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Packaging and Transportation Roadmap to Support Lifecycle of the USHPRR Program

Edward T. Ketusky and Jeffery L. England
Savannah River National Laboratory

ABSTRACT

The U.S Department of Energy's High Performance Research Reactor (USHPRR) conversion program is developing a low enriched U-Mo fuel as a candidate replacement for the Highly Enriched Uranium (HEU) fuel currently being used in several U.S. reactors. As part of the effort, a comprehensive packaging and transportation roadmap strategy was developed to ensure the needs and opportunities are comprehensively understood and evaluated.

The approach used in developing this packaging and transportation roadmap is considered inclusive-hybrid, where long-term needs and opportunities are fully analyzed based on the integrated USHPRR schedule, encompassing activities currently being performed as well as those planned to be performed in excess of 25 years from now, recognizing that future activities may be subject to change. To also ensure immediate/imminent needs are fully considered and appropriately prioritized, a detailed review of soon to be performed miniplate-1 (MP-1) tests was performed, where the MP-1 test results will provide the analytical results for down selecting the USHPRR base fuel process/product specifications.

To accomplish the overall-conversion, shipping of various "fresh" (i.e., both non-irradiated and unspent) materials including coupons, ingots, full size plates and assemblies will be required. Additionally, handling/shipping of post-irradiation fuels and assemblies will be necessary, and include the packaging and transportation activities of post analytical activities. This report describes the detailed MP-1 review.

BACKGROUND/APPROACH

An example of the *MP-1 Schedule* was used to identify the specific packaging and transportation events in the near phase, while providing an example of future packaging and transportation considerations applicable to each phase of the USHPRR effort. The specific packaging and transportation "events" were binned based on category of shipment, facilities involved, etc. In this manner, a list was compiled that includes packaging requirements (e.g. fuel type, size, etc.), preferred shipping packages, and shipping paths. The following were performed as part of this activity:

1.) A generic container selection and contents certification process was flowcharted. Factors affecting decision-making, such as the nature, form, and quantity or activity of the materials to be shipped were identified.
2.) An MP-1 detailed container analysis was performed.

GENERIC CONTAINER SELECTION FLOWCHART

When selecting appropriate shipping containers for nuclear material, it is important first have as much detail as possible on the material to be shipped. This includes physical form and description of material; size and mass; Isotopic and chemical characterization; desired schedule; capabilities of shipping and receiving locations; number of shipments planned; and, frequency of shipments. Figure 1 shows the general container selection flowchart developed as part of this effort.

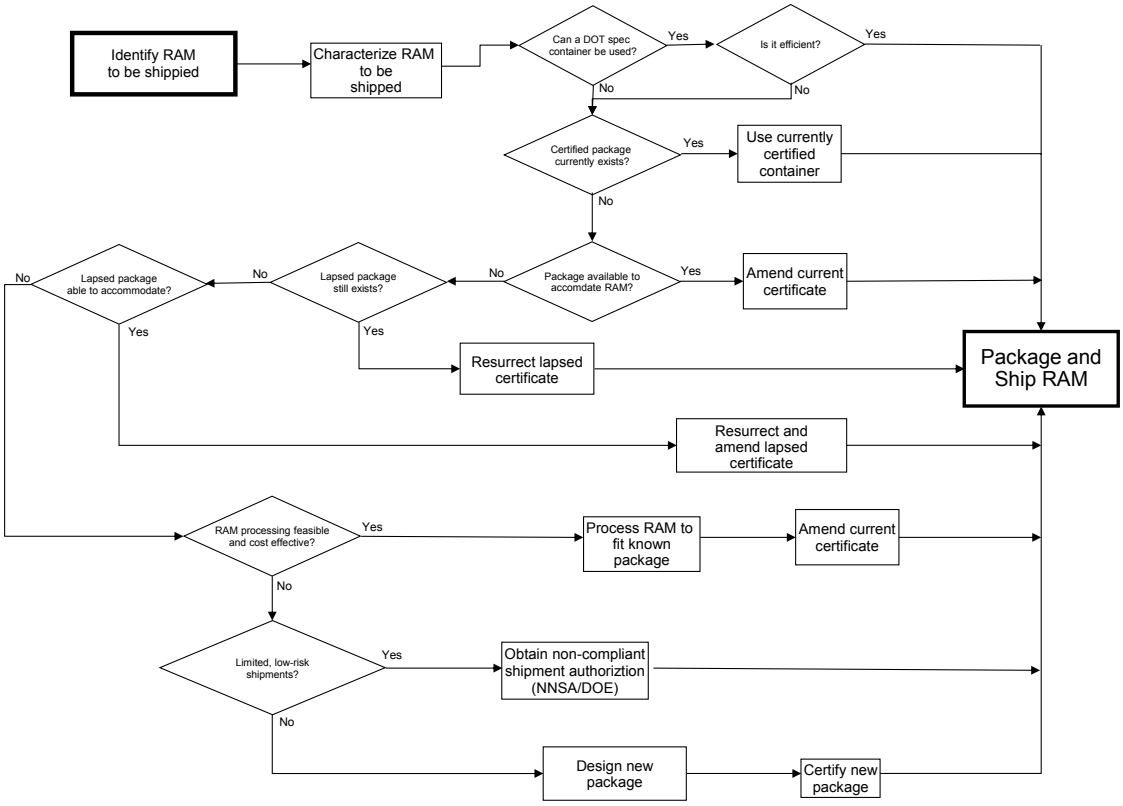

Figure 1. Flowchart for Container Selection

Certified shipping containers identity specific contents authorized to ship in their certificates. In some cases, additional contents can be added to existing certificates. Once the material to be shipped is characterized, that information will be used to research current Certificates of Compliance. If the material and shipping configuration fall within the approved contents of a package then the material can be shipped provided there are packages/containers/casks available for use. If no currently compliant or approved packages/containers/casks are found then existing packages/containers/casks will be evaluated for the possible addition of the material to the certificate. Additionally, packages/containers/casks with lapsed certifications will be evaluated to see if they can be resurrected and/or amended for use. Possible processing of material should be investigated to see whether it could be changed to be transported in an approved package configuration.

The process to develop a new shipping container, including certification, is about 3 to 5 years. That process, coupled with the manufacturer and implementation results in a 5^{+} year lead time for new containers. Before new container projects are initiated, it behooves the nuclear material program to research existing containers to determine if any can be used (or modified) for their materials. If so, a

license amendment may be needed before that container can be usable. The license amendment process is between 6 and 18 months. In either case, good planning is essential. The program's needs generally include shipment of fresh fuels, irradiated fuels, unirradiated experiments, irradiated experiments, and other fuel plate test components needed for fabrication.

The selection of a shipping container includes a focus on safety, efficiency, and effectiveness. A primary factor in improving safety, efficiency, and effectiveness is to reduce the number of times a container is handled and transported. One way to reduce handling is to increase the number of elements that can be packaged and transported at one time. For unirradiated shipments, it may also be beneficial that several containers be stackable or palletized. The impact of a change in Type B container selection on the shipping facility and receipt facility is generally manifest by significant preparation and operating cost increases.

A new Type A container used for transport of unirradiated fuels and other unirradiated materials generally has less of an impact on the facility because of the difference in rigor between the hands-on loading and handling of unirradiated materials versus the remote handling of irradiated materials versus hands-on handling of unirradiated materials. Further, Type B containers are much larger and heavier because of the shielding and confinement requirements and, therefore, require the use of cranes and large transports. Therefore, shipping containers/casks that are already approved into a facility are generally preferred because of the additional costs of getting the new casks authorized into a nuclear facility. Authorizing a new container/cask into a facility can involve the following activities:

- Nuclear Facility Safety Basis Reports (SAR) and supporting analyses revisions
- Personnel training
- New procedures
- Facility startup/readiness assessments
- Modifying or fabricating ancillary equipment and handling tools to prepare, assemble, dry, and test the fuel-loaded cask for shipment or receipt

MP-1 SHIPPING CONTAINER ANALYSIS

To help in the determination of the packaging required for MP-1, a Reactor/Fuel and Key Facilities Basic Description Table based on the USHPRR roadmap was developed as shown in Table .

Table 1. Research Reactor and Basic Fuel Description Supporting MP-1 Testing

Reactors /Fuel	
ATR	**Reactor/Fuel**: 250 MW, low temp.(160°F), low pressure(360 psia), pool type PWR at INL. The core is 4' x 4' and contains 40 fuel elements. An ATR fuel element (with box ends) is approx. 66.3" long, but only 52" when removed. The plate length is ~4' with 19 plates in each assembly. The plates have a 45-degree arc arrangement [1], with the planned fuel considered Base Monolithic. Currently ~110, assemblies/yr. are required, with only ~100 assemblies/yr. with LEU. MP testing for ATR will be performed at ATR, with PIE at INL.
MURR	**Reactor/Fuel**: 10 MW, low temp. (136°F) and low pressure (80 psia) open pool PWR. The fuel element length is 32.5", with the active length of 24". The current element used has 24 curved plates in a 45° arc, while there are only 23 fuel plates in the LEU design [2], with the LEU considered a Base Monolithic Fuel. HEU uses 23 assemblies/yr., with ~ 19 assemblies/yr. with LEU. BR2 will be used for irradiation testing to support MURR.
HFIR	**Reactor/Fuel**: 85 MW, based on a flux trap, where the core consists of 2 annular regions of fuel surrounding center. The core is cylindrical~24" x 15" dia. A 5" dia hole, referred to as the "flux trap," forms the center of the core. The fuel region is composed of 2 concentric fuel elements. The inner element contains 171 plates, and the outer element contains 369 plates. The fuel plates are curved in the shape of an involute, thus providing a constant coolant channel width. The fuel is non-uniformly distributed along the arc of the involute to minimize the radial peak-to-average power density ratio. The planned fuel is Complex Monolithic Fuel. For HEU, 7 cores /yr. are used, while under LEU ~ 7 cores/yr. are estimated. BR2 will be used for irradiation testing to support HFIR [3].
MITR	**Reactor/Fuel**: 6 MW, tank type heavy water reactor. Hexagonal core with rhombus-shaped fuel elements. Each rhomboidal fuel assembly is 26.4" long and currently consists of fifteen plates, but will be increased to 18 with the U-Mo LEU fuel. The core has 27 fuel element positions, normally configured with 24 elements and 3 positions available for in-core experiments. The close-packed hexagonal core design maximizes the thermal neutron flux in the heavy water reflector region where the re-entrant thimbles of the beam ports are located [4]. The future LEU fuel is Base Monolithic. For HEU, ~9 assemblies/yr. are currently required, while under LUE ~8 assemblies/yr. will be required. MP testing that supports MITR will be performed at ATR, with PIE performed at INL.
NBSR	**Reactor/Fuel**: 20 MW high burnup reactor. Moderation and cooling is by D_2O, which flows upward through the core from 2 concentric plena just below the lower grid plate. The NBSR includes an unfueled "gap" in the axial center of the elements, which contains moderator and structural materials. Unfueled region at core axial centerline provides flux peak for experiments. Each element is 35.5" constructed of 17 plates in each upper and lower half (i.e., 34 plates per fuel element). Each plate is curved and 13" long, with 11" of fuel. The fuel width is 2.4". There are 30 fuel elements in the NBSR core. The fuel is contained in 3 rings within a hexagonal pattern, with the inner 2 rings having 6 elements each and the outer ring having the remaining 18 elements [5]. The planned LEU is Base Monolithic. Currently for HEU ~30 assemblies/yr. are required, and will remain similar with similar with LEU. MP testing that supports MITR will be performed at ATR, with PIE performed at INL.
BR2	**Reactor/Fuel**: 100 MW BR2 is a high flux tank-in pool type reactor, completely submerged in water. The core has a diameter of 41" and a height of 37". The operating temperature is 40°C at ~ 17psia. The BR2 fuel element consists of 6 concentric fuel plates in 3 sectors. The outer diameter of the element is about 3" while the fuel is about 30"long [6]. BR2 will be used for irradiation testing to support MURR and HFIR.

In addition to reactors, there are key research and test facilities associated with MP-1. Table identifies key research and test facilities associated with the USHPRR.

Table 2. Key Research/ Test Facilities Basic Descriptions

Facility	Description or Planned USHPRR Support
ATRC	Referred to as the Advanced Test Reactor Critical (ATRC) facility. It is a full-size replica of the ATR operated at 5 kW max. It is used to evaluate impacts on ATR core experiment assemblies.
INTEC	Idaho-Nuclear Technology and Engineering Center, Tank Farms and Spent Fuel Storage.
MFC	Idaho Material and Fuels Complex, includes HFEF, location where the MP PIE activities will be performed.
HFEF	Idaho-Hot Fuel Examination Facility, part of MFC. Located about 20 miles from ATR.
B&W	Babcock and Wilcox, Nuclear Operations Group, Lynchburg, VA., where fabrication activities will be performed.
OSU	Oregon State University, location for flow testing.
LTC	Lead Test Core.
HMFTF	Hydro-Mechanical Fuel Test Facility (at OSU), facility used to develop hydro-mechanical a database supplementing qualification of prototypic fuel.
BR2	BR2 is currently identified within this document for completeness, but is not within USHPRR conversion scope
Y-12	Primary supplier of fuel material to B&W.
PNNL	Laboratory where zirconium electroplating will be performed on MPs, prior to completion of fabrication.

Facility	Description or Planned USHPRR Support
LANL	Laboratory where zirconium plasma spray will be performed on MPs, prior to completion of fabrication.

When considering the transport of the fuels both to and from reactors and test facilities, the fuel sizes and restrictions must be considered. Table summarizes the current reactor fuel restrictions and sizes that will affect the USHPRR Program.

Table 3. Summary of Fuel Restrictions / Sizes

Research Reactor	Fuel Restrictions / Sizes
MURR	DSA prohibits LTAs, tested using DDE's
NBSR	DSA prohibits LTAs, tested using DDE's
HFIR	Safety Analysis revised to allow use of 1 HEU and 1 LEU LTAs, DDE's, will be irradiated at BR2
MITR	DSA prohibits LTAs because of mixed fuel, therefore tested using DDE's
DDE-MURR	Designed for H position in Belgium Reactor 2
ATR Fuel Element	66.26 inches
ATR-FE w/ end boxes cut-off	52 inches
AFIP Full Size Plate	45.75 inches
DDE-NBSR Fuel Element	45.5 inches
DDE-MURR Fuel Element	32.5 inches
DDE-MITR Fuel Element	28.25 inches
MIT Fuel Element	26.36 inches
Mini-Plate Capsule	8.46 inches
DDE HFIR	31 inches
MP Capsule (4 stacked in container)	Approximately 34 inches

Table lists the shipping containers that have been identified for use in shipping the coupons and ingots as part of the USHPRR U-Mo monolithic fuel program.

Table 4. Shipping Containers for Coupon and Ingots

Coupon and Ingot Supporting Containers	
ES-3100 (Existing number approx. 600)	Designed to transport bulk high-enriched uranium in various forms. Cylindrical container composed of an outer drum and an inner containment vessel. The containment vessel is surrounded by a cement borated neutron absorber. The outer drum assembly consists of a stainless steel, standard mil spec 30-gal drum with an increased length. The volume formed between the drum and the attached inner liner is filled with Kaolite 1600™, which is comprised of concrete and vermiculite. The Kaolite 1600™ acts as both a thermal insulating and an impact limiting material. The lid assembly consists of a sealing lid, a closure nut, and external retaining ring, which holds both the assembly and closure nut together. The double ethylene-propylene elastomer O-rings in the top flange of the containment vessel permit leak testing of the containment vessel. The maximum gross weight of the package, including contents, is 420 lbs. The containment cavity is approx. 5” dia x 31“ [7]. **Currently:** under timely renewal.
ES-2100 (Number TBD)	The ES-2100 is a 55-gal, stainless steel drum that is 22.5” in dia and 34.75” tall fabricated from 16-gauge, 304 stainless steel. The package has an integral annular liner and the space between the liner and outer shell is filled with Kaolite 1600™, a mixture of cement and vermiculite, cast in place. A stainless steel structural member that attaches the annular liner shell to the drum forms the base for 18 threaded studs that are used to secure the drum lid in place. Inside the annular liner is placed a polyurethane insert that provides cushioning for the containment vessel [8]. The containment cavity is approx. 8”dia x approx. 20” long. **Certification:** Currently not approved for use, but anticipated as a soon available option.

Table lists the shipping casks that have been identified for use in shipping the Fresh Fuel associated with the USHPRR U-Mo monolithic fuel program.

Table 5. Shipping Casks Associated with Fresh Fuel

Fresh Fuel Casks	
ATR FFSC (Approx. number available for use =3)	**Details:** ATR Fresh Fuel Cask is used for most shipments from B&W (originally ATR, MURR, and MITR). The body is composed of two thin-walled, stainless steel shells. The outer shell is a square tube with an 8” cross section, a 73” length, and a 3/16” wall thickness. The inner shell is a round tube with a 6“dia and a 0.12” wall thickness. The inner tube is wrapped with ceramic fiber thermal insulation, overlaid with a stainless steel sheet. At the bottom end, the shells are welded to a 0.88” thick stainless steel base plate. At the top end (closure end), the shells are welded to a 1.5” thick stainless steel flange. The internal cavity has a 5.75” dia and is 68” long [9]. **Certification:** USA/9330/AF-96, expires on 1/31/2019.
NBSR FFSC (number available for use =1)	**Details:** Model called ST in NRC Certificate. A closed steel pipe for the transport of an unirradiated research reactor fuel element. The pipe is a 5.5” OD carbon steel pipe, ~71” long, with a closed bottom end and flanged top end. The top end is closed by a cover plate, which is ¼” thick and 6.5”in dia, with a gasket. The cover plate is secured to the pipe flange by 8 cap screws. A wooden nozzle support, bottom support and top support position the fuel element within the pipe The package weighs approximately 75 pounds including the fuel element [10].The internal cavity has an approx. 5” dia and is 70” long. **Certification:** USA/9246/AF expires on 1/31/2017.
HFIR FFSC (Approx. Number available for use 7)	**Details:** Packaging for unirradiated radioactive material as fuel elements for the HFIR. The containers are right circular cylinders with an 11-gauge carbon feel steel. The lid is attached to the container with sixteen 3/8” steel bolts. The steel sheet is filled with stacked fir plywood rings. The plywood rings form a central cavity that is lined with 1” thick polyethylene foam. The packaging for the inner HFIR fuel element has overall dimension of 25” OD by 45” high, 10-7/8” dia by 30.25” deep cavity, and a 660-pound gross weight. The packaging for the outer HFIR fuel element has overall dimensions of 31.5” OD by 45.75” high, and a 1,050-pound gross weight [16]. The internal cavity has a 17-3/8” dia and is 31-1/8” long [11]. **Certification:** NRC Certificate, USA/5797/B(U)F expires on 10/31/2017.
TN-BGC1 (TBD)	**Details: I**AEA 96 TSR-1 regulation for air and surface transport. Used in Europe, North America, Russia. The internal cavity is 7” dia and 58” [12]. **Certification:** USA/5797/B(U)F) expires 6/30/2018.

Table lists the shipping casks that have been identified as being associated with Spent Nuclear Fuel with the USHPRR Program.

Table 6. Shipping Casks Associated with Spent Fuel

Spent Fuel Casks	
BRR Cask (Approx. number available for use =1)	Used to transport fuel elements that have been irradiated in various test and research reactors, including MURR, MITR, ATR, and TRIGA reactors. The package has been developed to transport irradiated research reactor fuel. The fuel is primarily of two basic types: highly enriched Al-U plate fuel, and TRIGA fuel of varying enrichments. Within the package, the fuel is contained in basket structures specifically designed for each fuel type, and that provide for optimum heat rejection and criticality control. The packaging consists of a payload basket, a lead–shielded cask body, an upper shield plug, a closure lid, and upper and lower impact limiters. The package utilizes ASTM Type 304 stainless steel as its primary structural material. Internal cavity is ~15.6”dia x 53. 5” tall [13].
Idaho Internal Transfer Cask (Number available for use =1)	Used to support irradiated experiment shipments from the Advanced Test Reactor (ATR) at Idaho National Laboratory's (INL) ATR Complex to the Hot Fuel Examination Facility (HFEF) at INL's Materials and Fuels Complex (MFC). However, due to changes in GE-Hitachi’s business model, the continued availability of the GE Model 2000 cask is not guaranteed. Furthermore, the internal cavity of the GE Model 2000 cask is too short to support shipment of some larger M^3 experiments. The current plan is to develop and implement a process and equipment changes to allow qualification and use of the Battelle Energy Alliance, LLC (BEA) Research Reactor (BRR) cask for transferring M^3 Reactor Conversion Program irradiated experiments from the ATR canal to the HFEF Main Cell as an option to, or in place of the GE Model 2000 cask. [14].
GE-2000 (Number available for use=1)	Used for shipment of spent fuel from HFIR to SRS. Also used at Idaho for onsite shipments. It is a stainless steel transportation cask, lined with lead shield. It was purchased offsite transfer of HFIR and other DOE and university research reactor waste, including irradiated fuel rods and byproduct, source, or special nuclear materials. The internal cavity has a 26.5” dia x 54” long [15].
TN-106 (Number available for use=1)	The TN-106 is approved for international shipments by the U. S. Department of Transportation. Contents are limited to Content 26 as described in Appendix 26 to the French Certificate. Approved contents include uranium, plutonium, americium, neptunium, and/or technetium under metallic or nitride form. The internal cavity has a 7.9” dia and is 87 to 94” tall [16]**.**
NAC-LWT (Current number TBD)	NAC-LWT is a steel-encased, lead-shielded shipping cask. NIST has used the NAC-LWT, Certificate of Compliance No. 9225 shipping cask for the past three rounds of spent fuel shipping. Each cask can hold up to 42 NBSR elements, or 84 fuel sections. Three casks were shipped in 1997, two casks in 1999, and three in 2003. The dimensions of the internal cask are 13.4” dia x 178” long [17].
ATR Spent Fuel Cask (SFC)	The BRR will be used in the immediate future.
NBSR SFC	The BRR will be used in the immediate future.

A review of the NRC/DOE/IAEA Certificate of Compliance (COC) type documents were performed as part of ensuring that comprehensive containers/alternatives was performed. The results, with many of the larger spent commercial fuel casks eliminated because of extremely large length, are shown in Table 7.

Table 7. Alternative SNF Casks Considered

Package	Owner	Cavity Dimension	Load
ES-4100	DOE	5” dia x 58” tall	Transport bulk high enriched U in various forms. Four containment vessels per drum. **Certification:** Pending licensing.

Package	Owner	Cavity Dimension	Load
TRIGA-I	General Atomics	5” dia x 21” tall	TRIGA fuel elements containing uranium-zirconium-hydride or erbium-U-Zr-hydride whose fuel portion has nominal compositions clad with stainless steel, aluminum, or incoloy. Uranium is enriched to a maximum of 93.5 wt. % U-235. The H_2 to Zr atomic ratio within the fuel meat is restricted to less than 1.65 [18, 19]. C**ertification** USA/9037, 9034/AF expires on 12/31/2015.
TRIGA-II	General Atomics	5”dia x 50” tall	
JRF-90Y-950K	Japan Atomic Energy Agency	33”dia x 71’’ tall	Fresh fuel & low irradiated fuel [20]. **Certification:** DOT-IAEA Certificate, USA/0452/B(U)F-96 expires on 8/20/2017.
JRC-80Y-20T	Japan AERI (JAERI)	TBD	Irradiated MTR and TRIGA Fuel [20].**Certification:** USA/0208/B(U)F-96, expires on 8/20/2017.
JMS-87Y-18.5T	Rikkyo University, Japan	TBD	Irradiated MTR and TRIGA Fuel [20]. **Certification:** USA/0401/B(U)F-96 expires on 9/11/2018.
GNS-16	AREVA	TBD	The cask accommodates the basket that consists either of rectangular or circular shafts made of stainless steel or cast aluminum. The max. capacity of a basket is 33 fuel elements [21].**Certification:** Expired.
TN-7/2	Trans-Nuclear and NCS	TBD	The cavity of the cask accommodates the basket that consists either of rectangular or circular shafts made of stainless steel or cast aluminum. Max. capacity of basket is 64 elements. **Certification:** Expired.
TN-MTR	Trans-Nuclear	38” dia x 42.5” long	U.S. validation of the French certificate of approval F/357/B(U)F-96 (Ct) for the package design consisting of the TN-MTR loaded with either a MTR-52S or a MTR52SV2 basket and their respective authorized radioactive contents #4 and #9 (fuel assemblies irradiated in a MTR) U.S. validation of the French certificate of approval F/357/B(U)F-96 (Ct) for the packaging TN-MTR provided with the "SEC" lid [22]. **Certification:** Expired.
BM-1	DOE Idaho	15.5” dia x 54” tall	Irradiated TRIGA, MURR, MITR and HFIR type fuels [23]. Previously used for onsite shipments at INL, “replaced” with the GE-2000. **Certification:** DOE, USA/5957/B(U)F(DOE) expires on 9/30/2015. **Note: In commerce shipment are prohibited.**
AECL-CRL IRRADIATED PACKAGE	Atomic Energy of Canada Limited	5.6” sq.x 25.98” tall	Irradiated CANDU Fuel [24]. **Certification:** USA/0553/B(U)F-96 expires on 5/31/2018.
9975	DOE SR	5” dia x 15” tall	Type B quantities of U, PU metal oxides, and Np oxides; generally, in food pack can [25, 26, and 27]. **Certification:** • USA/9975/B(M)F-96(DOE) expires on 6/30/2018. • USA/9977/B(M)F-96(DOE) under renewal. • USA/9978/B(M)F-96(DOE) expires on 4/30/2019.
9977	DOE SR	5.95” dia x 20.25” tall	
9978	DOE SR	5.02” dia x 15” tall	

CONCLUSION

The approach used in developing this packaging and transportation roadmap was an inclusive-hybrid, where long-term needs and opportunities were analyzed based on the integrated USHPRR schedule, encompassing activities currently being performed as well as those planned to be performed in excess of 25 years from now, recognizing that future activities may be subject to change. To also ensure

immediate/imminent needs are fully considered and appropriately prioritized, a detailed review of soon to be performed miniplate-1 (MP-1) tests was performed, where the MP-1 test results will provide the analytical results for down selecting the USHPRR base fuel process/product specifications.

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