- Fuel storage lockers (see Figure 5).

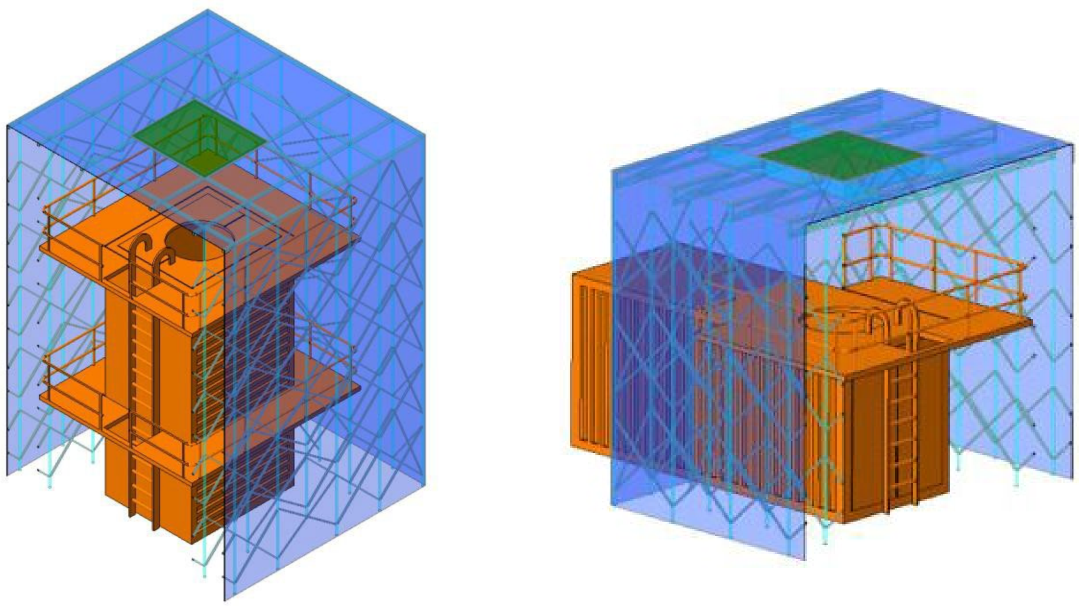

Figure 3: Reactor fueling platforms with cleanliness tent for foreign material exclusion.

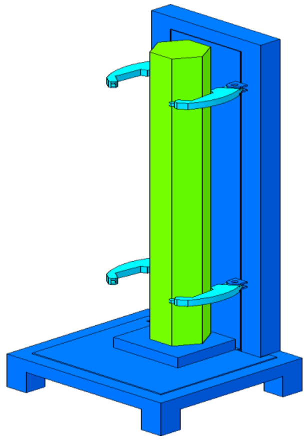

Figure 4: Conceptual image of the new fuel inspection stand.

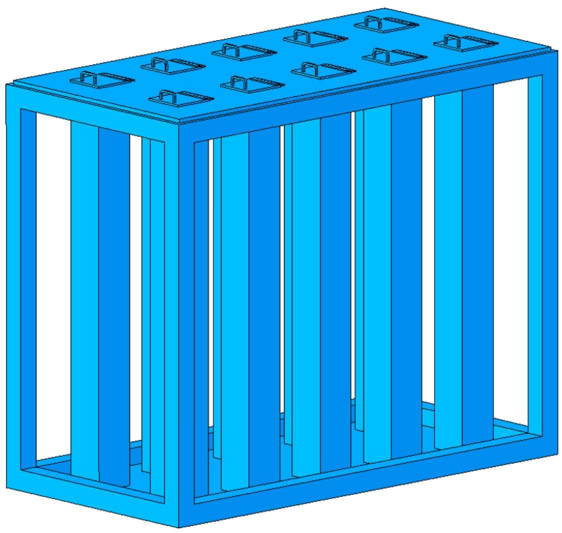

Figure 5: Fuel storage lockers.

## 3.7 On-Site Fuel Assembly

One of the planned DOME reactor demonstrators indicated a desire to ship small quantities of fuel compacts to INL as it would preclude the need to design and certify a new shipping container for a preassembled fuel module. The new fuel inspection stand could also be utilized to support prismatic graphite blocks while fuel compacts are being installed.

## 3.8 Fueling and Reactor Assembly Operations

New fuel or fuel modules are expected to be installed in the reactor using preapproved and safety-analyzed methods and procedures. An example of fuel loading protocol could look like the following scenario.

Initial fuel loading would begin with locating the first fuel module in the fuel storage lockers, opening the hinged port cover, and rigging to and lifting the fuel module out of the locker. The fuel module would then be transferred out of the new fuel preparation area tent and into the reactor fueling work area tent using the fuel handling crane.

The fuel module is then inserted into the correct position in the reactor vessel until it is fully seated. During the insertion operation, either the fuel handling crane is set to micro-speed or a chain fall hoist should be used to allow for slow and controlled movements. Rigging personnel should monitor a load-indicating device during fuel installation to identify and correct any load reductions due to hang-ups.

These operations are repeated for each fuel module in the core load. Depending on the reactor design, additional steps may be required, such as making any mechanical connections between the fuel modules and any reactor structural components or installing any additional above-core components (e.g., reflectors).

After all new fuel is loaded into the reactor vessel, the next step in reactor assembly is installing the closure head. It is envisioned that the closure head would be stored in the equipment laydown area, and the closure head would be lifted into the reactor fueling cleanliness tent in a way similar to the new fuel modules. Depending on the weight of the closure head, a specially designed lift rig or spreader may be required to perform the lift. After the closure head has landed, feeler gauge checks may be performed to ensure that it is fully seated and that the closure head can be tensioned. If a welded seal is used, seal welds could be performed manually or with a specially designed circumferential welding machine.

# 4. CONCLUSION

Considering the advantages and disadvantages of each initial fueling facility option, the DOME containment is the preferred location for initial fueling operations. Performing initial fueling operations in the DOME facility would likely require a small mobile crane that would provide the most flexibility for floor coverage, lift capacity, and could be removed after fueling operations. The fuel transported to INL could be in the form of typical fuel elements or as individual fuel compacts as determined by each reactor developer. Reactor developers are expected to provide reactor-specific tools, such as tensioners, welding equipment, and any specialized lifting and handling equipment beyond standard rigging practice (e.g., fuel lifting attachments).