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Test and Chemistry Plan for MEDE Treatment of Fermi-1 Blanket Materials

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July 2019

Idaho National Laboratory

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SUMMARY

There exists approximately 34 metric tons of Fermi-1 nuclear power reactor blanket assemblies at the Idaho National Laboratory (INL). Contained in this material is about 365 kg of sodium metal. In 2000, the *Final Environmental Impact Statement (EIS) for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel* (DOE/EIS—0306) was issued. In the EIS, the No Action Alternative was preferred for the Fermi-1 blanket material. Under the No Action Alternative, two options were analyzed:

- Continued storage until 2035 or until development of a new or currently less mature technology to treat all or part of the sodium-bonded material.
- Direct disposal of the sodium-bonded material in high-integrity cans.

This project will determine if the Melt-Drain-Evaporate (MEDE) process, developed by Argonne National Laboratory (ANL), can be used to treat all or part of the sodium-bonded material. This MEDE process will treat full-length unirradiated Fermi-1 blanket material to remove the sodium, eliminate the hazards associated with that metal, while minimizing the effort needed. Previous work by ANL showed the process worked very well with chopped, shorter segments of this material. If successful, the removal of sodium may allow the Fermi-1 blanket material to be disposed via existing or future planned disposal pathways for similar materials.

This document presents the test plan for the evaluation of sodium removal from intact Fermi-1 reactor blanket materials by the MEDE process. This test plan establishes the objectives for such testing, which includes the anticipated outcomes, a summary of the testing parameters, and an overview of the testing process. This test plan does not provide technical direction or work control guidance; that is the role of a Laboratory Instruction (LI) that will be issued to govern the work.

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ACRONYMS

ANL	Argonne National Laboratory
ANL-W	Argonne National Laboratory-West (now the Materials and Fuels Complex of the INL)
ASME	American Society of Mechanical Engineers
BEA	Battelle Energy Alliance
BWXT	BWXT Technologies, Inc.
CGD	Commercial grade dedication
EBR-II	Experimental Breeder Reactor-II
EDL	Engineering Development Laboratory
EIS	Environmental Impact Statement
EJ	Engineering Justification
DOE	Department of Energy
DU	depleted uranium
FASB	Fuels and Applied Science Building
FFTF	Fast Flux Test Facility
FCF	Fuel Conditioning Facility
FMF	Fuels Manufacturing Facility
F&OR	Functional and Operational Requirements
Fermi	Enrico Fermi Atomic Power Plant (Monroe, Michigan)
IFR	Integral Fast Reactor
HFEF	Hot Fuels Examination Facility
HMI	Human Machine Interface
INL	Idaho National Laboratory
INTEC	Idaho Nuclear Technology and Engineering Center
ITP	Installation and Test Procedure
LI	Laboratory Instruction
LLLW	Low Level Liquid Waste
LLW	Low Level Waste
LTC	Laboratory Transfer Cartridge
LWP	Laboratory-wide Procedure
M&TE	Measuring and Test Equipment
MEDE	Melt-Drain-Evaporate process for removing sodium from materials
MEDEC	Melt-Drain-Evaporate-Calcine/Carbonate process

MFC	Materials and Fuels Complex, Idaho National Laboratory
MSA	Management Self-Assessment
NQA	Nuclear Quality Assurance
NRC	Nuclear Regulatory Commission
PDD	Program Description Document
PLC	Programmable Logic Controller
QA	Quality Assurance
QSL	Qualified Suppliers List
RCRA	Resource Conservation and Recovery Act
SOPT	System Operability and Acceptance Test Procedure
T&FR	Technical and Functional Requirements

Test and Chemistry Plan for MEDE Treatment of Fermi-1 Blanket Materials

1. INTRODUCTION

The Enrico Fermi Atomic Power Plant in Monroe, Michigan (abbreviated Fermi-1 in this document) demonstrated the feasibility of a liquid metal (sodium) fast breeder reactor for electric power production. The reactor was decommissioned, and the U.S. Department of Energy (DOE) now manages 34 metric tons of the sodium-bonded blanket material at the INL. Blanket materials were grouped into two categories; axial assemblies and radial assemblies. Each radial assembly contains 25 elements and each axial assembly contains 16 elements. Elements consist of stainless-steel cladding tubes containing solid cylinders, or slugs, of depleted uranium-molybdenum metal alloy within stainless-steel cladding (see Figure 1). These elements are 6 feet long and contain 5 separate close-packed fuel slugs (not shown). The slugs are bonded to the cladding with sodium metal filling the annulus between the slugs and cladding and extending a few inches above the slug column.

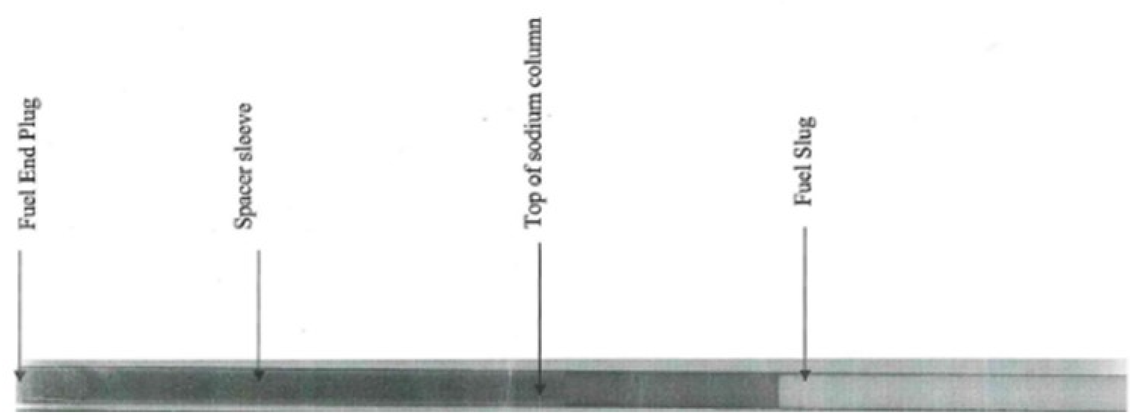

Figure 1. Radiography partial view of Fermi-1 element showing internal structure.

In order to perform the first set of experiments, unirradiated Fermi-1 blanket material was shipped from a museum in Michigan to INL in 2001. The shipment included two intact radial-blanket assemblies, two radial-blanket elements, two axial-blanket elements, and some extraneous pieces. One of the intact blanket assemblies was dismantled in 2003 as part of an initial MEDE treatment experiment. Two elements were extracted from this assembly, cut into smaller segments, and subjected to a MEDE process for sodium extraction. The majority of the element segments exhibited no detectible sodium after treatment. The balance of the elements exhibited 50 to 100 µg of sodium metal, which equated to an extent of sodium metal removal of ≥99.996 % (TEV-3506).

For additional historical background on the Fermi-1 blanket materials, see Appendix A.

1.1 Test Objectives

This project will determine if the Melt-Drain-Evaporate (MEDE) process can be used to treat all or part of the sodium-bonded elements. Treatment is accomplished by heating a sodium bonded element or elements then allowing the sodium to melt out of the element(s) and gravity drain into a crucible. The element or elements are then further heated to vaporize all residual sodium clinging to the element through capillary forces. Thus leaving a clean sodium-free element for disposal.

Testing objectives for this project answer the following questions:

- Is the "melt and drain" portion of the process necessary?

  If the capillary forces within the element retain the melted sodium, then efforts to drain during treatment could be removed. This could shorten the treatment time.

- How efficient is the MEDE process in removing sodium from a single in-tact element?

  Past MEDE demonstrations have been performed on sectioned blanket elements (see Appendix A). Handling, secondary waste, and treatment time would be reduced if bond sodium were removed from the elements without the need to section them into shorter lengths. Calculate the weight percent of pyrophoric elemental sodium left following MEDE treatment. This value will be labeled as the decontamination factor throughout this document.

- Can the MEDE process be used to remove sodium from an entire bundle of elements at once?

  If extraction of sodium from a single in-tact element is successful, that same extraction method applied to multiple elements at once would save a significant amount of time when treating the 34 metric tons of the sodium-bonded blanket material at the INL. Calculate the decontamination factor of an element bundle after the MEDE treatment.

- Can the MEDE process be used to remove sodium from a bundle of elements housed within an assembly?

  All of the sodium-bonded blanket material elements stored at the INL are packed into assembly housings. Each assembly housing holds either 16 (axial) or 25 (radial) of these elements. If the MEDE process is successful in removing sodium from an entire bundle of elements, it would further reduce handling time if the bundle of elements inside an assembly could be treated while still inside the assembly. Calculate the decontamination factor of an entire assembly following the MEDE treatment.

- How efficient is the MEDE process if only one end of an element is opened for draining?

  A heater element control failed during a previous small scale MEDE test on a full length EBR II element in 2017. This failure resulted in a temperature spike on the upper un-cut end of the element before the lower portion was sufficiently heated. Sodium in the upper sealed portion of the element melted and expanded. Solidified sodium below this area prevented release of the pressure resulting in a burst cladding. To mitigate this hazard, both ends of the all elements within this MEDE process are opened. This final MEDE test will determine (1) the additional draining time required to drain sodium from an element with only one end cut and (2) the additional treatment time required to treat an element with only one end cut for venting and the associated decontamination factor. Test results will provide sufficient data for future treatment methods. The additional treatment time and risk associated with venting only one end of an element may be worth the time and waste savings associated with up front pre-cutting of both element ends.

1.2 Approach

The approach for this study involves staging several un-irradiated Fermi-1 blanket elements and a single-blanket assembly, then subjecting them to MEDE processing. Figure 2 depicts this MEDE process using a high-level simplified flow chart. The MEDE process starts by extracting sodium from a single element. Lessons learned from this extraction are then applied to sodium extraction on a bundle of 9 elements. Lessons learned from the bundle extraction are then applied to sodium extraction from an entire assembly (containing 25 elements). Prior to the single element, element bundle, and the element assembly treatments, both ends of the elements were cut to facilitate an open pathway for venting. A fourth MEDE process test is identical to the single element treatment but with only one end of the element cut for venting. Lessons learned from the previous three tests would be applied to this fourth and final test.

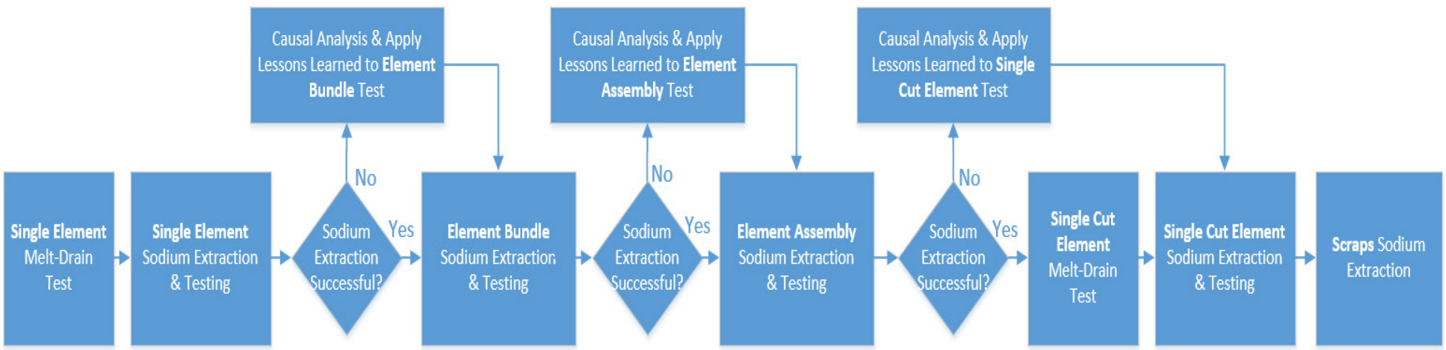

Figure 2. MEDE Testing Simple Flow Chart.

Two additional objectives for this activity involve 1) verification of the "Melt and Drain" portion of the Melt-Drain-Evaporate (MEDE) process and 2) removing sodium from scraps produced in the glovebox during the cutting operations.

Verification of "Melt and Drain" is performed as part of the first single element test. After cutting both ends of the element, the element is loaded into a MEDE basket with the plenum end down and then into a MEDE retort. The retort is then closed, stood upright, and loaded into the MEDE furnace with the plenum end down. Typically, the retort will be brought under vacuum (range of 10 to 200 mtorr) and the furnace temperature raised to 150°C then held at that temperature to facilitate sodium melting and draining into a base mounted crucible. The temperature is then increased again to 650°C and held until all remaining sodium is evaporated and collected in the base mounted crucible. In direct contrast, the initial single element test will be performed at atmospheric pressure (not vacuum) and the crucible will be inspected after exposing the element to 150°C for 2 hours. This is done to test the effectiveness of "Melt and Drain" portion of the MEDE process. If no signs of drained sodium in the crucible or condenser are present, then hold times at 150°C for subsequent tests on the bundle, assembly, and single cut element will be shortened.

Element cutting will occur within the glovebox. This operation may generate sodium contaminated scraps of depleted uranium slugs, cladding, and assembly ends. As part of the final treatment process, all of these scraps will be loaded into a MEDE basket. This basket will then be loaded into a MEDE retort and treated in the furnace to extract off the elemental sodium.

After each stage of sodium extraction, the furnace heaters would be de-energized, and the system pressure equalized. The MEDE apparatus would then be positioned horizontally for disassembly and unloading. Separation of element slugs from its cladding will be assessed, and samples of the separated element, cladding, and bond-sodium will be taken for elemental and isotopic analysis in the Analytical Laboratory. The MEDE test apparatus could then be reloaded for subsequent operations. Results from each analysis will be applied as lessons learned to the subsequent test.

Per LWP-21220, Laboratory Instructions will be developed and approved to provide the necessary work control for the testing activities.

1.3 Task Description

Project Implementation Includes:

1. Defining project parameters
2. Designing the equipment used to extract sodium
3. Fabrication and/or procurement of that equipment
4. Determining element cut points using Radiography
5. Installing and testing that equipment to ensure proper operability
6. Using that equipment to remove sodium from Fermi blanket elements
7. Then issuing a final report.

Project parameters include a schedule, a level 5-cost estimate, a test plan, a Functional and Operational Requirement (F&OR) document, and a technical and functional requirement (T&FR) document. An engineering job (EJ) form will document design activities and facility turnover.

Equipment design activities include a brainstorm session to identify tools needed to perform the sodium extraction task. Informal design reviews will follow the design of various components (Retort, furnace, tools, mockup elements & assembly). Drafting activities will follow the reviews and specifications (procurement and fabrication) will follow drafting. Thermodynamic and stress modeling will also be included in the design effort. This modeling will aid the designer in choosing the proper retort length to facilitate sodium condensation.

Procurement activities include placing a bid, approving a supplier, reviewing and approving the supplier's vendor data, then waiting for delivery. This project will purchase components designed by a manufacturer and purchase the services of a fabrication facility to build components designed by INL engineering. Manufacturer designed components will include the furnace, the furnace stand, the vacuum pump, and other miscellaneous components such as thermocouples, valves, piping, etc. INL designed components include the PLC furnace control cabinet, PLC HMI, retort, handling tools, mockup Fermi assemblies, and mockup Fermi elements.

A Radiography Lab will analyze both the mockup Fermi blanket components and the actual non-radiological Fermi blanket components. This analysis will identify pre-treatment cut points. Prior to treatment, cut points must be identified that will allow liquid and gaseous sodium to escape the elements during heating.

Assembly and Operability testing occurs after all MEDE furnace components arrive. The first phase of operability testing occurs at the Engineering Development Laboratory (EDL) building at MFC. A System Operability and Acceptance Test Procedure (SOPT) directs work at EDL. Operability testing includes assembly of all major components at EDL followed by mockup element cutting, mockup assembly cutting, leak testing, functional testing, and furnace loading with mockup components. Lessons learned from the EDL installation will influence the FASB installation.

Furnace temperature measurements will be taken using thermocouples. During a MEDE test, the temperature must be taken from the exterior of the retort. To establish the internal temperature, a temperature profile will be made of the interior of the retort during mockup testing at the EDL facility, and a correlation will be established with external temperature readings. Dummy blanket elements and assembly will be placed inside the retort to simulate the blanket elements.

The second phase of operability testing occurs at the FASB facility. An Installation and Test Procedure (ITP) directs work at FASB. Operability testing at FASB includes assembly of all major components in and around the FASB pyro-chemistry glovebox followed by leak testing, functional testing, and furnace loading with mockup components. A System Design Description will document the final configuration at FASB. Facility turnover will be document on the EJ after installation and testing of all MEDE furnace components at FASB. A graded approach readiness assessment will be performed to ensure the MEDE furnace system is ready for implementation.

Personnel training on the new system occurs following facility turnover. Facility operations includes cutting the ends off both the elements and assemblies to allow the escape of liquid and gaseous sodium during heating. These elements or assemblies are loaded into the retort. This retort is loaded into the clamshell MEDE furnace following vertical rotation within the glovebox. Heat is applied and sodium is removed. This sodium condensation and collection occurs in the bottom of the retort. Subsection 3.1 provides a detailed account of this operational process. The depleted uranium slugs area separated from the element cladding. Both cladding and slugs are sent to the INL Analytical Laboratory for sodium analysis. All Cutting, treatment, and slug/cladding packaging for analysis occurs within a glovebox. Subsection 3.5 provides a detailed account of this analytical process. A final report documents the treatment system and results from the analysis.

A deliverable schedule is provided in Section 7 of this report for all seven tasks listed above.

2. ASSUMPTIONS AND RISKS

2.1 Assumptions

There are several assumptions that apply to this work.

1. There is only one unirradiated full-assembly of radial, Fermi-1 blanket elements. There are also 25 individual elements. Some of these individual elements will be treated by another technique (vitrification), and are not available for MEDE treatment. It is assumed the few MEDE tests that can be performed will yield sufficient data to understand the effectiveness of the MEDE process as applied to Fermi-1 blanket materials.
2. It is not anticipated that a highly accurate mass balance can be achieved as the exact amount of sodium added to each blanket element during manufacture is not known. Also, the weight of the elements (uranium-molybdenum alloy and cladding) or the weight of an assembly element will far outweigh the mass of sodium (essentially trying to find something very small in a large sample). Thus, emphasis should be placed on determining how much, if any, residual sodium remains following MEDE treatment. It is assumed that the analytical method documented in this report will yield sufficient precision and accuracy to determine the effectiveness of the MEDE process.
3. Based on previous MEDE results from chopped, shorter sections of elements, the MEDE process will NOT remove 100% of the sodium from the full-length Fermi-1 blanket elements. Final removal of the trace sodium, left on the Fermi-1 blanket elements after the MEDE process, is assumed to be outside the scope of this project.

2.2 Risks

The MEDE process has been used multiple times in the past. There remain risks, both in equipment design and test execution.

1. There is a risk the furnace may not heat an entire blanket assembly to a desired equilibrium temperature due to the large thermal mass of an assembly. Careful design should minimize or eliminate this risk.
2. The analytical technique might not yield accurate enough results to draw conclusions about the effectiveness of the MEDE process. The errors involved in the analytical technique used should be understood.
3. Programmatic risks include funding and scheduling challenges that might arise on any project.

3. EXPERIMENT DESCRIPTION

The evaporative removal of bond sodium from Fermi-1 blanket elements is based on its volatility, as shown in the sodium vaporization curve of Figure 3. Using off-the-shelf vacuum systems (e.g., a dry-scroll vacuum pump), a reduced pressure in the range of 10 to 200 mtorr may be attained. A concurrent rise in temperature would drive sodium metal to first melt and then vaporize. The vaporized sodium would transport to a cooler region of a condenser, where the sodium would condense into a liquid and then drain into a collection container (crucible). This process has proven effective at removing sodium metal from crevices, and it could also apply to bond-sodium removal from a thin annulus in a blanket element. However, previous studies of sodium removal did not investigate crevice lengths nearly as long as that found in a blanket element, i.e., a 72-in. long (183 cm) annular gap of bond sodium between the column of depleted uranium metal slugs and the stainless-steel cladding.

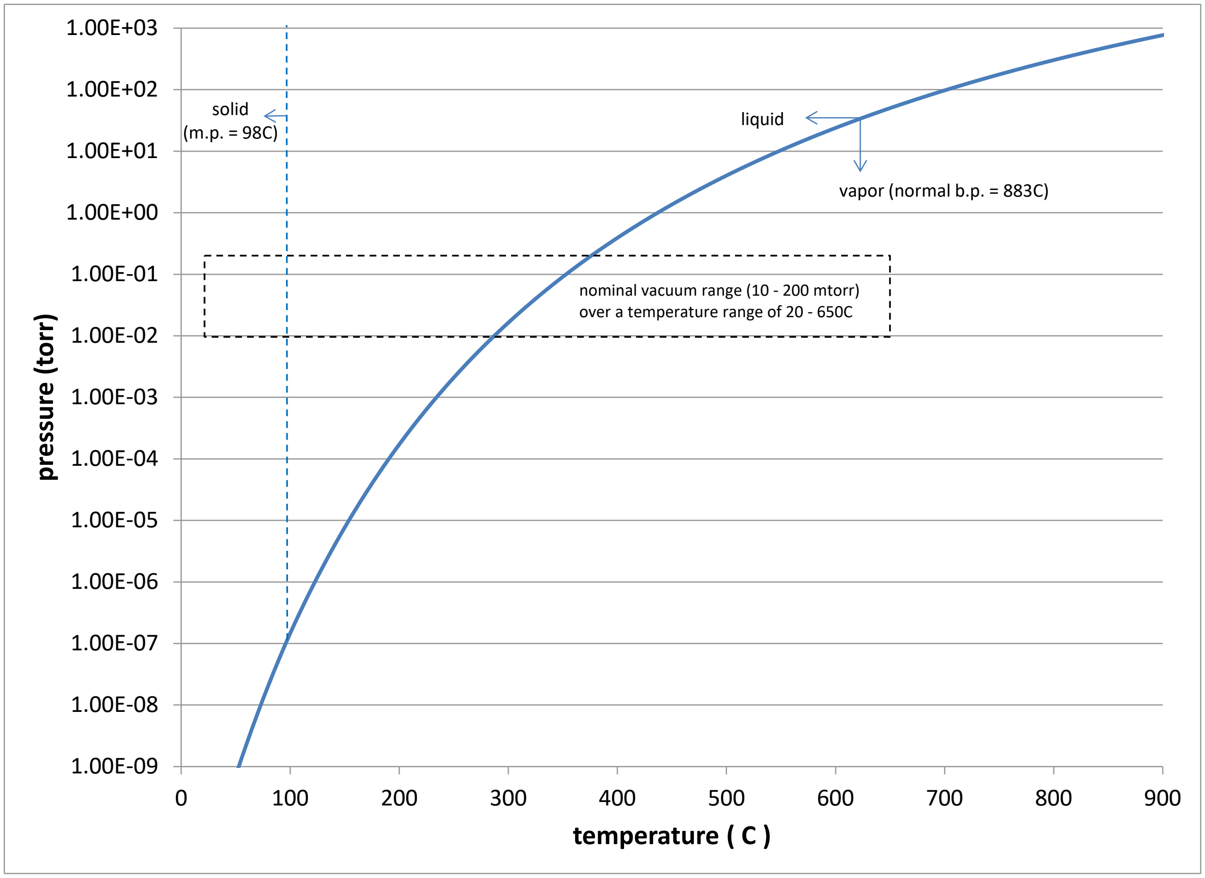

Figure 3. Sodium vaporization curve (Reference: HSC, v7.1).

Assuming an effective evaporative removal of bond sodium and given the absence of any significant fuel swelling, the individual depleted uranium metal slugs in a Fermi-1 blanket element should slide out of its cladding following a MEDE process. This would enable characterization of the cladding to assess its disposition options. This would also enable characterization of portions of the separated depleted-uranium metal slugs for residual sodium in addition to fission product content, the results of which would be used to assess disposition options for the treated element.

The following sections provide the MEDE operational sequence for sodium extraction treatment of a single element (Subsection 3.1), a bundle of the loose elements (Subsection 3.1), and an entire Fermi-1 assembly (Subsection 3.2). A single element is treated again with only one end of the element cut (Subsection 3.3). At the conclusion of this final treatment, sodium bearing waste scraps from the glovebox cutting operations are treated as well (Subsection 3.4). All of the above mentioned operations, with the exception of waste scraps, terminate with testing those treated components for residual sodium. Therefore, an additional operational sequence of analytical testing is provided (Subsection 3.5). Appendix B provides an off-the-shelf parts list and a design-build parts list for all the components listed in this section.

3.1 Operational Sequence (Single Element and Element Bundle)

This sequence starts by performing radiography on the loose unirradiated Fermi-1 elements to identify and mark subsequent end-of-slug cut points at both ends of each element. These loose elements (contained within a box) are then transferred from the Fuel Conditioning Facility (FCF), Room 20a, to the Fuels and Applied Science Building (FASB) West Room. In the West Room, a single 5 lb. 6-ft-long element or 9 elements in a bundle are manually lifted out of the transfer box. With the element plenum end(s) facing outwards, the 5 lb. element or the 45 lb. element bundle is slid through the 12-in. glovebox port, into an 8-ft long bag-in bag, and onto 2 rolling glovebox dollies (located inside the glovebox). Once the elements are inside the glovebox, a new bag is slid into the 12-in. glovebox port pushing the old used bag end into the glovebox while maintaining the seal. The bag-in bag is then removed from around the element(s).

3.1.1 Cut and Weigh Element(s) and MEDE Basket

The un-bagged element(s) are rolled over to a pre-positioned Cold Saw and V-block, then manually lifted off the dollies and placed/secured on the saw and V-block supports. The saw is used to cut through the elements at the pre-marked cut point locations. Following this cut, the element(s) are slid down the glovebox to a second V-block until the second pre-marked line is in front of the saw blade. The saw is then used again to cut through the elements at the second marked location. Both waste ends potentially contain depleted uranium (DU)-moly slug fragments and bond sodium. These waste ends are placed in a waste bag for further MEDE treatment. See Subsection 3.4 for scrap treatment.

Following the cutting operation, each of the element ends will have open-element cladding tubes with DU-moly slugs and bond sodium inside. These cladding tubes will be inspected for burs caused during the cutting process. If burrs are present, they will be removed with either a hand-held deburring tool or a drill-mounted deburring tool. The cut element(s) are then weighed for the post-treatment decontamination factor (DF) calculation. After weighing, the element(s) are loaded into a pre-weighed MEDE basket and the element(s)/basket combination are weighed on a large balance for gross sodium accountability.

3.1.2 Weigh the Retort

The retort is disassembled, and the retort's body, the retort's nickel nozzle, support rod, and the retort's crucible (Figure 10 provides a retort diagram) are weighed on the large balance for gross post-treatment comparison. The retort is then reassembled and horizontally positioned on retort stands near a junction between the larger and smaller sections of the glovebox. A retort stop is inserted into pre-existing glovebox shelf holes located at this junction to prevent the retort from sliding when loaded. The retort is then pushed up against this stop.

3.1.3 Load Element(s) into Retort

Using roller dollies, the element(s)/basket combination is manually transferred from the scale to the open end of the retort where the basket rod is attached to the outer MEDE basket. At this point, the MEDE basket should line up with the retort opening. The MEDE basket is then manually slid into the retort and countersunk using the basket rod. While leaving the basket rod inside the retort, a nickel retort funnel is attached to the end of the retort with a flange strap.

3.1.4 Load the Filled Retort into the Furnace

To facilitate retort lifting, a ball-detent lift pin is installed into a pre-existing hole in the side of the nickel funnel and a second ball-detent lift pin is installed into a pre-existing hole on the closed end of the retort (see Figure 10 for pin locations).

Ropes from glovebox hoists are attached to the detent rings on the retort. The retort stop is removed from the glovebox shelf and the retort is lifted from both ends with both hoists and carried into the larger section of the glovebox. The retort is then rotated vertically by feeding out the hoist rope in the narrow section of the glovebox. Once vertical, the retort is lowered by the hoist rope in the larger section of the glovebox onto a supported crucible base and secured with a flange strap. To provide additional support against tipping, the retort is manually held in place as the 2 detent rings are removed and the clam-shell furnace is rolled into place and strapped around the retort. Figure 4 provides a loaded furnace depiction.

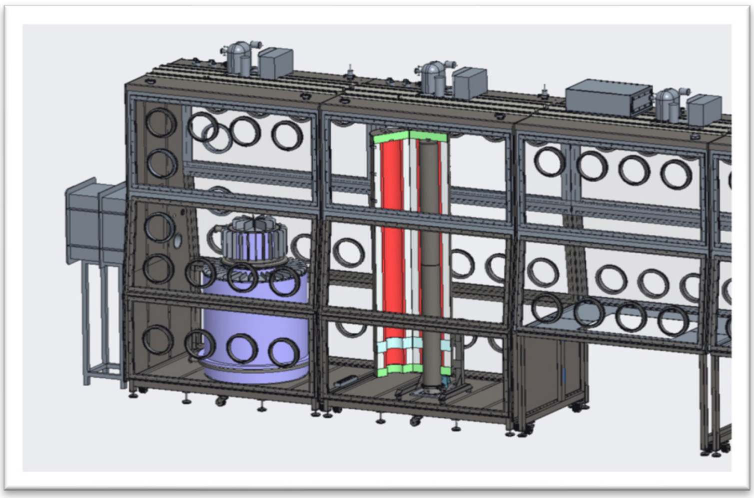

Figure 4. Conceptual layout of a MEDE apparatus (tall unit) inside a new glovebox at FASB.

3.1.5 Run the Melt and Drain Test Sequence

NOTE: *This melt and drain test is only performed during the single element campaigns. If the single element campaign is inconclusive, then a second melt drain test is performed on the element bundle. This initial test determines the amount of sodium that is extracted during the Melt and Drain stage of the MEDE process.*

When treating a single element, an initial melt and drain only test is performed. In this initial test, the element is brought up to Na melting temperature (150°C) under atmospheric pressure and held at that temperature for 2 hours to allow the sodium to melt in the element and drain down to the collection crucible. The crucible is then cooled. The furnace is opened and the retort is manually supported as the furnace is rolled away. The ball-lock lift pin at the crucible top is re-attached along with its associated rope. The crucible-base flange strap is removed and the retort is lifted. The pre-weighed crucible is removed, photographed, and weighed (with a small balance). Using a mirror and light source, the condenser is visually inspected for signs of sodium hold-up. The crucible is then returned to the crucible base. This process is reversed to return the retort back to its base and within the furnace. If an insignificant amount of sodium is present within the crucible, this initial MEDE test is also performed for the multiple element bundle.

3.1.6 Run the MEDE Sodium Extraction Sequence

Run the MEDE sequence by evacuating the retort (10 to 200 mtorr) then gradually heating the elements to 150°C and holding at this temperature for 2 hours. The element temperature is then gradually increased to 650°C to effect sodium vaporization. Each temperature increase starts at the base of the retort and gradually reaches the retort top. This gradual increase is designed to prevent sodium melting and expansion above a solid sodium plug. The vaporization temperature is then held until the retort pressure approaches the starting vacuum pressure. This entire heating cycle will start at the beginning of a 10 hour day and terminate at the end of the day.

The retort is then cooled overnight under constant vacuum. Once temperature is below the melting temperature (98°C), the vacuum pump is de-energized and the pressure in the retort is equalized. The furnace is opened, and the retort is manually supported as the furnace is rolled away. Detent rings are re-attached along with associated ropes. The crucible-base flange strap is removed, and the retort is lifted. The pre-weighed crucible will be removed, photographed, weighed again, and placed in a sealed storage container.

3.1.7 Remove Treated Element(s) from the Retort and Weigh

The retort base is lifted by the hoists until it is horizontal. Both hoists are then used to move the horizontal retort onto the roller dollies within the smaller section of the glovebox. The retort is then rolled over the retort stands where it is subsequently manually moved to those stands. The nickel funnel is then unstrapped and removed. The retort stop is replaced, and the retort is pushed up against it. While manually supporting the retort, the basket rod is pulled out of the retort, pulling the element(s)/basket combination out of the retort. The element(s)/basket combination is moved to the large scale for post-treatment weighing. The element(s) are pulled from the basket and the element(s) weight is recorded for use in the DF calculation. The elements shown as red circles in Figure 5 are segregated and labeled for subsequent analytical testing. The centermost element, in the element bundle, is labeled for later comparisons. The retort is then disassembled and the retort's body, nickel nozzle, basket rod, and MEDE basket are weighed on the large balance for pre-treatment comparison.

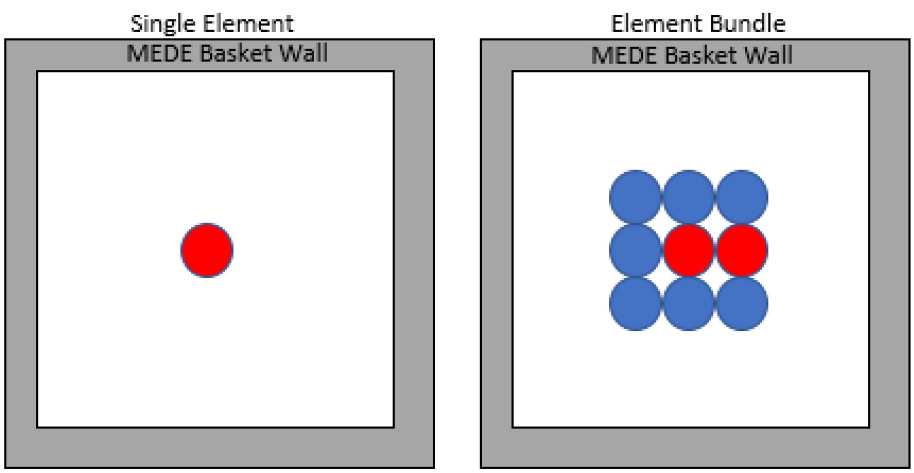

Figure 5. Single element and element bundle MEDE test configurations.

Analysis of the segregated element is initiated. Elements are color-coded in this diagram for analytical testing discussions. Results of this analysis are reviewed through a causal analysis. Lessons learned from the causal analysis are incorporated into all subsequent tests. Subsection 3.5 describes both the qualitative and quantitate analytical methods used to determine the success of this operational sequence.

3.2 Operational Sequence (Assembly)

3.2.1 Prepare and Load Assembly into FASB PC Glovebox

This sequence starts by transferring the unirridiated Fermi-1 assembly (contained within a box) from the Fuel Conditioning Facility (FCF), Room 20a, to the FCF mockup shop. The bottom cylindrical nozzle of the assembly (see left hand diagram in Figure 6), which does not contain elements, is cut off of the 8-ft long assembly. The resulting square assembly is approximately 6.5 feet long and weighs approximately 140 lbs. The remaining bottom-assembly housing is marked for subsequent cutting on both ends based on data obtained from a previous radiography. A cover is added to the assembly's cut ends to prevent bag puncture during glovebox loading.

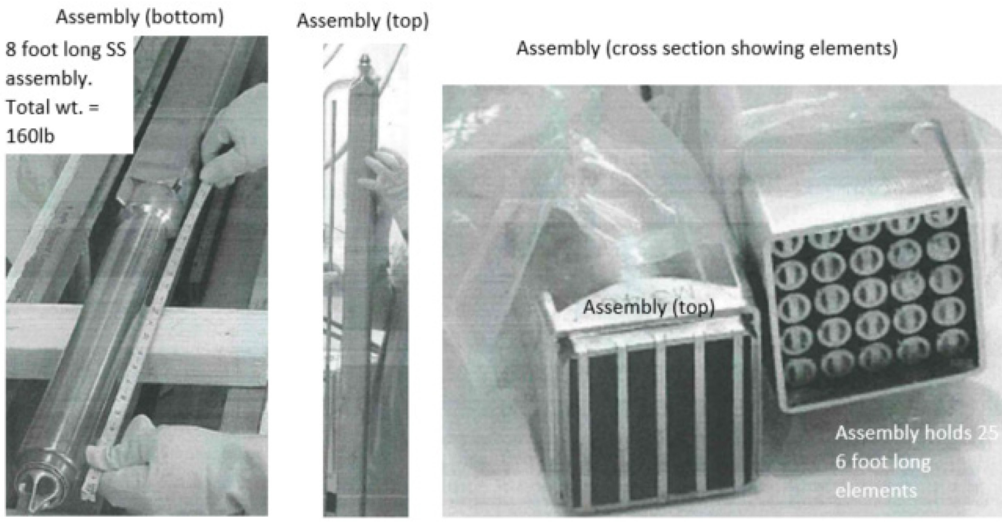

Figure 6. Fermi-1 assembly and internal elements.

Following the initial cutting operation, the cut assembly is re-boxed and moved to the Fuels and Applied Science Building (FASB) West Room. In the West Room, the assembly is lifted from the transfer box onto a lift table positioned in front of the 12-in. bag-in bag-out port. The assembly is oriented on the lift table, so the cut end of the assembly is facing towards the 12-in. port. The assembly is then elevated until it is in line with the port. The 140 lb. assembly is then manually slid through the 12-in. glovebox port, into an 8-ft long bag-in bag, and onto 2 rolling glovebox dollies (located inside the glovebox). The port is plugged and the assembly is cut on both ends in the same fashion as elements in the Subsection 3.1. The cut assembly is then weighed for the DF calculation. After weighing, the assembly is loaded into MEDE basket and the combination is weighed for gross sodium accountability. The retort is then positioned on the retort stand with retort stop in place. The loaded assembly/basket combination is positioned on roller dollies in front of the mounted retort where it is manually inserted into the retort. All subsequent steps associated with closing up the retort and transferring it into the furnace are identical to the elements step in Subsection 3.1.

The MEDE sodium extraction sequence is run, per Subsection 3.1.6. The retort is lifted and positioned horizontally onto roller dollies within the smaller section of the glovebox and the assembly/basket is removed and weighed. The assembly is weighed for the DF calculation. The elements shown as red circles in Figure 7 are segregated and labeled for subsequent analytical testing. The centermost element is labeled for later comparisons.

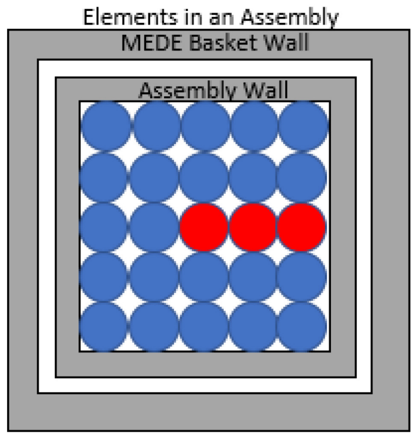

Figure 7. Assembly MEDE test configuration.

Analysis of the segregated element is initiated. Results of this analysis are reviewed through a causal analysis. Lessons learned from the causal analysis are incorporated into all subsequent tests. Subsection 3.5 describes both the qualitative and quantitate analytical methods used to determine the success of this operational sequence

3.3 Operational Sequence (Single Cut Element)

NOTE 1: *This test determines the effectiveness and heating duration for MEDE treatment performed on elements that are only cut at one end.*

NOTE 2: *Rupturing the element cladding, due to a run-away heater scenario, is undesirable but is a planned and mitigated event. Placing an element in a MEDE basket will facilitate easy removal, following cladding rupture.*

A single element is loaded into the glovebox and positioned on the saw and V-block in the same fashion as the previously treated single and multiple elements. At the saw, this element is only cut at the plenum end. The retort is positioned on the retort stand with retort stop in place. An empty MEDE basket is loaded with this single cut element, weighed, and then positioned on roller dollies in front of the mounted retort. The MEDE basket is manually inserted into the retort. All subsequent steps associated with closing up the retort and transferring it into the furnace are identical to the single element steps. The Meld and Drain test sequence and the MEDE sodium extraction sequences are run and the retort is opened, the MEDE basket and retort are weighed, and the element is removed from the basket for subsequent analytical testing.

Analysis of the segregated element is initiated. Results of this analysis are reviewed through a causal analysis. Lessons learned from the causal analysis are incorporated into all subsequent tests. Subsection 3.5 describes both the qualitative and quantitate analytical methods used to determine the success of this operational sequence.

3.4 Operational Sequence (Scraps)

The retort is positioned on the retort stand with retort stop in place. An empty MEDE basket is positioned on roller dollies in front of the mounted retort. The MEDE basket is manually inserted into the retort and the scrap components are removed from their waste bag, weighed, and placed inside the basket. All subsequent steps associated with closing up the retort and transferring it into the furnace are identical to the assembly steps. The MEDE sodium extraction sequence is run and the retort is opened and scrap components are removed and weighed in the same fashion as an element.

3.5 Analytical and Measurement Methods

Figure 8 provides a detailed flow chart depicting the operational and analytical MEDE process method.

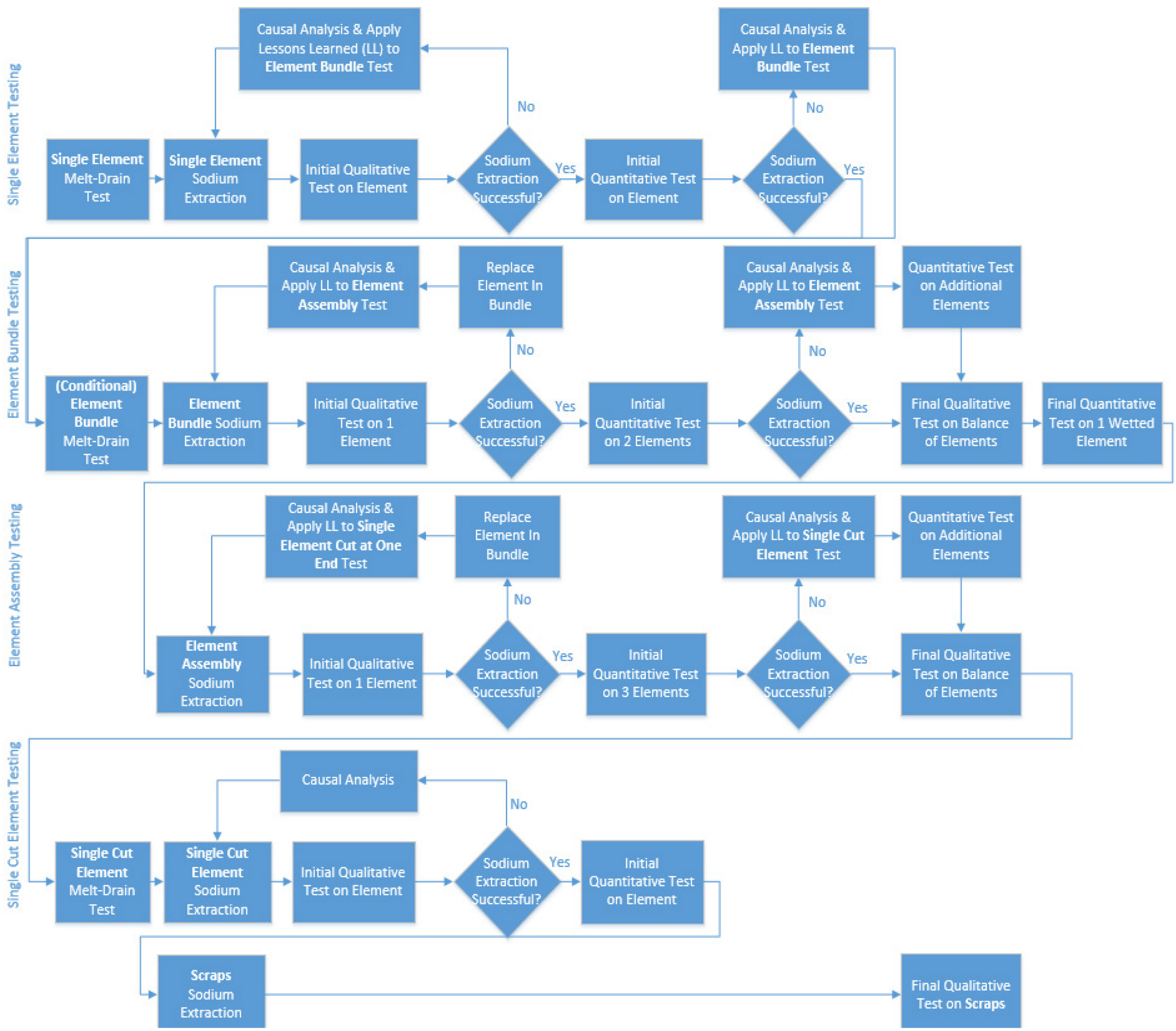

Figure 8. MEDE Testing Detailed Flow Chart.

Measurements that are important to the MEDE tests are the temperature of the retort and pressure (vacuum) within the retort. The amount of sodium recovered can be weighed. The amount of residual sodium (if any) can be determined by qualitative and quantitative analyses.

The pressure (and vacuum) can be monitored to determine when sodium is being volatilized. While under vacuum, when the temperature is high enough, sodium will begin to volatilize (see Figure 3), and the pressure will increase. When all the sodium is removed, the pressure will fall again. The pressure vs.

time plot for a MEDE test run will show how long the process takes. The change in pressure vs change in time will provide information regarding the "tortuousness" of the vapor path through the blanket elements.

Weight of the assembly and individual loose elements are recorded before and after treatment to determine the amount of sodium originally present in each element. The weight of elemental pyrophoric sodium left in each element after treatment is then determined through quantitative analytical testing (hydrogen analysis). The weight of sodium originally present and the weight of sodium remaining after treatment are used in calculating the decontamination factor. The weight originally present in all of the elements collectively is then compared to the before and after weights of the crucible and retort to balance the amount of sodium collected on a gross scale. Accuracy of weight measurements are assured through the use of three separate calibrated scales of increasing weight capacities (see Appendix B).

Analytical testing for the MEDE project involves removing all elements from the MEDE basket or assembly then performing an initial qualitative test. This initial qualitative test consists of tipping the elements for indication of freely moving slugs within the cladding (free moving slugs suggest the absence of bond sodium). If the DU-Moly slugs move freely, then the element slugs are separated from the element cladding. Both slugs and cladding are photographed, and the elements shown as red circles on and are sent to the MFC analytical lab for an initial quantitative hydrogen analysis. Results from the hydrogen analysis are used to determine the test's decontamination factor. If this factor proves sufficient, then a final qualitative analysis is performed on the remaining elements. This final qualitative analysis involves submerging the remaining slugs and cladding in an alcohol bath then recording any reaction (bubbling) on video. A quantitative hydrogen analysis is then performed on one of the alcohol wetted elements. Providing a blank for comparison. There are a total of eight (8) elements being sent to the analytical lab for hydrogen analysis (1 from single element test + 2 from bundle test + 3 from assembly test + 1 from single cut element test + 1 from test on wetted element). Since cladding and slugs are sent separately to the lab, this equates to sixteen (16) hydrogen analysis runs.

3.5.1 Initial Qualitative Analysis in the Glovebox

Extract the centermost element in the MEDE basket. Treatment should have removed the sodium used to bond the slugs to the interior cladding wall. Tilt the cladding tube, allowing the interior slugs to slide out onto a prepared surface for examination.

If slugs do not move freely within the cladding during separation, then all of the elements will be reassembled and replaced in the assembly or returned to the original bundle configuration. The assembly or bundle is placed within a MEDE basket which will then be loaded back into the retort and treated again. A follow-up causal analysis will be performed and all lessons learned will be applied to subsequent MEDE tests.

3.5.2 Initial Quantitative Analysis at the MFC Analytical Lab

If no significant resistance is discovered during slug/cladding separation, then all elements shown as red circles on and are weighed on the small scale for accountability before transport. Each of the 6-ft long claddings will be loaded into a 7-ft long, 0.5-in. diameter lab transfer cartridge (LTC) (see Figure 9). A slug collection from each element will also be photographed and loaded into a single separate LTC.

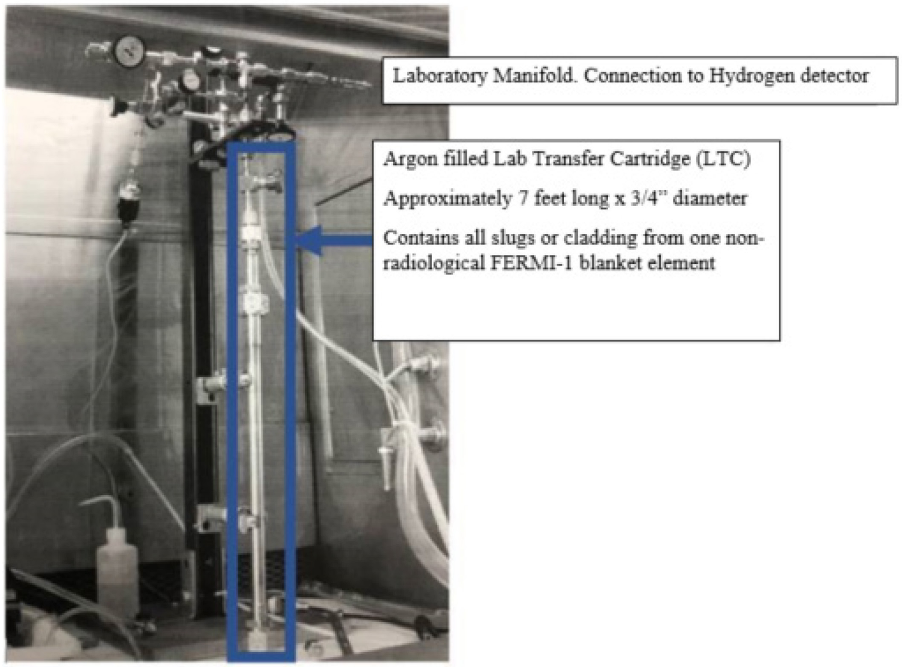

Figure 9. Lab transfer cartridge and laboratory manifold.

A 4-ft long bag, pre-penetrated and sealed to a LTC halfway up the LTC length, is attached to the 12-in. glovebox port. The LTC is pushed into the glovebox port leaving the LTC laboratory connections outside the glovebox. Using two wrenches, LTC end plug inside the glovebox is removed and one full-length cladding or the associated DU-moly slugs are inserted. The end plug is resealed, and the LTC is pulled out of the glovebox, then the bag ends are closed with twist-tie-cut-fold-tape.

This bagged and loaded LTC is transported to the MFC Analytical Laboratory. In the Analytical Laboratory, each sealed LTC housing a segment of fuel or cladding will be individually coupled to analytical equipment as shown in Figure 9. (The transfer container for the fuel and cladding also served as the reaction chamber for residual sodium analysis.) Water will be introduced into the reaction chamber to dissolve any residual elemental or oxidized sodium. Elemental sodium reacted with water (see reaction below) to form sodium hydroxide, liberating hydrogen gas, which will be collected in a gas sample bottle and analyzed via gas analysis.

$$2Na\ (s) + 2H20 \rightarrow 2NaOH\ (aq) + H2\ (g)$$

Oxidized sodium would not produce hydrogen gas, but would merely dissolve in the water, forming sodium hydroxide. Sufficient water will be introduced to wet all of the cladding or fuel surfaces, after which the solution will be titrated to quantify the sodium hydroxide concentration, yielding the total sodium for the particular clad or fuel segment.

Following lab testing, the dried LTC is brought back to the FASB, Room 102, opened outside the glovebox with wrenches, and the contents are emptied into a waste container. The LTC is refitted with another 4-ft glovebox bag-in bag and the process is repeated. To speed up lab work, batches of up to four LTCs are transferred to the lab for testing.

If the lab results show a significantly lower DF than seen in previous testing of segmented elements, then a causal analysis will be performed, laboratory quantitative analysis on additional elements may be performed, and all lessons learned will applied to subsequent MEDE tests.

3.5.3 Final Qualitative Analysis in the Glovebox

If the lab results show low to no sodium levels, then remove the remaining elements (shown as blue circles in Figure 5 and Figure 7). Remove the DU-moly slugs (max 14 in. long) from the 6-ft long element cladding. Transfer the 6-ft long element cladding to the cool saw and cut the cladding into 14-in. long sections using either the saw or a tube cutter. Submerge both the DU-moly slugs and the cut cladding pieces in an alcohol filled graduated cylinder located inside the glovebox. Record the reaction on video and in a manual log noting any visual bubble formations. This same qualitative test will be performed on the scrap materials following treatment.

3.5.4 Final Quantitative Analysis at the MFC Analytical Lab

Following the element bundle testing, one of the alcohol wetted elements are loaded into an LTC and sent to the Analytical lab. Results from this hydrogen analysis will provide a basis of comparison between the wetted element and a non-wetted element.

3.6 Equipment and Materials

A design of MEDE test equipment for this study is shown in Figure 10. The clam-shell opening furnace is not shown. The equipment is fabricated from stainless-steel tubing and fittings to create a sealed system with three functional zones – a vaporization zone, a condenser zone, and a collection zone. The equipment is designed such that a cut blanket element is positioned entirely in the vaporization zone. A blanket element with both ends cut open is pushed through the upper portion of the condenser zone and into the vaporization zone with a basket rod. The upper-condenser zone is then sealed to the lower-condenser zone with a standard vacuum connection and high-temperature elastomer seal, which sandwiches the basket rod between the blanket element and a funnel in the lower-condenser zone. A collection chamber, containing a sodium collection crucible, is then sealed to the lower-condenser zone with a standard vacuum connection and high-temperature elastomer seal. The collection chamber is connected to a vacuum line, including appropriate filter media and pressure indication.

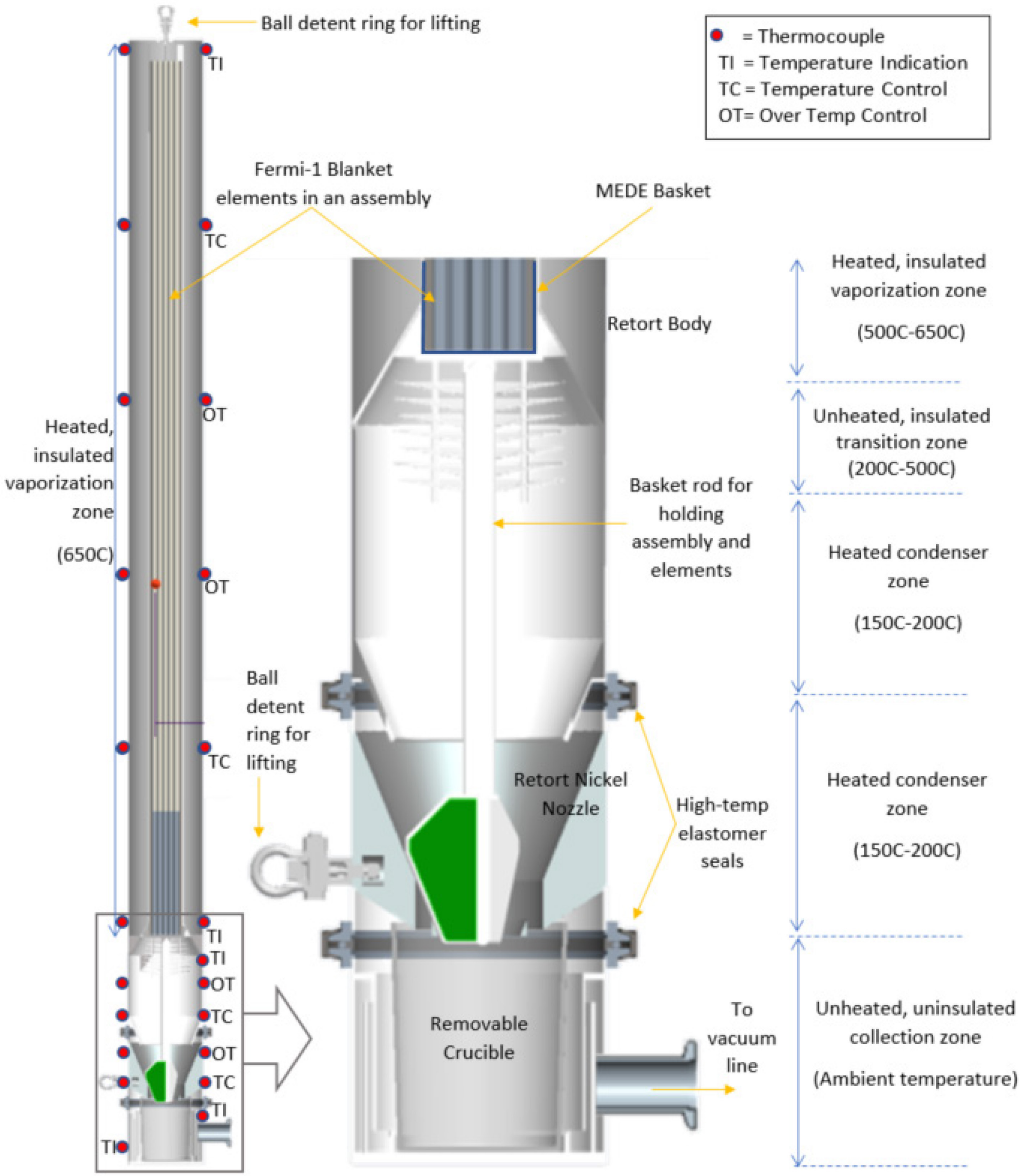

Figure 10. Schematic illustration of the MEDE retort system.

The vaporization zone is insulated and heated to facilitate a controlled temperature of 650°C on elements. A section of the upper-condenser zone is insulated, but unheated to facilitate a steep temperature gradient between the vaporization zone and a heated, uninsulated portion of the upper condenser zone. The heated portion of the lower-condenser zone is maintained at 150°C. The collection zone is uninsulated and unheated to facilitate solidification of the removed sodium.

The MEDE test equipment is designed and configured to facilitate a gravity-assisted melting, draining, evaporating, condensing, and collection of bond-sodium from Fermi-1 blanket elements.

Several additional off-the-shelf components and design-build parts are required for the MEDE process. Examples of such components include 3 separate scales, lift table to get the assembly into the glovebox, cool saw for cutting the elements and assembly, cameras, a drill, a retort stop, and many more. Appendix B provides a list of these components, there quantity, and use.

3.7 Test Matrix

The number of un-irradiated tests is limited by the quantity of individual radial Fermi-1 blanket elements and the single, radial blanket assembly. The order of the tests proposed are:

1. Single element
2. A bundle of elements
3. An entire assembly
4. Single element cut at only one end.

The single-blanket element will be used to verify and test the MEDE apparatus. This test will allow fine tuning of temperature controllers, vacuum parameters, and the operating LI. It will provide the initial material for testing the residual-sodium analysis technique and verify the treatment melt and drain efficiency.

The “bundle” test will further the knowledge of the MEDE system and allow the initial comparison of elements treated in the same batch. Additional samples for residual sodium analysis will also be obtained. Experience gained in the analytical technique will improve the accuracy and precision of the analyses.

The full assembly test is very important. It is the most complex test because the assembly jacket provides extra thermal mass that must be heated and might act as a radiant-heat shield. There is the possibility that all of the blanket elements may not heat evenly. This could reveal itself through differing (or increased) amounts of sodium remaining on different blanket-element slugs throughout the assembly. However, if the analytical results are all similar, then there is the potential that a simple, relatively easy technique might be possible to treat the 34 metric tons of blanket material.

The single element cut at only one end will be used to verify how much longer the MEDE treatment for a single-cut element would take over a double-cut element. Additionally, this test would provide insight on sodium removal efficiency between single-cut elements and double-cut elements. This will facilitate cost and time cutting measures for treatment of 34 metric tons of Fermi-1 nuclear power reactor-blanket assemblies.

3.8 Data Analysis

The results from these tests will be analyzed and those results, interpretations, and recommendations will be documented in a final report at the conclusion of the MEDE testing program. It is expected the results will include the researcher’s impression regarding the ease or complexity of conducting MEDE on full-length blanket elements. It will include recommendations for design changes/improvements to the MEDE apparatus that might be needed for deployment with irradiated Fermi-1 blanket material. The results will include an interpretation of the effectiveness of the MEDE process for these kinds of materials. The analysis will include an evaluation of the potential errors that are associated with the experimental and analytical techniques.

The effectiveness of the MEDE process will be measured by the decontamination factor. The following equations document how this factor is derived and how this factor is applied to the assembly elements and the loose elements within the single element test and the bundle test.

ISW= Initial sodium weight: Initial sodium weight in the element before the MEDE treatment. From calculations below.

ISW for assembly test:

$$ISW = \frac{(Weight\ of\ assembly\ before\ MEDE - Wight\ of\ assembly\ after\ MEDE}{25\ elements/assembly}$$

ISW for single element or element bundle tests:

$$ISW = Weight\ of\ element\ before\ MEDE - Wight\ of\ element\ after\ MEDE$$

FSW= Final sodium weight: Final pyrophoric elemental sodium weight after the MEDE treatment. From analytical hydrogen analysis.

DF= Decontamination factor: Percent of sodium removed from an individual element after MEDE treatment.

$$DF = \frac{(ISW - FSW)}{ISW} x100$$

Ultimately, results from this testing will answer the following five questions and provide support to decision making regarding treatment of the existing 34 metric tons of Fermi-1 nuclear power reactor blanket assemblies at the Idaho National Laboratory (INL).

1. Is the “melt and drain” portion of the process necessary?
2. How efficient is the MEDE process in removing sodium from a single in-tact element?
3. Can the MEDE process be used to remove sodium from an entire bundle of elements at once?
4. Can the MEDE process be used to remove sodium from a bundle of elements housed within an assembly?
5. How efficient is the MEDE process if only one end of an element is opened for draining?

3.9 Waste

Project generated wastes will consist of some low-level liquid waste (LLLW), and solid low-level waste (LLW). The liquid waste generated in FASB may include liquid ethyl alcohol, recovered sodium metal, stainless-steel cladding, and the DU-moly alloy blanket slugs. Cutting fines will also be recovered. The analytical laboratory waste will include residual water (as LLLW). Other waste streams might be generated (e.g., the entire manifold used in the analytical laboratory might serve no other purpose and would be disposed as LLW). The waste streams mentioned in this section were identified in the approved Environmental Checklist for this project. All of the waste streams associated with this project are routinely handled by INL Waste Generator Services. All the wastes that can be generated by this project have a defined disposition pathway. Liquid ethyl alcohol, pyrophoric cutting fines, and recovered sodium will be mixed low level waste managed in a Satellite Accumulation Area.

4. REQUIREMENTS

Technical requirements, design requirements, testing requirements, maintenance requirements, reliability, and quality requirements for the MEDE system are captured in FOR-438, "Functional and Operational Requirements for the MEDE Project." The MEDE system consists of the furnace, retort (to contain the blanket test articles), a control system, a vacuum system, and a data recording/monitoring system.

5. ENVIRONMENT, SAFETY, AND HEALTH

This project will follow INL environmental, safety, and health requirements. An Environmental Checklist has been approved for this work. No special requirements were identified. The MEDE process will be governed by a work activity-specific Laboratory Instruction (LI).

Due to the reactive nature of sodium, the work will be conducted within an inert atmosphere (i.e., dry argon gas). The easiest way to mitigate any hazards from sodium, is to perform the work within an inert glovebox. This work will be conducted in the Pyro-chemistry Glovebox in FASB. Because this is a radiological glovebox, the work will also follow INL Radiological Control requirements (i.e., a Radiological Work Permit will apply).

6. QUALITY ASSURANCE AND DATA/RECORD MANAGEMENT

The data from these tests will be used by the DOE to make decisions regarding the treatment and disposition of the Fermi-1 blanket material. There are 25 individual, unirradiated-radial blanket elements and only one, intact-unirradiated radial assembly. Thus, it is essential the MEDE tests be performed in a manner that establishes confidence in the results and assurance those results are accurate.

Battelle Energy Alliance (BEA), through its contract to operate the INL, implements a Quality Assurance Program that follows the requirements of ASME NQA-1 2008 and the 2009 NQA-1a Addendum. Part 1 of NQA-1 provides much of the guidance required to ensure compliance with the Nuclear Regulatory Commission's (NRC) guidance found in 10 CFR 50 Appendix B *Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants.* There are 18 criteria within Part 1:

1. Organization
2. Quality Assurance Program
3. Design Control
4. Procurement Document Control
5. Instructions, Procedures, and Drawings
6. Document Control
7. Control of Purchased Material, Equipment, and Services
8. Identification and Control of Materials Parts and Services
9. Control of Special Processes
10. Inspection
11. Test Control
12. Control of Measuring and Test Equipment
13. Handling, Storage, and Shipping
14. Inspection, Test, and Operating Status
15. Nonconforming Items
16. Corrective Action
17. Quality Assurance Records
18. Audits

A graded approach to Quality will be applied within this project to ensure the proper level of control is maintained over the testing program and to ensure the data that result from the testing are accurate and precise, thereby providing user confidence in those data. A summary of how this project will implement QA requirements per the 18 criteria is below:

1. Organization. BEA INL maintains an overall organizational structure to support the DOE's research missions. A project-organizational structure, detailing positions needed to accomplish this project mission will be maintained in project records.
2. Quality Assurance Program. This project will work to INL policies and procedures that are designed to meet the requirements of NQA-1

3. Design Control. INL has a Program Description Document "Conduct of Engineering" (PDD-10000) that defines the INL Engineering process. The design of the MEDE testing equipment will be performed per the procedures contained within the INL Conduct of Engineering. This project is initiated by a Functional and Operational Requirements document (FOR-438) and a Technical Evaluation (TEV-3506) that establishes the testing objectives and needs of the project. Those are used to develop an Engineering Job which governs all design and fabrication activities of the project. Near the completion of an Engineering Job (EJ-2972), a graded readiness assessment will be conducted that will authorize the project to begin its testing program. While a graded, readiness assessment is not a formal requirement for work performed in less-than-Hazard Category III nuclear facilities, this project will use the process due to the importance of the data to be obtained and the limited number of test articles available for the testing.
4. Procurement Document Control. Procurement of items and materials for the project will follow INL procedures. It is anticipated some items and materials will be commercially available and adequate for use. A Quality Level Determination (QLD-MFC-001519) shall be used to determine the quality-affecting components of the testing apparatus and program. Commercial grade dedication (CGD) may be invoked if a commercial grade item or component must serve a quality function (e.g., a thermocouple readout might not be available from a NQA-1 approved vendor and must be purchased through a non-Q supplier. CGD would be used to qualify the equipment for use.). Some equipment may be procured from vendors on the INL Qualified Supplier List (QSL). The project is not large enough to require addition of vendors to the INL QSL. The procurement history of quality-affecting items will be maintained in the project files.
5. Instructions, Procedures, and Drawings. Any project drawing will adhere to the requirements of the INL Engineering Job process. Procedures and testing instructions will be governed by INL's Laboratory Instruction (LI) process. The LI is the document that provides overall testing guidance for the conduct of a MEDE test, any step-by-step instructions that may be required, and is the Work Control for the testing activity (as required by Conduct of Operations).
6. Document Control. The INL Document Control procedure will be followed for this project.
7. Control of Purchased Material, Equipment, and Services. The INL procurement procedure governs how purchased material and equipment are managed and maintained. It is not anticipated that any services will be procured by this project.
8. Identification and Control of Materials Parts and Services. Any special identification of any items or parts will be done in accordance with INL procedure (green tagging). There are no services that require identification for this project.
9. Control of Special Processes. There are no special processes defined for this project.
10. Inspection. Any inspections needed will be conducted and documented by INL's Quality Assurance organization. These will be maintained in the project records.
11. Test Control. As previously mentioned, tests will be controlled by Laboratory Instruction.
12. Control of Measuring and Test Equipment. M&TE will be maintained by INL procedures. It is anticipated the only M&TE that will require control are temperature-reading devices, thermocouples, vacuum gauges, pressure-reading heads, and electronic balances. If analytical chemistry data are needed, those pieces of M&TE are typically maintained by that organization. A project is responsible for establishing the precision and accuracy of the measurements needed, and the analytical service proposes the method and instruments needed to meet those requirements. That information typically accompanies the data report from the analytical laboratory.
13. Handling, Storage, and Shipping. Material storage and handling will be performed in accordance with INL procedures. There are no shipping activities to be performed.

14. Inspection, Test, and Operating Status. Any inspections will be conducted by INL's Quality Assurance organization.
15. Nonconforming Items. It is envisioned that only procured items would be considered within this criterion. The Fermi-1 test articles will be inspected, though it is difficult to imagine finding a nonconforming item (they are what INL received from the Henry Ford Museum). However, if something is found (e.g., an unusual dimensional measurement), that will be documented, reviewed, and consensus reached prior to using the article in MEDE testing.
16. Corrective Action. Corrective actions will be dispositioned through the INL LabWay system. That system provides the guidance and methodology to ensure any needed corrective actions are sufficient to resolve any issue.
17. Quality Assurance Records. The project will follow the INL records procedure.
18. Audits. It is not anticipated the project will undergo any formal QA audit. However, the limited scope Management Self-Assessment (MSA) a graded self-assessment, will be conducted prior to testing is, by INL design, a rigorous process. Further, should any upset condition be encountered during testing, INL invokes a thorough investigation process to determine cause and corrective actions needed. Finally, any data/publication resulting from this work will be subjected to a peer review prior to release (per INL procedure).

7. SCHEDULE

The proposed project schedule is shown in Table 1.

Table 1. Schedule of Fermi-1 MEDE testing activities.

			FY-19	FY-19	FY-20	FY-20	FY-20	FY-20	FY-21	FY-21	FY-21
Subtasks	Milestones		Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3
1	Define Project Parameters										
		Issue Test & Chemistry Plan									
2	Design Equipment										
		Complete MEDE Furnace Design									
3	Bid, Procure, VDR review, Ship										
4	X-ray Radiography Elements & Assemblies										
5	Equipment Testing & Installation										
		Complete Phase 1 MEDE Construction									
		Complete Phase 1 MEDE Qualification Test									
		Complete FASB MEDE Construction									
		FASB Operational Readiness									
6	Operations										
		Complete Element Testing									
		Complete Assembly Testing									
7	Closeout and Reporting										
		Issue Final Report									

8. REFERENCES

10 CFR 50, Appendix B, *Quality Assurance Criteria for Nuclear Power Plants and Fuel Reprocessing Plants*

DOE/EIS—0306, *Final Environmental Impact Statement (EIS) for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel,* U.S. Department of Energy Idaho Operations Office, Idaho Falls, Idaho, July 2000

EJ-2972 Engineering Job, "FASB Pyrochemistry Glovebox Fermi MEDE Furnace"

FOR-438, "MEDE System"

Idaho, 1995, "Settlement Agreement, State of Idaho, Department of Energy, and Department of the Navy, to resolve all issues in Public Service Co. of Colorado v. Batt, No. CV-91-0035-S-EJL (D. Id.) and United States v. Batt, No. CV-91-0065-S-EJL (D. Id.)," U.S. District Court of Idaho, dated October 16, 1995.

LWP-21220, "Work Management"

PDD-10000, "Conduct of Engineering"

QLD-MFC-001519 Categorical QLD for FASB MFC-787

TEV-3506, "Advancement of Technology to Remove Bond Sodium from Fermi-1 Blanket Material," October 18, 2018.

Appendix A

MEDE Project Historical Background

Appendix A

MEDE Project Historical Background

The Enrico Fermi Atomic Power Plant in Monroe, Michigan (abbreviated Fermi-1 in this document) was to demonstrate the feasibility of the sodium-cooled, liquid metal fast breeder reactor for electric power production. The reactor achieved initial criticality in 1963 and operated until September 1972.

The reactor was decommissioned, and the U.S. Department of Energy now manages 34 metric tons of the sodium-bonded blanket material at the INL. This material has been stored at the Underground Fuel Storage Facility (CPP-749) on the INL site since 1974-5. The material was loaded into 14 stainless-steel canisters that contained carbon-steel baskets. The blanket material was then shipped from the Michigan reactor site to the INL in 14 shipments. The canisters are 3.46 meters (134 in.) long and 64.8 centimeters (25.5 in.) in diameter. Once the canisters were loaded, they were filled with helium and seal welded. Twelve of the canisters contain the radial-blanket subassemblies and two of the canisters contain the shorter axial-blanket subassemblies. The 14 canisters are stored in a single row of storage wells on 4.6-meter (15-ft) centers. The location of the Fermi-1 blanket storage wells at CPP-749 are shown in Figure 11. CPP-749 is located at the INTEC site within the INL.

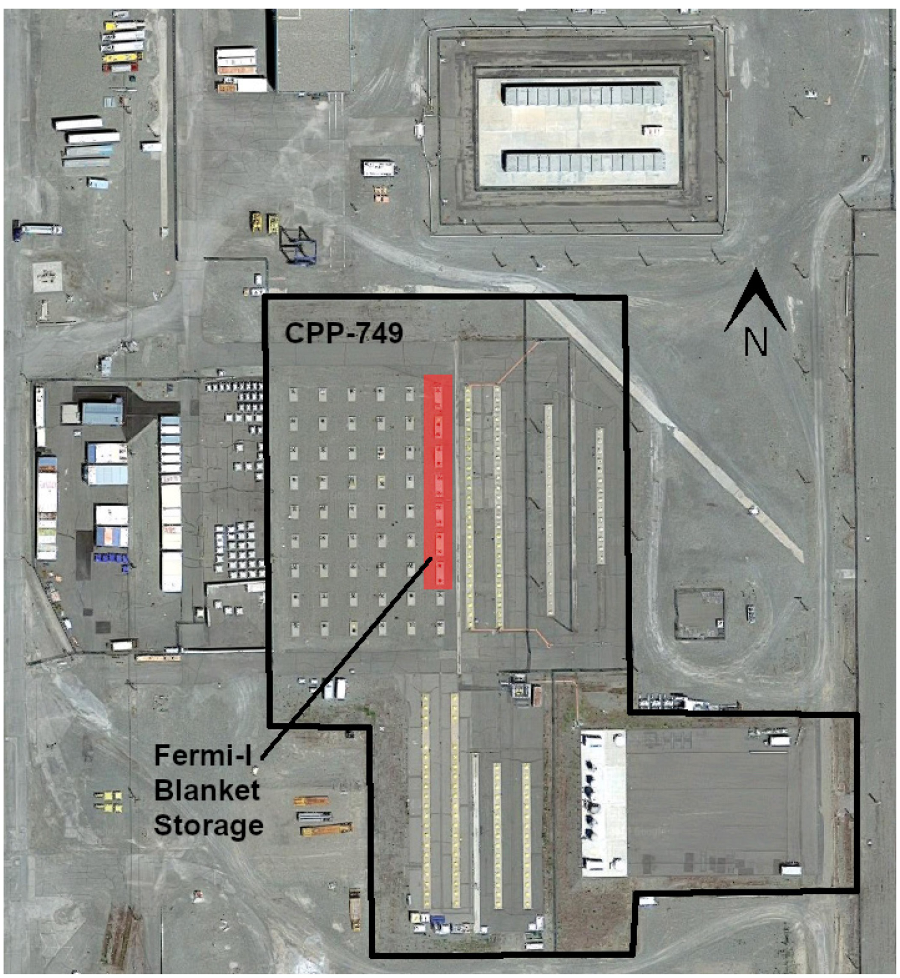

Figure 11. Location of the Fermi-1 blanket storage wells at CPP-749 are highlighted in red..

1. Characteristics of the Fermi-1 Blanket

The characteristics of the blanket material are shown in Table 2 and Table 3. Table 2 depicts the number of radial (inner and outer) blanket assemblies and axial-blanket assemblies that were shipped to INL. The characteristics of the individual blanket elements, assemblies, and composition of the blanket material are shown in Table 3.

Table 2. Individual Fermi-1 blanket assemblies and blanket elements.

Blanket Material Type	Number of Assemblies	Number of Elements (calculated)
Outer Radial	318	7,950
Outer Radial (Nozzle Removed)	168	4,200
Inner Radial (Nozzle Removed)	73	1,825
Total Radial	**559**	**13,975**
Upper Axial	202	3,232
Lower Axial (Nozzle Removed)	132	2,112
Lower Axial	69	1,104
Total Axial	403	6,448
Total number of Axial + Radial	**962**	**20,423**

Table 3. Characteristics of the Fermi-1 blanket materials.

Property	Axial Blanket	Radial Blanket
Element Description:		
Cladding material	Stainless-steel 304	Stainless-steel 304
Clad outside diameter (inches)	0.443	0.443
Clad thickness (inches)	0.010	0.010
Uranium length (inches)	14	65
Fuel elements (pins or rods) per assembly	16 in upper blanket 16 in lower blanket	25
Assembly Description:		
Cross-section shape	Square	Square
Outside dimension (inches)	2.646	2.646
Wall thickness (inches)	0.096	0.096
Number of assemblies	403	559
General Composition:		
Uranium alloy composition	U–2.75 Mo	U–2.75 Mo
Uranium-235 enrichment (percent)	0.35	0.35
Sodium (grams/element)	5.5	20.7

The radial blanket was composed of inner and outer assemblies. While the number of individual blanket elements in both types of assemblies was the same, the inner blanket assemblies comprised the first row of assemblies beyond the reactor fuel core. These assemblies were within the high-pressure sodium-coolant region of the reactor (91 psi). The outer assemblies, where neutron capture and buildup of plutonium occurred more slowly, did not require as much cooling, so they were supplied with coolant from the low-pressure sodium system (10 psi). These different pressure regimes account for the difference in the nozzle design of the two types of radial assemblies. The two types of radial assemblies are shown in Figure 12.

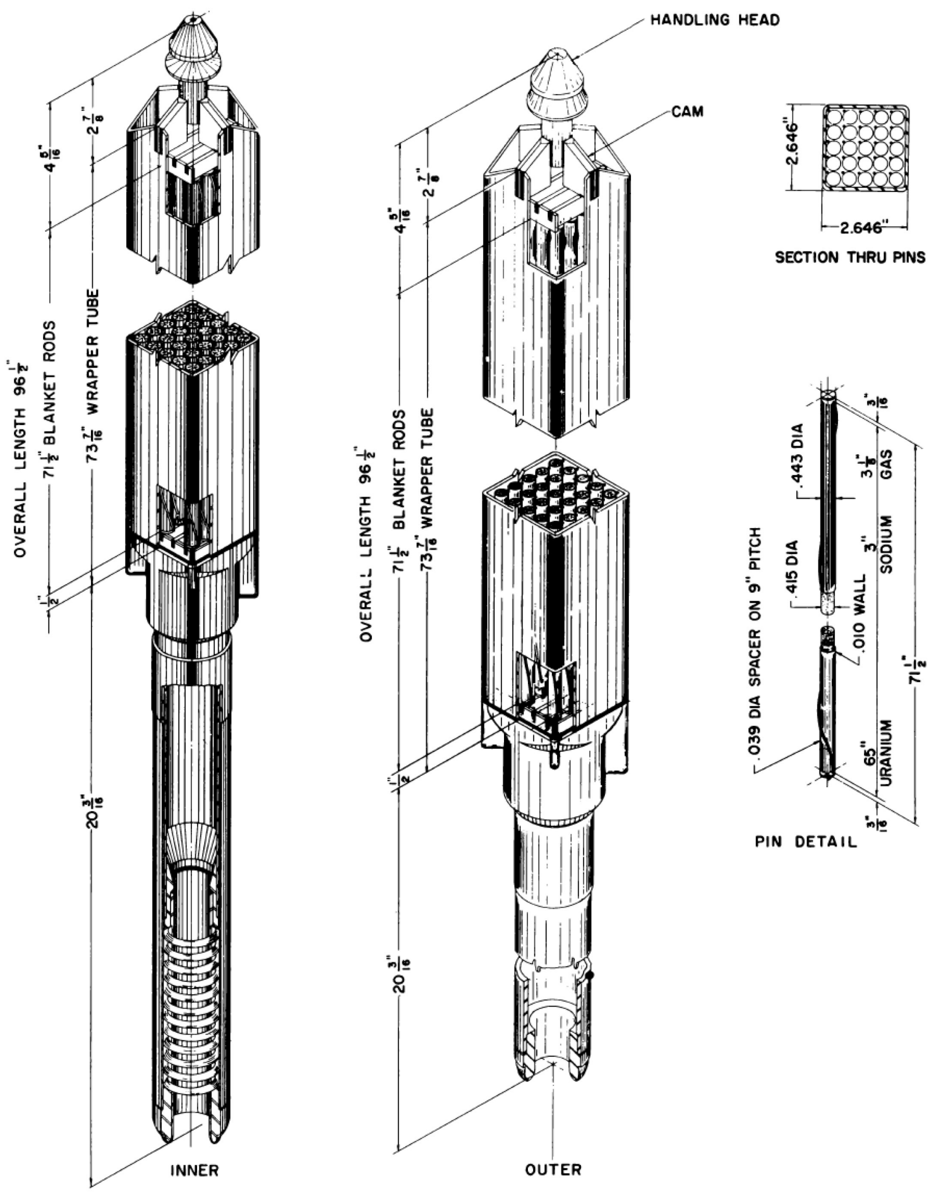

Figure 12. Inner and outer radial assemblies used in the Fermi-1 reactor.

The inner assemblies were the first row of blanket assemblies that bounded the reactor fuel core. The inner assemblies were cooled as part of the high-pressure sodium system that cooled the reactor fuel. The outer assemblies occupied 8 rows between the inner blanket and the reactor's steel rod thermal shield.

The axial assemblies were mounted above and below the fuel core as illustrated in Figure 13. The axial blanket elements were 14-in. long (35.5 cm). These were held within a 17-in. section (43 cm) as shown in the illustration). The diameter and other characteristics of the blanket elements are the same as the radial-blanket elements. There are some literature sources that state the axial-blanket elements are of a larger diameter than the radials, however, this claim has not been proven. It should be noted that if the wire used to wrap the blanket elements were a smaller diameter, then it is feasible to enlarge the axial elements. Certainly, there would be sufficient cooling as the 16 axial elements are arranged around the periphery of the assembly, leaving the center section empty. Whether the axial elements are larger or not, it is not expected to complicate the application of the MEDE process to the elements.

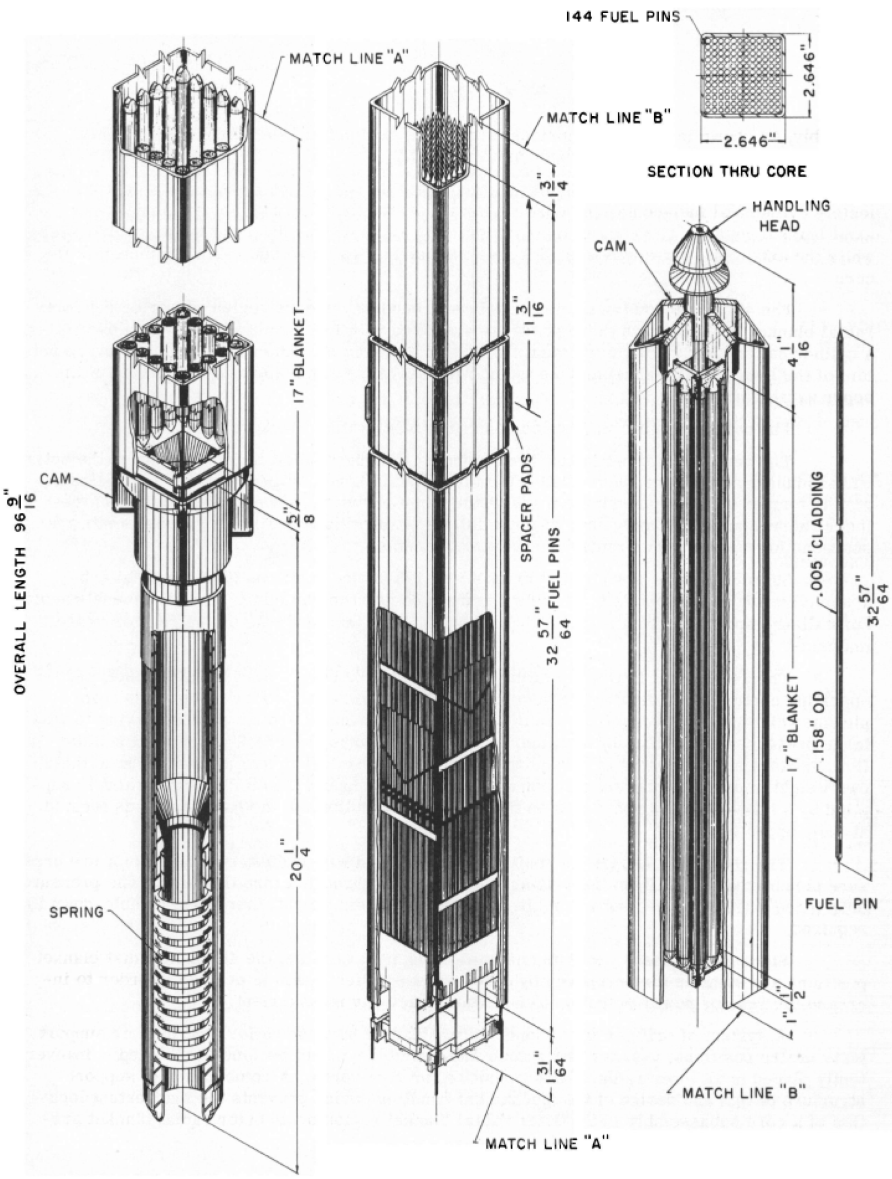

Figure 13. The axial blankets.

The axial blankets are located above and below the reactor fuel within each fuel assembly. Note the blanket elements are arranged in a 5x5 pattern, although the elements are located only in the outer layer of that pattern (yielding a total of 16 blanket elements/axial assembly).

2. Background

The Fermi-1 blanket material is currently stored at INL, awaiting removal from the State of Idaho by January 1, 2035 per the 1995 Settlement Agreement[a]. In 2000, the Final Environmental Impact Statement (EIS) for the Treatment and Management of Sodium-Bonded Spent Nuclear Fuel was issued. In the EIS, the No Action Alternative was preferred for the Fermi-1 blanket material. Under the No Action Alternative, two options were analyzed:

- Continued storage until 2035 or until development of a new or currently less mature technology to treat all or part of the sodium-bonded material.
- Direct disposal of the sodium-bonded material in high-integrity cans.

In 2009, the U.S. terminated efforts to license a proposed high-level waste, mined geologic repository at Yucca Mountain, Nevada. Under the EIS, the proposed repository represented the only disposal pathway for the Fermi-1 blanket material. However, the termination of the repository program does not absolve the DOE from its obligations under the 1995 Settlement Agreement.

As mentioned, Fermi-1 blanket material is not suitable for disposal in its current configuration, due to the reactive characteristic of its bond sodium. Consequently, a technical feasibility study to remove the bond sodium from the Fermi-1 blanket material via a melt-drain-evaporate (MEDE) process has been proposed. The evolution of the MEDE process began in the 1980s. The process was developed at ANL-W as a means for removing sodium from reactor fuels, blankets, and associated sodium contaminated components. The initial development of a melt-drain-evaporate process was also coupled with a calcine or carbonate process to treat the recovered sodium. This early melt-drain-evaporate-calcine/carbonate process was abbreviated, "MEDEC."

Early MEDEC testing focused on optimizing the parameters that would allow effective sodium removal (i.e., the vessel design, heating requirements, seal design, and vacuum requirements). Several test campaigns were completed in the early 1980s by the Sodium Waste Technology Programs using the Sodium Process Demonstration equipment. Testing demonstrated that the MEDEC process was capable of removing sodium from crevices 8-in. deep (20.3 cm) and from a slot 2-in. long and 0.005 in. wide (5 cm and 0.13 mm). Sodium was also effectively removed from mating bolt and nut threads. Sodium vapor transport tests were performed that demonstrated that MEDEC was capable of removing sodium from internal pockets through channels several feet long. These tests were followed by the processing of unirradiated blanket elements. Blanket elements were examined in the ANL-W Analytical Laboratory before and after processing and were found to be virtually free of sodium after MEDEC processing. An EBR-II cold trap, a full-scale reactor component with a highly complicated internal geometry, was also successfully cleaned.

The bulk of the sodium in the materials could be collected as liquid and transferred to a separate collection vessel. Once the bulk sodium was removed, the materials were heated under absolute vacuum to evaporate the remaining sodium, and this sodium was condensed and captured in a drain tank. The sodium was later pressure-transferred to the collection vessel. Once collected, the sodium was processed to a sodium-oxide waste form in a calciner (the first "C" in the expression MEDEC). It was later determined that sodium oxide was not a suitable waste form, and the process further evolved such that a "carbonation" process was developed to treat the sodium. This produced a sodium carbonate waste form (with the second iteration of the letter "C" becoming carbonate).

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a. The Idaho, 1995, "Settlement Agreement" is a legal agreement between the State of Idaho, the U.S. Department of Energy, and the Department of the Navy that directs the cleanup of the Idaho National Laboratory site and specifies dates when radioactive wastes must be removed from the State. https://www.deq.idaho.gov/inl-oversight/oversight-agreements/1995-settlement-agreement/

With the completion of the test campaigns, production scale operation was initiated in late 1983 to demonstrate the removal of sodium from unirradiated EBR-II fuel elements that had been fabricated with no enrichment. Four hundred of these fuel elements were successfully treated, however, at that time DOE chose to suspend operations. Then, in 1985 and 1986 the system was reactivated and was used to remove sodium from unirradiated fuel elements that had defective cladding. In addition, the blanket slugs from about 500 radial-blanket elements and 300 axial-blanket elements (also with defected cladding) were recovered. These slugs were recycled into new EBR-II and Integral Fast Reactor (IFR) fuel and blanket elements. About 1700 total defective clad items were successfully processed in this production campaign.

Between 2000 and 2003, testing was performed to qualify the MEDEC process for use on blanket materials from the Fermi-1 reactor. This testing involved both small-scale glovebox tests and bench scale testing in the Hot Fuels Examination Facility (HFEF) hot cells using irradiated, low-burnup EBR-II blanket material as a stand-in for irradiated Fermi-1 blanket material. An effort was made to minimize the vacuum requirements used in the 1980's MEDEC campaign in order to employ standard off-the shelf vacuum technology that would be "friendlier" for deployment in a hot cell. By raising the operating temperature, it was found the vacuum requirements could be relaxed.

The goals of that testing were to demonstrate sodium removal with an efficiency of greater than 99%, and to keep the treatment approach simple and cost-effective. Testing was performed in which both radial- and axial-blanket elements were segmented and subjected to the MEDEC removal process. The tests resulted in the removal of 99.80-99.97% of the sodium in the unirradiated Fermi-1 blanket material. Likewise, tests performed with low burn-up EBR-II blanket fuel were successful in removing 99.95% of the total sodium. The minimal quantity of sodium left behind was mostly in the form of sodium oxide; typically, 0.005% of the original sodium in the Fermi-1 fuel was left behind as metallic sodium. This amounts to about 1 mg of metallic sodium per radial-blanket element. No specific de minimus value for residual sodium has ever been defined by Resource Conservation and Recovery Act (RCRA) regulations. However, it was assumed that residues as low as those achieved in this study would prove acceptable for geologic disposal.

In the 2007-2008 timeframe, the "C" (carbonate treatment of the recovered sodium) in MEDEC began to be dropped. There were (and are) several methods for treating sodium waste. A new MEDE system was constructed and installed in the Fuels Manufacturing Facility (FMF) in that timeframe. Due to funding and priority constraints, the system was not used until the 2014-15 timeframe. When the system was put to use, it was used as a distillation-only system. That is, no specific temperature step was provided for draining of molten sodium. The system was simply heated to the point at which the sodium would evaporate and could be distilled. Certainly, some liquid sodium would drain from the fuel elements as they were heated, but the emphasis was placed on distillation. Approximately 7000 unirradiated EBR-II Mark 1A through Mark IV fuel elements, 150 Fast Flux Test Facility (FFTF) fuel elements from the MFF-2 through MFF-8A series, and several other items (e.g., Sandia sodium debris beds) were treated in this system. Much of the recovered uranium was utilized by BWXT's Nuclear Fuel Services to produce commercial fuel elements. Uranium oxide recovered from the debris beds and the remaining highly-enriched uranium (HEU) is still awaiting disposition at INL.

As discussed, the MEDE process has been used extensively at INL for treating EBR-II fuel, FFTF fuel, and other sodium-bearing materials. This test plan addresses the testing needed to extend the use of the process for treating Fermi-I low-irradiated blanket materials for the purpose of reclassifying this material and potentially opening other avenues for its disposition.

Appendix B

MEDE Project Parts List

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The following is a list of all the off-the-shelf parts identified in the steps above.

List of Off-The-Shelf Parts		
Quantity	**Part**	**Use**
1	Lift Table	Lifts 130lb assembly up to the glovebox port.
6	8'Lx1'D Glovebox Bag	Used to bag in 1 Assembly and 5 element bundles into the glovebox though the 12" port.
4	Roller Dollies	Rolls 1 Assembly and 1 Retort around the glovebox.
5	12" Port Plug	Used to seal off the glovebox 12" port after the Assembly and elements are bagged in. Company: CRL, Part# CRL-42971
1	Cool Saw	Cuts Assembly, elements, and cladding inside the glovebox. No sparking
4	V-block	Holds the Assembly and element cladding during cutting. Also holds the assembly, the MEDE basket, and element(s) on the large balance during weighing.
1	Waste Bag	Holds the cut scrap parts from the assembly and elements.
2	Ball Detent Rings	Lifts Retort during furnace loading and unloading. Baskets into Retort top and Retort middle. Company: Carr-Lane, Part# CL-6-LFP-0.25-S
1	Manual Deburring Tool	Used to deburr element cladding after it is cut with the saw. Aids in DU-Moly slug removal from cladding after treatment.
1	Drill Mounted Deburring Tool	Used to deburr element cladding after it is cut with the saw. Aids in DU-Moly slug removal from cladding after treatment.
1	Drill	For drill mounted deburring tool.
1	Camera	Photographs retort after the initial MEDE run and after the final MEDE run
1	Small Balance	2 lb. balance for weighing the crucible after the initial and final MEDE run and for measuring the element slugs before and after the laboratory analysis.
1	Medium Balance	35 lb balance for weighing the smaller retort parts and the MEDE basket before and after the initial and final MEDE run and for measuring the element slugs before and after the laboratory analysis.
1	Large Balance	220 lb. balance for weighing components of the retort, the filled MEDE basket, and the cut assembly before and after the MEDE treatment.
1set	Calibration Weights	Calibration weights for the balances.
3	Storage Container	Sealed storage container used to store the sodium filled MEDE crucible (approximately 4.5” OD x 6” L) following a MEDE process.
1	1/4" Metal Dowell	Help push DU-Moly slugs out of 1/2" cladding after treatment.
4	18" Graduated Cylinder	Holds alcohol to test low risk slugs and cladding for Na in the glovebox.
1	Video Camera	Records reaction between slugs, cladding, and alcohol during Na testing.
25	4'Lx1'D Glovebox Bag	Bag the Lab Transfer Cartridge in and out of the glovebox through the 12" port. Lab Manifold connection of Transfer Cartridge does not enter the glovebox.
4	Hand Wrenches	Needed in and out of the glovebox to remove and reattach Lab Transfer Cartridge ends.
2	Over pack	Container for glassy carbon crucible if damaged during MEDE treatment.

The following is a list of all the design-build parts identified in the steps above. These parts will required modeling, drafting, and fabrication at a subcontractor facility.

List of Design-Build Parts		
Quantity	**Part**	**Use and/or Added Design Feature**
1	Clam-shell Furnace	Both sides of clam shell shall swivel out. Base stand shall allow furnace to role away from mounted Retort.
1	Retort Body (Retort Top)	Interior centering fins shall allow insertion of MEDE basket. Top of Retort body shall contain hole for ball detent ring attachment.
1	Nickel Nozzle (Retort Middle)	Side of nozzle body shall contain hole for ball detent ring attachment.
1	Crucible Base (Retort Bottom)	Holds glassy carbon crucible and vacuum attachment. Base shall be of a weight and surface area that facilitates self-supporting vertical Retort (Retort >7 ft tall. Retort > 200 lbs.). Attachment for hoist.
1	Basket Rod (Retort Interior)	Rod that positively holds the MEDE basket and Assembly inside the Retort. Used for pushing in and pulling out basket and Assembly.
1	MEDE Basket	This basket shall be square in shape and slightly larger than Assembly outer dimensions to allow insertion of scrap Assembly parts from cutting operation. Basket also used to hold scrap, an assembly, a single element, and a bundle of 9 elements.
1	Retort Stop	Used during Retort Loading. Inserted into glovebox shelf holes. Provides surface for Retort to push against during Retort loading and unloading.
2	Retort Stand	Used during Retort loading. Lifts the Retort up to match the Retort hole with the Assembly when the Assembly is on its roller dollies.
1	Glovebox Block & Tackle Lid	Round glovebox roof port lid with block and tackle attachment. Used to gradually lower Retort bottom during furnace loading. Used to lift Retort bottom after treatment.
4	Crucible: Glassy Carbon	Designed to hold sodium from MEDE treatment
4	Crucible: Stainless-steel	Backup for glassy carbon crucible in case of crucible fracture
4	Lab Transfer Cartridge (LTC)	Contains 6' long 1" diameter pipe to hold both the cladding and slugs form one 6' element. Contains valve and fittings to mate with Lab Manifold.
1	Lab Manifold	Contains valves and attachments to facilitate filling the LTC with water and measuring the hydrogen released in a hydrogen analyzer.