USED FUEL TESTING TRANSPORTATION OPTIONS -DRAFT

Fuel Cycle Research & Development

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EXECUTIVE SUMMARY

This report fulfills milestone M4FT-15PN0813014 "Transportation of Used Fuel Segments" under work package FT-15PN081303.

This report evaluates available shipping packages/casks for use by the Used Nuclear Fuel Disposition Campaign Program (UFDC) to ship fuel rod pieces from high-burnup used nuclear fuel (UNF) assemblies to and between U.S. Department of Energy (DOE) research facilities for purposes of evaluation and testing in support of the high burnup nuclear fuel (HBU) Confirmatory Demonstration. The package that is recommended for the transport of contaminated HBU fuel cladding is also evaluated.

This report identifies potential options for the transport of 6- to 10-in.-long high burnup used fuel rod segments taken from high burnup pressurized-water-reactor (PWR) fuel assemblies. Also identified are the actions that would need to be taken, if any, to obtain U.S. Nuclear Regulatory Commission (NRC) or other regulatory authority approval to use each of the packages and/or shipping casks for this purpose.

Six packages were identified for the shipment of HBU fuel segments. Most of the packages (some are shipping casks) would require modification of their certificates of compliance (CoCs), safety analysis reports for packaging (SARPs), and possibly their designs to accommodate HBU fuel segments. However, one package, the 10-160B cask, has a current CoC that authorizes a broad range of fissile material contents and has a history of use in transporting a wide range of radioactive material contents. These two factors along with consideration for experience of DOE sites with the 10-160B cask suggest it can be easily adapted for transporting HBU fuel segments. Therefore, the evaluation recommends use of the 10-160B cask for the UFD project to support the sister pin segments transportation. Additionally, the 9975 shipping package is recommended for the transport of contaminated HBU fuel cladding segments.

The HBU Confirmatory Demonstration is expected to provide data about the dry storage of fuel under prototypic conditions. This will be important to the U.S. nuclear power industry, which will be required to store HBU UNF for many years. Those data will also serve to assist the UFDC in confirming and validating models used to predict UNF properties for extended storage periods.

The demonstration benefits UFDC in other ways. The 25 HBU fuel rods represent the first fully intact HBU fuel rods available to the national laboratories for testing. In addition to the characterization data requested by the Electric Power Research Institute (EPRI) team to document the initial conditions of the fuel that will be loaded into the demonstration cask, there will be the opportunity to do more characterization and testing to satisfy UFDC needs.

As proposed, the 25 fuel rods will be shipped to a laboratory for examination and testing in an unaltered state, preserving the characteristics of the fuel as it was stored in the spent fuel pool. A partial list of the examinations and tests needed to be conducted includes:

- detailed visual examination of the fuel rod clad surfaces
- eddy current examination for defects and oxide layer thickness on the fuel rod clad
- gamma radiation analysis to determine the location of specific fission products in the fuel
- length and profilometry to establish the initial length and diameter of fuel rods

- neutron radiography to determine location of internal fuel pellets and the extent of bonding of fuel pellet and cladding that occurs during reactor service
- determination of the fuel rod internal pressure, gas volume, and the percent release of fission gases that are generated during reactor service
- microscopy to evaluate the microstructural characteristics of the fuel rod
- mechanical properties tests to determine the initial strength of the fuel rods and individual components (i.e., clad, bonding layer of fuel meat and clad).

The data from these tests can be used to support predictive modeling and simulation of high burnup used fuel properties that will then be confirmed at the end of the demonstration when sister cask is opened, the fuel recovered, and those aged fuel rods subjected to similar characterization. All of these data can be used by industry in support of their extended dry storage licensing strategies and to support certification of transportation casks for shipping high-burnup and long-cooled used nuclear fuel.

The report identifies and evaluates the potential use by the UFDC of shipping casks and packaging to ship commercial nuclear power reactor fuel rod segments. This analysis evaluates potential casks and packages with respect to how well their use would support the UFDC research and development testing objectives.

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ACRONYMS

ANL	Argonne National Laboratory
ASME	American Society of Mechanical Engineers
ASME B&PVC	ASME Boiler and Pressure Vessel Code
ASTM	ASTM International (formerly American Society for Testing and Materials)
ATR	Advanced Test Reactor
BEA	Battelle Energy Alliance
BRR	BEA Research Reactor
BWR	boiling water reactor
CoC	certificate of compliance
CV	containment vessel
DOE	U.S. Department of Energy
DOE-EM 33	DOE Office of Environmental Management, Office of Packaging and Transportation
GWd/MTU	gigawatt-days per metric ton of uranium
HAC	hypothetical accident condition
HBU	high-burnup nuclear fuel
HEU	highly enriched uranium
INL	Idaho National Laboratory
LEU	low enriched uranium
LWR	light water reactor
MOX	mixed oxide
LWT	legal weight truck
MWd/MTU	megawatt-days per metric ton of uranium
N/A	not applicable
NAC	NAC International (formerly Nuclear Assurance Corporation)
NNSA	National Nuclear Security Administration
NRC	U.S. Nuclear Regulatory Commission
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PWR	pressurized water reactor
R&D	research and development
RH-TRU	remote handled transuranium (waste)
ROM	rough order of magnitude

SAR	safety analysis report
SARP	safety analysis report for packaging
SET	separate effects testing
SNF	spent nuclear fuel
SRNL	Savannah River National Laboratory
SST	small-scale testing
TID	tamper-indicating device
TRIGA	Training, Research, Isotopes, General Atomics Reactor
TRU	transuranic
UFDC	Used Fuel Disposition Campaign
UNF	used nuclear fuel

USED FUEL TESTING TRANSPORTATION OPTIONS

1. INTRODUCTION

The U.S. Department of Energy's (DOE's) Used Fuel Disposition Campaign (UFDC) Program plans to transport high-burnup nuclear fuel (HBU, burnup exceeding 45 gigawatt-days per metric ton of uranium [GWd/MTU]) from domestic nuclear power plants to DOE national laboratory facilities, and between laboratory facilities for purposes of evaluation and testing. The evaluation and testing of high-burnup used nuclear fuel (UNF) is integral to DOE initiatives to collect information that is useful in determining the integrity of fuel cladding for safe transportation of the fuel in the future, and for determining the effects of aging on the integrity of UNF subjected to extended storage and subsequent transportation. The UFDC began identifying the research and development (R&D) opportunities (Hanson et al. 2012) necessary to establish the licensing basis for extended storage; including storage of high-burnup light water reactor (LWR) fuels. These R&D needs have been evaluated using a requirements analysis methodology to define the programmatic capabilities required. An overview of spent nuclear fuel transportation is provided by the Electric Power Research Institute (EPRI 2004).

This work addresses the R&D opportunities associated with research data for high-burnup fuel samples. More research is needed because limited information is available on the properties of high-burnup fuel, and because much of the fuel currently discharged from today's reactors exceeds this burnup threshold. As the burnup of fuel increases, a number of changes occur that may affect the performance of the fuel, cladding, and assembly hardware in storage and transportation. These changes include increased cladding corrosion layer thickness, increased cladding hydrogen content, increased cladding creep strains, increased fission gas release, and the formation of the high-burnup structure at the surface of the fuel pellets. One of the focuses of the UFDC will be to obtain the data on high-burnup fuel and the newer cladding materials and develop a technical basis for determining how the storage and transportation systems perform to address the growing inventory of high-burnup fuel.

To meet UFD's research objectives, including establishing the licensing basis for extended storage, this report evaluates multiple options for transporting used fuel to and between research facilities for testing. Specifically, the report identifies for evaluation the transportation packages and shipping casks that are candidates to transport used nuclear fuel to support the research program's objectives. The report lists the transportation packages and shipping casks based on factors that gauge their viability for use.

The UFDC Program plans to partner with the U.S. commercial nuclear industry to identify and obtain UNF for testing. Individual fuel rods are needed for both separate effects testing (SET) and small-scale testing (SST), whereas entire assemblies may be necessary for SST. It is assumed that the UFDC Program would need to provide funding to the owner(s) of suitable transportation casks to obtain amendments to the U.S. Nuclear Regulatory Commission (NRC)/DOE certificates of compliance (CoCs) for the casks, if needed. Then, the casks could be used to ship the selected high-burnup nuclear fuel rods and/or assemblies to a national laboratory. It is possible that the privately owned casks could also be used to ship segments of high-burnup fuel rods between laboratory facilities.

The high-burnup UNF rods or assemblies will be characterized by visual examination, reactor records, and other physical examinations at the commercial nuclear power plant(s) before shipment. Following delivery to a host hot cell facility, the UFDC Program researchers plan to further characterize the fuel and then segment a selection of high-burnup fuel rods into 6- to 10-in.-long sections (assumed for the purposes of this study, based on the sizes necessary for the currently planned SET) so that the nuclear fuel and cladding can be more easily examined and transported to other laboratories for independent and laboratory-specific SET. It is assumed Idaho National Laboratory (INL), Pacific Northwest National Laboratory (PNNL), Oak Ridge National Laboratory (ORNL), and Savannah River National Laboratory (SRNL) will be capable of receiving segments of UNF with the fuel still in the cladding. The researchers also plan to ship sections of cladding with the nuclear fuel removed to Argonne National Laboratory (ANL) for SET.

While options for transporting full-length fuel rods or assemblies appears to be limited to a currently licensed cask (NAC-LWT), options are available for selecting packaging or casks to transport segments of fuel rods. Selection from among the options will depend on the quantity, burnup, cooling time, and size of segments to be shipped. As a follow-on and update to a report that evaluated the potential shipping options in FY 2014 (Ross et al. 2014), this report was prepared to select a transportation option to transport used fuel that facilitates the greatest possible range of samples for testing. To that end, this report focuses on the objective of shipping used fuel segments. The report also contains updated information that significantly changes the findings of the 2014 report regarding the transportation packages being recommended for use to ship samples. The 9977 package, which was identified as the preferred alternative in the 2014 report, is no longer recommended because independent funding to upgrade its design, safety analysis report, and CoC has been withdrawn. Also, the 10-160B cask is now recommended for use because an estimate obtained from EnergySolutions, Inc. (EnergySolutions), for the cost to obtain an amendment to the cask's CoC to allow shipment of HBU samples is significantly less than the estimate reported in the 2014 report. Lastly, this report recommends selection of the 9975 package to transport samples of fuel rod cladding that would be contaminated by high-burnup nuclear fuel—a purpose not addressed in the 2014 report.

Section 2 of this report briefly describes the testing to be accomplished by identifying a package for transport of high-burnup fuel segments. Section 3 briefly discusses the capabilities of the shipping and receiving facilities to be evaluated as the needs of the program are better defined. Section 4 describes the packaging options for shipment of fuel segments. Section 5 presents a summary of the findings of this report.

2. USED FUEL DISPOSITION TESTING

To support HBU fuel testing, up to 25 HBU fuel rods will be removed; prepared for shipment using normal, approved vacuum-drying procedures; and shipped to a national laboratory for detailed nondestructive and destructive examination. These “sister rods” have very similar characteristics to those that will be stored in the HBU Confirmatory Demonstration and will be taken from either assemblies having similar operating histories (symmetric partners) to those that are selected for storage in the demonstration. The detailed examination at the national laboratory will provide essential information on the physical state of the high burnup rods and the fuel contained in the rods prior to the loading, drying, and long-term dry storage process. Similar tests are to be performed at the end of the long-term storage period to identify any changes in the properties of the fuel rods during the dry storage period.

The testing that will be accomplished under the UFD R&D testing program includes:

- Nondestructive examinations of fuel assemblies and individual rods
  - visual, leak testing, dimensional measurements, eddy current flaw detection, among others
- Destructive examinations
  - fission gas analysis
  - cladding mechanical properties
  - cladding microstructure examinations
  - fuel pellet characterizations.

As currently envisioned, the program will be conducted in two phases: the first to formulate a technical basis for extended dry fuel storage; and the second is to validate that basis. Formulating the technical basis will involve initial testing of fuel rods, rod segments, and cladding. Validating the basis will be dependent on periodic evaluations of the dry stored fuels, rod segments, cladding, and storage systems at specified time intervals.

Formulating the technical basis will require receiving and examining a moderate amount of used fuel rods representing a sampling of typical fuels and storage system components. The fuel rods will require sectioning along with fission gas analysis as they are being sized. The resulting fuel rod samples will be tested based on the R&D needs required to establish the basis.

For validation, an assortment of fuel assemblies will have a baseline examination and then be stored in various dry storage systems for a predetermined amount of time. At a specified time, some of the fuel assemblies will be removed from the dry storage systems and undergo examination and testing. Some fuel rods will be extracted from these assemblies for detailed testing similar to the initial tests performed to formulate the basis. Techniques to induce accelerated aging are envisioned. Intact fuel would then be returned to dry storage for further aging with the intent of subsequent re-examinations at specified time intervals.

2.1 National Laboratory Testing Scope

The specific testing to be performed at national laboratories will be described in a future document.

2.2 Used Fuel Transportation Requirements

The evaluation of packages that could be used to transport segments of high-burnup fuel rods assumed the segments would be taken from fuel rods from a 17x17 pressurized water reactor (PWR) fuel assembly and could be up to 6 to 10 in. long. To bound the radiation and radionuclide contents for a single package in a shipment, the evaluations assumed that the burnup of the fuel in each individual segment could be as high as the worst-case pin from the sister pins being evaluated (58,000 MWd/MTU). The cooling time would be as low as 5 years, and the initial enrichment of the fuel would be 5 wt% ^{235}U. The number of segments to be transported in a single package will be determined. The number of samples required for evaluations and testing at the research facilities will be determined by the specific tests being conducted.

3. SHIPPING AND RECEIVING FACILITIES CAPABILITIES

The specific capabilities of each of the potential shipping and received facilities will be investigated as the needs of the program are better defined. Based on past operating experience of the facilities, it is expected they have capability to handle the packages and casks described in this report.

4. TRANSPORTATION OPTIONS FOR USED NUCLEAR FUEL

This section describes the options evaluated and presents the preferred option based on the evaluation criteria for the transportation package for segments of used nuclear fuel rods. The criteria for selecting a package for this purpose, including any needed changes to the package's safety analysis report for packaging (SARP) CoC to accommodate segments of high-burnup used nuclear fuel rods are also discussed. The objective was to find a package providing the UFDC Program a practical and economical means to transport segments of high-burnup UNF fuel rods from 6 to 10 in. long. The reviewed packages are described, including limitations on contents currently authorized by their CoCs. For each of these casks, the feasibility of obtaining regulatory approval to use the cask to transport high-burnup used nuclear fuel is considered, as well as estimates of the costs to obtain the necessary approvals. Also discussed are the transportation options for a shipping package for contaminated cladding.

4.1 Fuel Characteristics

The fuel to be analyzed by the UFD research testing program will be high-burnup fuel rods removed from fuel assemblies discharged from a commercial nuclear power reactor. The fuel rods will be shipped to the host laboratory where they will be received and cut into segments. Some of the fuel rod segments will be prepared for subsequent shipment to other laboratories. A range of rod segment lengths up to 10 in. shipped from the host facility provides flexibility to select a transportation package and also for the destination facilities, regarding the size of rod segments they could elect to receive. The number of rod segments that will be needed by a facility will be determined based on the types of tests to be conducted and the range of characteristics of the used fuel to be tested. The expected burnup of the fuel will be greater than 45,000 MWd/MTU. For purposes of evaluating transportation casks and packaging PWR fuel having a burnup of 58,000 MWd/MTU, 5 wt% ^{235}U and 5-year cooling was chosen. These characteristics are representative of the "worst case" sister pin in the testing program.

4.2 Transportation Packages

Table 4-1 presents the casks/packages evaluated to ship fuel rod segments associated with the sister fuel for the DOE UFD research program. Each cask/package is evaluated in more detail in the following sections.

4.2.1 NAC-LWT Cask

The NAC-LWT cask (USA/9225/B(U)F–96) is a steel-encased, lead-shielded shipping cask with a forged stainless steel lid and 12 closure bolts, tailored payload baskets to the contents being shipped, water-ethylene-glycol neutron shield, and top- and bottom-end impact limiters (Figure 4-1). The cask is designed to transport one PWR assembly or two boiling water reactor (BWR) assemblies by truck. Five of the legal weight truck (LWT) casks are owned and offered for use by NAC International, based in Norcross, Georgia.

The LWT cask CoC authorizes its use to ship research reactor spent fuel, nuclear power plant spent fuel assemblies and fuel rods, and other irradiated materials. When used to ship commercial nuclear power reactor fuel rods, the maximum burnup authorized by the CoC is 80,000 MWd/MTU. For fuel assemblies, the maximum authorized burnup is 35,000 MWd/MTU. The CoC authorizes shipment of up to 25 individual fuel rods with as many as 14 of the rods being classified as damaged. Damaged rods may include fuel debris, particles, loose pellets, and fragmented rods. Damaged fuel rods must be placed in a fuel rod insert or individual failed fuel rod capsules prior to placement in the fuel rod insert. The fuel rod insert must be transported in a PWR/BWR transport canister in the cask's PWR basket.

The cask can be loaded wet in a pool or dry in hot cell facilities or facilities with small pools and limited crane capacities. The NAC-LWT cask can be used for full-length assemblies, or pieces of fuel and its cost is well established.

Table 4-1. Transportation Casks Considered

Cask	Package ID Number	CoC Expiration Date	Packages Available	CoC Contents
		HBU Full Length Fuel Rods or Fuel Segments		
NAC-LWT	USA/9225/B(U) F–96 (NRC 2013)	NRC, 04/2020	5	25 full-length, high burnup fuel rods. 14 of the fuel rods can be classified as damaged
T-3	USA/9132/B(M) F (DOE 2008)	NRC, 01/2010 DOE, 01/2019	3	Designed for sodium bonded and cooled FFTF nuclear fuel
		HBU Fuel Segments		
ES-2100[(a)]		DOE, In process	125 at DOE Y-12 facility	Type B quantities of nuclear weapons radioactive material
ES-3100	USA/9867/B(U) F-96 (DOE)	DOE, 09/30/2015	1+	Type B quantities of nuclear weapons radioactive material
9975	USA/9975/B(M) F-96 (DOE)	06/30/2018	1+	35 gallon drum ex - Pu/U oxides NRC licensed also.
9977	USA/9977/B(M) F-96 (DOE)	09/30/2017	1+	35 gallon drum ex - Pu/U oxides
10-160B	USA/9204/B(U) F–96 (DOE 2012)	DOE, 12/31/2014 - under timely renewal NRC, 10/31/2015	2 casks in service one owned by DOE	200 thermal watt limit, TRU special form fissile material in secondary containers, RH-TRU, radioactive sources, TRU material in secondary containers
8-120B	USA/9168/B(U) (DOE 2013a)	DOE, 06/30/2018 NRC, 08/31/2017	10	100 thermal watts waste material. Not currently certified for fissile material contents.

(a)DOE 2002

BEA = Battelle Energy Alliance, CoC = certificate of compliance, DOE = U.S. Department of Energy, FFTF = Fast Flux Test Facility, ID = identification, NRC = U.S. Nuclear Regulatory Commission, RH=remote handled, TRU = transuranic

Figure 4-1. NAC LWT Shipping Cask (printed with permission from NAC International)

4.2.2 T-3 Cask

The T-3 shipping cask (USA/9132/B(M)F) (Figure 4-2) is stored at the Fast Flux Test Facility near the Hanford Site in southeastern Washington state. Three T-3 shipping casks are available. The cask previously had both NRC and DOE CoCs. The NRC CoC was allowed to expire in January 2010. The DOE CoC has been maintained and its current expiration date is January 2019. The authorized contents include UO_2 fuel rods and a maximum of 1400 thermal watts. Because the cask only has a DOE certificate, it can only be used for shipments made by DOE or by DOE contractors for the DOE.

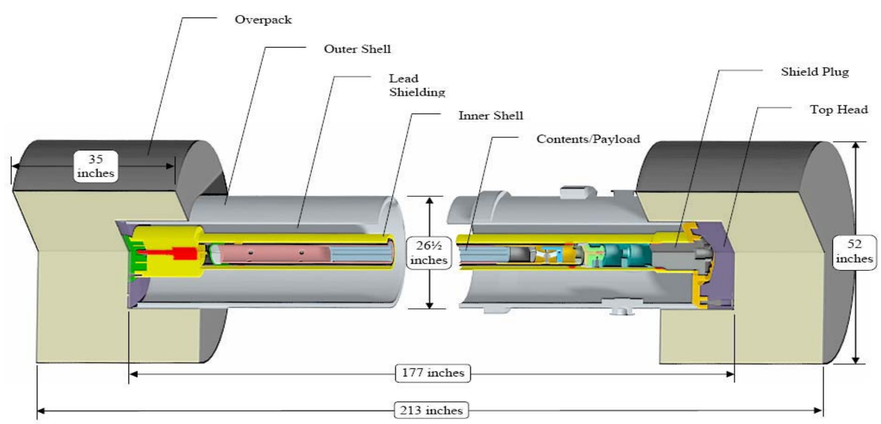

Figure 4-2. T-3 Shipping Cask

The T-3 cask is a stainless steel and lead-shielded irradiated fuel shipping package (cask). The cask is a right circular cylinder with upper and lower steel-encased rigid polyurethane foam (0.32 g/cm^3, 20 lb/ft^3) impact limiters. The overall dimensions are 541.5 cm (213.2 in.) in length and 132.1 cm (52 in.) in diameter. The cask without the impact limiters measures 450.1 cm (177.2 in.) in length and 67.16 cm (26.44 in.) in diameter. The outer cask shell is composed of a 2.54-cm- (1-in.-) thick stainless steel shell overlaid with a 10-gauge stainless steel cover.

Between these two materials is a 0.2-cm (0 .08-in.) diameter wire wrap, providing an air gap for additional thermal protection. The inner shell (containment vessel) is a standard seamless stainless steel Schedule 40 pipe having an outside diameter of 21.9 cm (8.625 in.) with a nominal wall thickness of 0.82 cm (0.322 in.). The annular space between the inner and outer shells is filled with lead having a thickness of approximately 20.3 cm (8.0 in.).

Before a T-3 package could be used to ship full-length high-burnup commercial nuclear fuel rods and/or segments of fuel rods, an addendum to the cask's SARP would need to be prepared and submitted to the DOE regulatory authority for review and approval to obtain a revision to the cask's CoC. As part of this effort the ability of the T-3 design to accommodate high-burnup fuel needs to be evaluated. The maintenance capabilities do not currently exist for this cask and the state of required spares are unknown. The rough order of magnitude (ROM) estimate for SARP Addendum, costs to return a T-3 cask to service, and costs of regulatory review to obtain a revised CoC is between $1 million and $2 million. Estimated costs for transportation are $75K-$100K per shipment.

4.2.3 ES-2100 Package

Another option for the shipments is the National Nuclear Security Administration (NNSA) ES-2100 packages. The ES-2100 package was previously authorized by the NNSA certification authority for shipments of Type-B quantities of the agency's radioactive materials. NNSA's Y-12 organization has prepared an update to the transportation SARP for the ES-2100 package. The SARP was submitted to the NNSA certification authority in April 2014. The Y-12 organization's objective is to obtain a CoC for general use of the package for the shipment of radioactive materials. The ES-2100 package is a 23-in.-diameter, 36-in.-tall drum type package with a gross weight of 605 lb. (Figure 4-3). The package has an 8.3-in.-diameter, 20-in.-tall contents cavity. The maximum weight for package contents is 120 lb., which would include the weight of any shielding that a radioactive source, such as HBU fuel might require. It is reported that there are 125 ES-2100 packages that are not in use at the NNSA Y-12 site in Oak Ridge, Tennessee.

Because of the limitation on the weight of the contents, the ability of the package to be used to ship used fuel segments 10 in. long will need to be evaluated. The use of shielding will increase the overall weight of the package. Although a possibility, the package's ability to pass all tests with higher weight contents (to meet shielding requirements) has not been analyzed.

Figure 4-3. ES-2100 Shipping Container

The Model ES-2100 consists of four main components: confinement drum (including drum liner and top-plug assembly), Kaolite-1600™ cast refractory thermal insulation, polyurethane foam spacer sleeve and pancake lid, and containment vessel (CV).

Before the ES-2100 package could be used to ship segments of high burnup used nuclear fuel rods a SARP Addendum would need to be prepared and reviewed by the regulatory authority. Then a revised CoC that authorized the new contents could be issued. The ROM estimate to prepare a SARP Addendum and obtain such a revised CoC is between $500,000 and $1 million. Estimated costs for transportation are $50K per shipment.

4.2.4 ES-3100 Package

The ES-3100 is licensed by the NRC under certificate number USA/9315/B(U)F-96 and meets all the requirements of the U.S. Code of Federal Regulations, 10 CFR 71. The Y-12 National Security Complex developed this state-of-the-art, Type B fissile material-shipping container. The ES-3100 is the DOE’s replacement for the U.S. Department of Transportation’s Specification 6M container; however, its capabilities far exceed that of the 6M container.

This general-purpose fissile material container will accommodate many forms of highly enriched uranium and other special nuclear materials in bulk quantities for ground and air transport. The package uses a patented insulation technology and a containment system with a critically safe geometry of 5-in. inner diameter. The inner length of 31 in. is ideal for many conceivable content configurations.

Y-12 continues to enhance the ES-3100 shipping container. Many amendments to the license have already been approved and several are under review. Future capabilities of the container include transporting other material forms such as plutonium oxide in STD-3013 canisters, materials that require shielding, and heat-generating materials. The ES-3100 has the potential to transport any fissile material.

Some of the features of the ES-3100 included a capacity of up to 31 in. of content length. Licensed for HEU metal, oxide, and crystal up to 33kg ^{235}U, oxide in the form of UO_2, UO_3, or U_3O_8, HEU fuel forms, and a gross shipping weight of 420 lb. The containment vessel is stainless steel construction designed to American Society of Mechanical Engineers Boiler and Pressure Vessel Code, Section III with a double O-ring seal (ASME 2013). The outer drum is of stainless steel construction with Kaolite 1600 refractory insulation that offers thermal protection and impact resistance. There is a permanent neutron absorber encapsulated in liner, easy-to-install top plug, a lid with only eight fasteners, and silicone rubber shock insulation pads throughout (Figure 4-4).

Because of the limitation on the weight of the contents, the ability of the package to be used to ship used fuel segments 10 in. long will need to be evaluated. The use of shielding will increase the overall weight of the package. Although a possibility, the package’s ability to pass all tests with higher weight contents (to meet shielding requirements) has not been analyzed.

Before the ES-3100 package could be used to ship segments of high burnup used nuclear fuel rods, a SARP Addendum would need to be prepared and reviewed by the regulatory authority, and then a revised CoC could be issued that authorized the new contents. The ROM estimate to prepare a SARP Addendum and obtain such a revised CoC is between $500K and $750K. Estimated costs for transportation are $25K-$50K per shipment.

Figure 4-4. ES-3100 Shipping Container

4.2.5 9975 Package

The Model 9975 Package (CoC No. USA/9975/B(M)F-96 (DOE) (DOE 2013b), whose certificate expires on 6/30/2018, is a radioactive materials transportation package used by DOE and the NNSA to transport radioactive components. Approximately 6000 of the packages have been constructed. The Model 9975 Package (Figure 4-5) is a drum-style Type B Fissile package with double containment designed for transport of plutonium metal and oxide up to 5 kg. The drum is designed, analyzed, and fabricated in accordance with Section III, Subsection NF of the ASME Boiler and Pressure Vessel Code (ASME 2013).

The Model 9975 Package outer container is a 35-gallon removable-head drum designed and fabricated in accordance with 49 CFR 178 Subpart L. The drum and its lid are fabricated of 18-gauge (0.048 inches) Type 304L stainless steel. Drum welds satisfy the requirements of the ASME Boiler and Pressure Vessel Code (ASME B&PVC), Section III, Subsection NF. Four ½-in.-diameter vent holes are drilled into the drum approximately 90° apart, 1 in. below the drum flange, and they are covered with a plastic Caplug ® (fusible plug).

The drum lid is bolted to a 1¼-in.-wide by 1/8-in.-thick angle flange welded to the top of the drum body using 24, ½-in. high-strength bolts. The lid is recessed 0.55 in. below the top surface of the closure flange on the drum. A 1/8-in.-thick by 1¼-inch-wide circular ring is welded to the outer section of the lid. Visual examination of the welds will be performed in accordance with the ASME B&PV Code, Subsection NF (ASME 2013), and the American Welding Society structural welding code for Stainless Steel, D1.6. The ring serves to reinforce the lid and prevents it from shearing away from the bolts during a hypothetical accident condition (HAC) event. Four ½-in. pins, asymmetrically positioned on the lid bolt circle, function as alignment keys, restricting the lid installation to a single orientation. A 0.31-in.-diameter hole drilled in the alignment pins and 0.19-in. hole drilled in the shank of each lid bolt is used to install a tamper-indicating device (TID).

Radiation shielding is provided by a lead cylinder assembly that surrounds the primary and secondary containment vessels. Note: Although double containment is no longer required by the regulations, the applicant has elected to retain the licensed double containment design of Model 9975. The shielding assembly consists of an approximately 7½-in. inner diameter by 20-gauge 304L stainless steel cylinder with a 20-gauge bottom, surrounded by 0.47 to 0.51 in. of lead. An aluminum lid, ½-in. thick, completes the assembly. The lid has four equally spaced bolt holes near the edge for attachment to the cylinder body (¼–20 Unified Coarse (UNC) threaded steel inserts). This is per Drawing R-R2-F-0020-A, 9975 Shielding Body Subassembly. Lead Shielding Bodies have a 20-year minimum service life from the data of manufacture.

The primary containment vessel consists of a stainless steel pressure vessel designed in accordance with Section III, Subsection NB of the ASME B&PVC (ASME 2004), with a design condition of 900 psig at 300°F. The primary containment vessel is fabricated from 5-in. Schedule 40, seamless, Type 304L stainless steel pipe (0.258-in. nominal wall), and has a standard Schedule 40, Type 304L stainless steel pipe cap (0.258-in. nominal wall) at the blind end. A stayed head, machined from a 6-in.-diameter by 2¼ in.-long Type 304L stainless steel bar, is welded to the pipe top end. The head is machined to include 5½-12UN-2B internal thread and a female cone-seal surface with a 32-μin. finish. Both vessel body joints are circumferential full-penetration, complete fusion butt welds examined by radiographic and liquid penetrant methods. These welds satisfy ASME B&PVC, Section III, Subsection NB requirements.

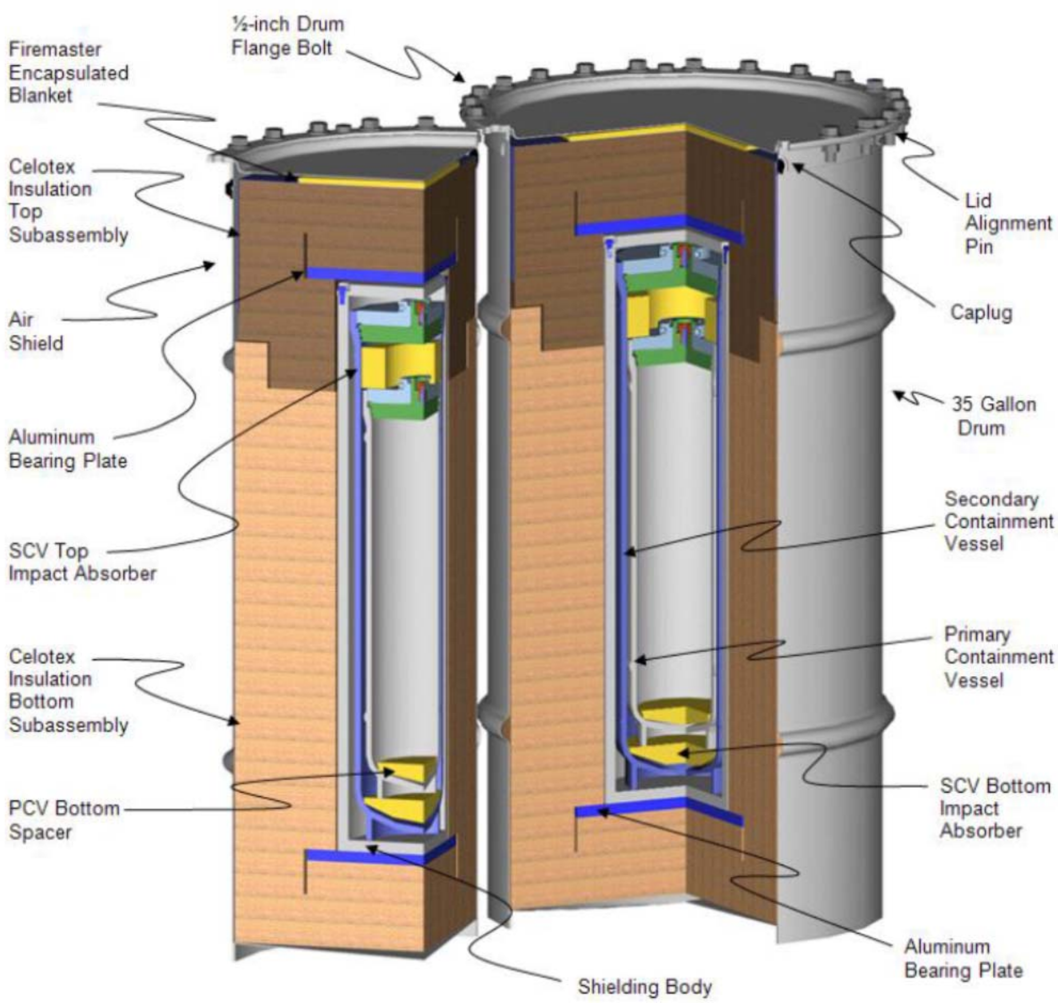

Figure 4-5. Model 9975 Shipping Package

The secondary containment vessel consists of a stainless steel pressure vessel designed in accordance with Section III, Subsection NB of the ASME B&PVC (ASME 2004) edition, with a design condition of 800 psig at 300°F. The secondary containment vessel is fabricated from 6-in., Schedule 40, seamless, Type 304L stainless steel pipe (0.280-in. nominal wall), and has a standard Schedule 40, Type 304L stainless steel pipe cap (0.280-in. nominal wall) at the blind end. A stayed head machined from a 7½-inch diameter by 2¼-inch long Type 304L S bar is welded to the pipe top end. The head is machined to include 6½-12UNS-2B internal threads and a female cone-seal surface with a 32-μin. finish. Both vessel body joints are circumferential full penetration, complete fusion butt welds examined by radiographic and liquid penetrant methods. These welds satisfy ASME B&PVC Section III, Subsection NB requirements. The secondary containment vessel closure is virtually identical to that used on the primary containment vessel, except that the secondary containment vessel is 1 in. larger in diameter. Also, for neptunium oxide contents, per Content Envelope C.8, the secondary containment vessel is backfilled with argon gas, such that the oxygen content is no greater than 3 percent by volume at closure.

If the Model 9975 package is to be used to transport segments of used nuclear fuel rods, a revision to the package could include a tungsten liner and a shielded pig to provide increased radiation shielding for UNF and other planned radioactive material contents. A pig, specific to the fuel rod content, would need to be designed and procured to enable use of a package to transport fuel-rod segments. Regulatory approval of the updated SARP containing revisions to the design and contents for the Model 9975 package and issue of a revised CoC would be required before use. The cost for the CoC update including an update to the SARP is estimated to be $500K-$750K. The cost of a single transport with an approved package is estimated to be $25K-$50K.

4.2.6 9977 Package

The Model 9977 Package (Offsite Transportation Certificate No. USA/9977/B(M)F-96 (NNSA))(DOE 2013b), whose certificate expires on 9/30/2017, is a radioactive materials transportation package used by DOE and the NNSA to transport radioactive components. More than 50 of the packages have been constructed. The Model 9977 Package (see Figure 4-6) outer container is a 35-gallon drum modified with a bolted-flange closure. The drum shell and liner are fabricated of 18-gauge Type 304L stainless steel. The drum is designed, analyzed, and fabricated in accordance with Section III, Subsection NF of the ASME B&PVC (ASME 2013). Vent holes are drilled at multiple locations around the drum, and all of the holes are filled with appropriately sized Caplug®[a] fusible plastic plugs.

The top portion of the drum incorporates a 3/16-in.-thick reinforcing rim (vertical flange) and reinforces the drum head and protects both the closure lid and bolts during hypothetical accident condition events. The rim includes eight, 1-in. diameter drain holes that are qualified as package lifting and tie-down points. The drum bottom includes a rolled "wear ring," 0.060-in.-thick by ¾-inch inside diameter attached by welds external to the drum shell.

The drum closure lid is fabricated from 1/8-in.-thick Type 304L stainless steel plate and fastened with eight heavy hex-head bolts with washers. The bolt heads are drilled through with a 1/8-in. hole to received tamper-indicating devices. The lid top and lid bottom chambers are fabricated from 18-gauge and 14-gauge Type 304L stainless steel, respectively. Four holes through the lid plate allow the lid top and lid bottom volumes to exchange gases. The lid top chamber is vented by four holes covered with Caplug® fusible plastic plugs.

The 9977 is designed with a containment vessel (CV) with a nominal inner diameter of 6 in. (6CV). The 6CV is a stainless steel pressure vessel designed, analyzed, and fabricated in accordance with Section III, Subsection NB of the ASME B&PVC (ASME 2013). The 6CV is fabricated from 6-in., Schedule 40, seamless, Type 304L stainless steel pipe (0.280-in. nominal wall). A support skirt to stand the 6CV vertically is formed from a short segment of 5-in., Schedule 40 Type 304L stainless steel pipe welded to the base. Two rectangular notches milled into the bottom edge of the skirt can engage a rectangular key to prevent vessel rotation during removal and installation of the closure assembly.

[a] A registered trademark of Caplugs, Buffalo, New York.

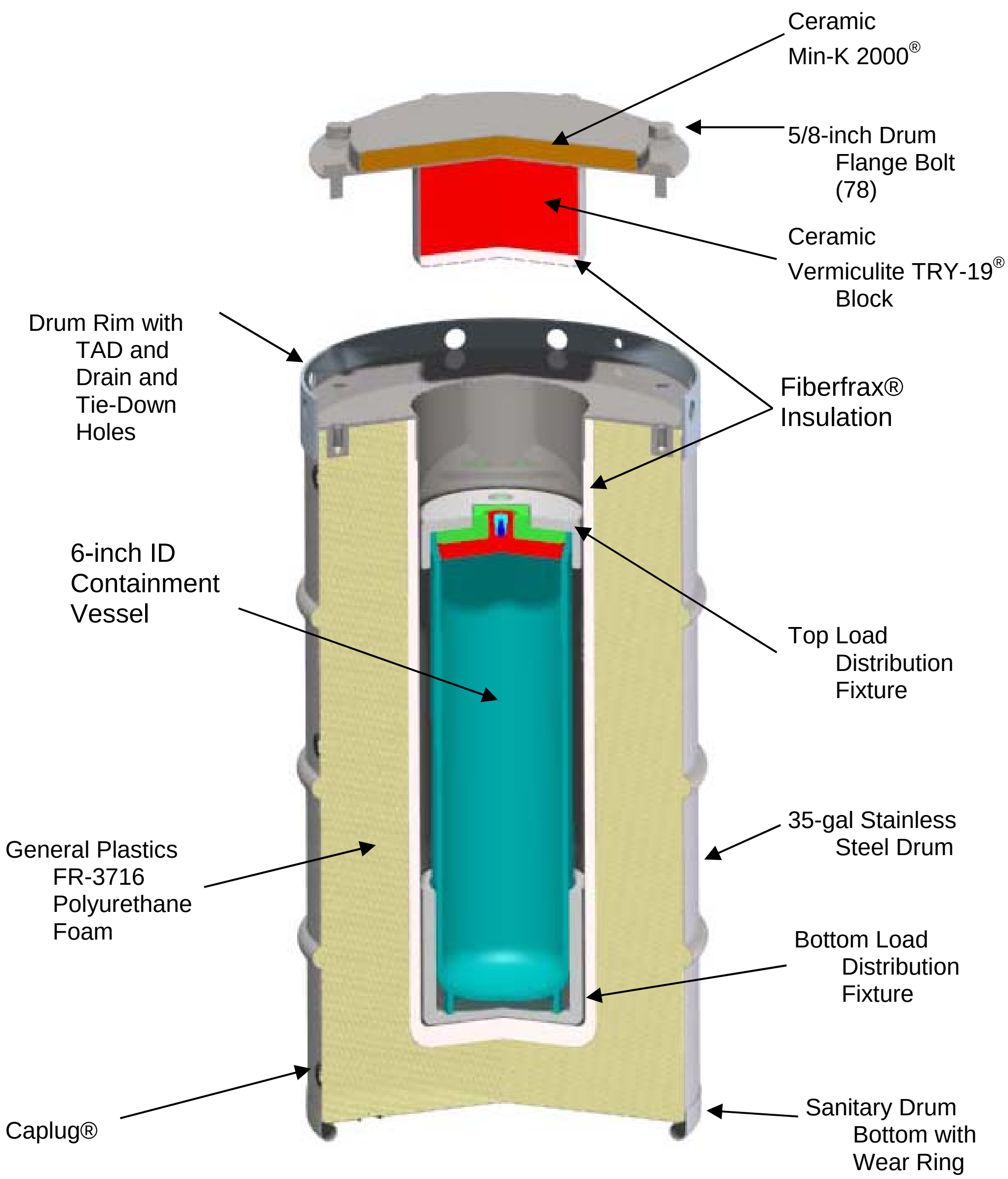

Figure 4-6. Model 9977 Shipping Package

The 6CV closure assembly consists of a Type 304L stainless steel cone-seal plug shaped in part like a truncated cone and a threaded cone-seal nut made from Nitronic 60 stainless steel. To minimize the potential for thread galling, the cone-seal nut and the containment vessel body are made from dissimilar materials. Two O-ring grooves (outer and inner) are machined in the face of the external cone-seal plug with Viton® GLT/GLT-S O[b] rings fit into these grooves to complete the leaktight closure assembly.

[b] Viton is a registered trademark of the E.I. du Pont de Nemours and Company,

For operator safety, a 0.094-in. diameter vent hole is located in the stayed head between the threads and the internal sealing surface. The vent hole is clocked 90° from the notches in the vessel support skirt. Unscrewing the cone-seal nut a few turns will unseat the cone-seal plug from the internal cone-seal surface and route any pressurized gases from the CV through the vent hole.

A leak-test port is incorporated into the cone-seal plug and connected by a drilled radial passage to the annular volume between the two O ring grooves in the cone-seal plug. The leak-test port provides a means of verifying proper assembly of the vessel closure and is itself closed by the leak-test port plug. The vessel containment boundary is formed by the vessel body weldment, the cone seal plug, the leak test port plug, and the outer O ring. The internal volume of a closed 6CV is approximately 608 $in.^3$. The nominal assembly weight is 52.3 lb. and nominal overall length is 24.03 in. The usable cavity of the 6CV is a minimum of 20.25 in. deep with a minimum diameter of 5.95 in.

The top and bottom load distribution fixtures are made from 6061 T6 aluminum round bar and fit within the drum liner cavity, above and below the 6CV. These center the 6CV in the liner, stiffen the package in the radial direction, and distribute loads away from the 6CV.

Neither current 9977 materials nor component geometry provides significant radiation shielding. Dose rate attenuation is provided primarily by the distance between the source and points external to the package with minimal attenuation provided by the materials of the 6CV, Fiberfrax®[c], polyurethane foam, and the drum.

To increase the shielding capability of the 9977 package, the heat dissipation sleeve (completely around 6CV), currently made from 6061 T6 aluminum, will be replaced with a duplicate part made of tungsten. A tungsten-shielded container will be placed inside the 6CV to reduce dose rate for the used fuel content. The 9977 has already used containers specifically designed to provide additional gamma, neutron or photon shielding inside the 6CV to reduce the dose rate.

The 9977 design does not incorporate materials or other design features (e.g., neutron absorbers, flux traps, spacers) specifically for the purpose of poisoning or moderating neutron radiation. Subcriticality is ensured by limiting the package fissile material mass and/or through the use of content components providing the volume and spacing control necessary to ensure subcriticality.

The Model 9977 SARP (DOE 2006) would need to be revised for used fuel segment contents. The revision includes a tungsten liner and tungsten shielded container to provide increased radiation shielding for UNF and other planned radioactive material contents. A tungsten pig, specific to the fuel rod content, would need to be designed and procured to enable use of a package to transport fuel-rod segments. Regulatory approval of the updated SARP containing revisions to the design and contents for the Model 9977 package and issue of a revised CoC would be required before use. The cost for the CoC update including an update to the SARP is estimated to be $500K-$750K. The cost of a single transport with an approved package is estimated to be $25K-$50K.

[c] Fiberfrax is a registered trademark of the Uniprix Corporation in Niagara Falls, New York

4.2.7 10-160B Cask

The 10-160B cask is a cylindrical carbon steel and lead shielded shipping cask designed to transport fissile and non-fissile radioactive waste material. The cask is transported in the upright position and is equipped with steel encased, rigid polyurethane foam impact limiters on the top and bottom (Figure 4-7). The cask's approximate dimensions, shielding, and weight are listed in Table 4-2.

Figure 4-7. 10-160B Cask

Table 4-2. 10-160B Cask Dimensions

Cask Part Description	Dimension
Cask height	88 in.
Cask outer diameter	78½ in.
Cask cavity height	77 in.
Cask cavity diameter	68 in.
Overall package height, with impact limiters	130 in.
Overall package diameter, with impact limiters	102 in.
Lead shielding thickness	1 7/8 in.
Gross weight (package and contents)	72,000 lb.
Maximum total weight of contents, shoring, secondary containers, and optional shield insert	14,500 lb.

The cask body consists of a 1 1/8-in.-thick carbon steel (ASME SA516 or SA537) inner shell, a 1 7/8-in.-thick lead gamma shield, and a 2-in.-thick carbon steel outer shell (ASME SA516). The inner and outer shells are welded to a 5½-in.-thick carbon steel bottom plate. The cask cavity has an optional 11-gauge stainless steel liner. A 12-gauge stainless steel thermal shield surrounds the cask outer shell in the region between the impact limiters. The impact limiters are secured to each other around the cask by eight ratchet binders.

The cask lid is a 5½-in.-thick carbon steel plate, and has a 31-in.-diameter opening equipped with a secondary lid. The primary lid is sealed with a double elastomer O-ring and 24 equally spaced 1 3/4-in.-diameter bolts. The secondary lid is 46 in. in diameter, centered within the primary lid, and sealed to the primary lid by a double elastomer O-ring and 12 equally spaced 1 3/4-in.-diameter bolts. The space between the double O-ring seals is provided with a test port for leak testing the primary and secondary lid seals. The optional cask drain and vent ports are sealed with a plug and an O-ring seal.

The package is equipped with four tie-down lugs welded to the cask outer shell. Two lifting lugs and two redundant lifting lugs are removed during transport. The lid is equipped with three lifting lugs which are covered by the top impact limiter and rain cover during transport.

An optional carbon steel shield insert may be used within the cask cavity and is installed in the DOE-owned cask.

Supplemental analysis and an application to DOE may be required for an amendment to the DOE CoC to obtain approval to use the 10-160B cask to ship high burnup fuel rod segments. The cask's shielding, augmented by a reusable shield insert (6-in. lead wall) that has been approved for shipment of highly radioactive sources, is expected to be adequate for shipment of HBU fuel segments. A recent EnergySolution, Inc., estimate to evaluate the containment performance of the 10-160B cask for use to transport used fuel segments as package contents and prepare a request for an amendment to the cask's CoC, if required, ranges from $56K to $155K. (Note: The DOE-owned 10-160B cask was used to, and thus has been approved to, transport transuranic waste that included irradiated nuclear fuel debris and high-level-radioactive-waste-glass debris from the Battelle West Jefferson, Ohio facility to laboratories in Hanford and Savannah River.) This cost does not include the DOE-EM 33 review team, if required. The reusable shielded insert cost is estimated at $50K-$145K. HBU fuel rod segments would be loaded from a hot cell into a reusable shield insert. The shield insert with the HBU fuel rod segments inside would be moved from the hot cell facility and placed into the 10-160B cask's cavity. The expense per shipment is estimated to be $75K for the DOE-owned cask, and $175K for the cask owned by Energy Solutions.

4.2.8 8-120B Cask

The 8-120B cask is carbon steel-encased, lead-shielded 74-in. outside diameter by 88-in.-high cask for transporting non-fissile radioactive waste materials (Figure 4-8). The cask is a right circular cylinder with a 62-in. inner diameter by 75-in.-high cavity. The walls of the cask contain a lead thickness of 3.35 in. encased in 0.75-in.-thick inner steel shell and 1½-in.-thick outer steel shell. The exposed sides of the package are provided with a thermal barrier consisting of a 5/32-in.-diameter wire wrap on 12-in. centers and covered with a 3/16-in.-thick steel jacket. The bottom weldment is made of two, 3 1/4-in.-thick carbon steel plates. The primary lid is sealed with a double silicone O-ring and 20 equally spaced 2-in.-diameter bolts. The centered secondary lid is sealed with a double silicone O-ring and 12 equally spaced 2-in.-diameter bolts, and covers a 29-in. opening in the primary lid. The optional drain line is sealed with a 3/4-in.-diameter cap screw and a silicone O-ring. The lid sealing surfaces are stainless steel and the space between the double O-ring seals is provided with a test port for leak testing. The top and bottom of the cask are provided with steel-encased, rigid polyurethane foam impact limiters. The impact limiters are secured to each other about the cask with eight 1-in.-diameter ratchet binders. The impact limiters are 102 in. in diameter and the overall height of the package with the impact limiters attached is 132 in. The package is provided with four tie-down and two removable lifting devices. Each lid is provided with three lifting lugs. The gross weight of the packaging and contents is approximately 74,000 lb.

Figure 4-8. CNS 8-120B Cask

Supplemental analysis and an application are required to DOE for an amendment to the CoC to obtain approval to use the Model 8-120B cask to ship high-burnup fuel rod segments. As part of this revision, the current shielding design would need to be evaluated for adequacy for shipment of HBU fuel segments. Supplemental analysis and an application to NRC for an amendment to the CoC to obtain approval to use the Model 8-120B cask to ship high-burnup fuel rod segments would be required. As part of this revision, the current shielding design would need to be evaluated for adequacy for shipment of HBU fuel segments. An estimate to evaluate used fuel segments as package contents ranges from $100K to $175K. This cost does not include the DOE-EM 33 review team. The shielded insert cost is estimated at $50K to $145K. The lease rate for the package is $2084/day or $47,938 per month.

Because the 8-120B cask is not currently approved for transport of fissile material, an estimate of the cost to evaluate its use for transport of used fuel segments has not been made. A revised safety analysis report and regulatory review and approval would be needed. It is likely that such a revised safety analysis report would need to include a nuclear criticality analysis that is not included in a safety analysis for a package such as the 8-120B cask, which is approved only for the transport of non-fissile contents. The cost to prepare the revised SARP and to obtain regulatory review and approval could exceed $1 million.

4.3 Evaluation of Other Transportation Packages

Table 4.1 lists the transportation casks from Ross et al. (2013). The table includes the identification numbers for each of the casks and applicable expiration dates of the casks' CoCs. Table 4.1 also presents the estimated number of each of the listed casks available for use and briefly summarizes the authorized contents listed in the CoCs. (Note: Some of the listed casks do not currently authorize UNF contents. An application to the regulatory authority would be required to use these casks to ship used nuclear fuel contents.) Also, the packages presented in Table 4.1 are organized by which packages could ship full-length fuel rods, fuel rod segments, or both. No attempt was made at ranking the packages in Table 4.1; however, for fuel-length fuel rods the NAC-LWT cask can ship HBU today.

This section presents an evaluation of the viability of a selection of shipping casks to transport high-burnup UNF fuel rods and segments of fuel rods to support the UFD R&D objectives. Included in this evaluation are a consideration of the range of burnup, number of samples, and length of samples that could be transported. Costs are also addressed including the cost of new applications that may be needed to revise CoCs to allow transport of UNF. Costs to prepare safety analyses and obtain regulatory approval for changes to CoCs that authorize use of the packages to transport UNF rod segments are presented as ROM estimates. ROM estimates of costs are based on the report authors' judgment and indicate that detailed analyses of the potential costs have not been performed.

In general, the cost to obtain regulatory authorization to use a cask or package to transport UNF segments is believed to fall in the range of $250,000 to $3 million. The lower end of the range, $250,000, represents the cost to obtain authorization to use a package having a CoC that currently authorizes transport of sections of used nuclear fuel rods but does not authorize contents having the range of properties of UNF fuel rod samples that may be transported for the UFD Program. The upper end of the range, $3 million, represents the cost that would be incurred to obtain authorization to use a package that has an expired CoC and has not been previously approved for the transport of fissile material.

Although not fully assessed as part of this effort, in order to fully describe the acquisition and use of the transport cask(s)/package(s) described in Table 4-1 it will be necessary to collect the following information regarding each cask/package:

- design descriptions of the casks/packages
- CoCs issued by regulatory authorities
- preparation costs of SAR/SARP, submittal to DOE (or other certifying agency), and technical interactions with DOE (or other certifying agency) to obtain CoCs for HBU (fuel rods, rod segments, cladding segments) contents
- assessments of the scope of tasks to obtain regulatory authorization for use of each candidate cask/package to transport the specified UNF (and fuel cladding) contents
- shipping and receiving facility procedures
- descriptions of ancillary equipment needed for facilities to handle, load, and unload the casks/packages
- current condition, location, and ownership of the casks/packages
- contract considerations for casks/packages owned by industry
- requirements for return following use of casks/packages owned by other government agencies or other organizations within DOE.

4.4 Shipping Options Comparison

Table 4-3 presents a comparison of the casks considered to support the UFD R&D testing objectives. In this table, two different categories of costs are presented. The first is the cost to lease or otherwise obtain a cask to transport fuel rod segments to support the UFD Program's research activities. For DOE-owned casks, these costs include those related to returning a cask to service, consumables related to shipping, maintenance, and shipping/receiving facility operational costs. The second category of costs are those estimated for performing engineering analysis and preparing updates to documents to obtain authorization to use a cask or package to transport segments of high-burnup fuel rods.

The estimates of costs to obtain approvals to transport HBU segments in radioactive material packages presented in Table 4-3 are uneven in terms of their ranges and uncertainty for several reasons.

First, the sources of information, in many cases technical managers responsible for directing work to obtain amendments to CoCs for the packages, could not provide more specific estimates for conducting analyses and obtaining regulatory approvals for a radioactive material source type they and their regulators would be unfamiliar with. This uncertainty seemed to cause estimates to be conservative. This situation was particularly the case for packages certified for use by NNSA, which include the ES-2100, 9977, and 9975. However, the amount of conservatism could not be determined.

Second, estimates of the cost to activate and to obtain authorizations to use packages that did not have an active sponsor and that had been inactive, such as the T-3 cask, could only be obtained by interviewing knowledgeable sources. It seems likely that packages that have not been used for a long period of time and do not have an active sponsor would be more difficult to return to service and obtain necessary certification as is indicated by the estimates provided. In the case of the 10-160B cask, the estimates of costs were obtained from the commercial source, EnergySolutions, which owns and operates one of the casks and maintains the CoC. The individual contacted was the person responsible for obtaining amendments to the CoC for the cask and was familiar with the commercial and DOE-owned packages' history of use for commercial clients and for DOE.

Last, in the case of the 8-120B cask, this package is not approved for the transportation of fissile material. When discussing the possible use of the 10-160B cask with EnergySolutions, the 8-120B cask was also discussed. EnergySolutions commented that it was considering whether there was a "business case" that would support the cost of certifying the 8-120B cask to transport fissile material contents, but had not made a decision. A reasonable estimate for the cost to upgrade the 8-120B cask's CoC to authorize transportation of fissile material contents would exceed $1 million.

4.5 Activities Involved in the Transport of UNF Samples

Once a transportation cask or package is selected for transporting UNF samples between research facilities, the following activities would need to be conducted:

- establishing agreements for use with the owner(s) of a cask(s)/package(s) that would be used to transport UNF between research facilities
- as may be required, obtaining regulatory authority authorization for use of a selected transportation cask(s)/package(s) for the UNF contents of shipments that would be made
- at the shipping and receiving facilities, preparing operations procedures for receiving, handling, loading, preparations for shipment, and shipment of UNF in a selected transportation cask(s)/package(s)
- at the shipping and receiving facilities, conducting training of operations personnel in cask/package handling, receiving, loading, shipment preparations, and shipping operations for UNF shipments

- as may be required, retrieving records and other documentation regarding the selected transportation cask(s)/package(s) that would be necessary for its certification and use to transport UNF samples
- identifying ancillary equipment and services that would be needed at shipping and receiving facilities for handling, loading, and testing shipping casks/packages
- identifying shipment operations and support activities necessary for the movement of transport casks/packages containing UNF between research facilities, which would involve
  - logistics management activities including obtaining state permits
  - in-transit security activities
  - transportation carrier services
  - delivery of ancillary equipment to shipping/receiving facilities
  - decontamination services
  - acquisition/construction of special components that may be needed to position UNF samples within transport packages.

Table 4-3. Comparison of Casks to Support UFD Research and Development Testing Options

Package	CoC Content	Current Capability (Fuel Piece) 6 in./10 in.	Shielding	Certificate Expiration Date (NRC/DOE)	CoC Upgrade Needed	Cost for Certificate Upgrade($K)
NAC-LWT	25 full-length, high burnup fuel rods. 14 of the fuel rods can be classified as damaged	Yes/Yes	Adequate for SNF transport	04/ 2020	No	N/A
T-3	Irradiated, (a) MOX fuel pins and assemblies, (b) reactor fuel composed of ^{235}U and/or ^{239}Pu oxides, carbides, nitrides, or metallic alloys	Yes/Yes	Adequate for SNF transport	NRC – 01/2010 DOE – 01/ 2019	Yes	$1000 - $2000
ES-2100	Type B quantities of nuclear weapons radioactive material - LEU and HEU	Yes/Yes	Analysis and tungsten pig design required $100 k to $250 k depending on material (Pb vs W)	DOE - In process	Yes	$500 - $1000
ES-3100	Type B quantities of nuclear weapons radioactive material - LEU and HEU	Yes/Yes	Analysis and tungsten pig design required 100 kg to 250 kg depending on material (Pb vs W)	DOE - 6/01/2017	Yes	$500 - $1000
9975	35 gallon drum example - Pu/U oxides	Yes/No	Analysis and tungsten pig required	NRC 10/31/2019 DOE - 6/30/2018	Yes	$500 - $750
9977	35 gallon drums Max gross wt. - 350 lb.	Yes/Yes	Analysis and pig required	DOE - 10/31/2012 In timely renewal Active NNSA certificate	Yes	$500 - $750
10-160B	200 thermal watt limit, TRU special form fissile material in secondary containers, RH-TRU, radioactive sources, TRU material in secondary containers	Yes/Yes	Shielding analysis may be required	DOE - 12/31/2014 - under timely renewal NRC - 10/31/2015	TBD	Content evaluation - $20 - $50 If needed, addendum request - $160
8-120B	100 thermal watts waste material. Not currently certified for fissile material contents.	Yes/Yes	Shielding analysis may be required	DOE - 6/30/2018 NRC - 8/31/2017	Upgrade from Type B non-fissile to Type B fissile package would be required	If needed, addendum request - $160

Table 4-3. (contd.)

Package	Time for Certificate Upgrade (months)	Package Availability	Cost to Use per Shipment ($K)	Package Use Questions	Package Owner
NAC-LWT	N/A	5	$350	Many national laboratories including PNNL and ORNL have handled the NAC-LWT	NAC International
T-3	N/A	2	$25-$50	Addendum to the cask's SARP would need to be prepared and submitted to the regulatory authority for review and approval to obtain a revision to the cask's CoC. As part of this effort the ability of the T-3 design to accommodate high-burnup fuel needs to be evaluated.. All maintenance equipment has been scrapped. Status of spare parts is unknown.	DOE
ES-2100	12 - 18	125	$25-$50	SARP Addendum would need to be prepared, and reviewed by the regulatory authority. A revised CoC would be issued to authorize the new contents.	NNSA
ES-3100	12 - 18		$25-$50	Maximum weight of all contents including shielding is 90 lb. This may not accommodate the required shielding.	DOE - NNSA
9975	12 - 18	Inventory is 6000+ 25+ available for shipment	$25-$50	Need to evaluate shielding and the use of existing pigs to go in the 9975 cavity. Possible new pig design.	DOE
9977	12 - 18		$25-$50	Dose	DOE/NNSA owns all of the 9977s
10-160B	12 - 18	2	DOE-owned - $75 Energy Solutions - $175	Supplemental analysis and an application to DOE for an amendment to the CoC to obtain approval to use the Model 10-160B cask to ship high-burnup fuel rod segments would be required Current shielding design would need to be evaluated for adequacy for shipment of HBU fuel segments. DOE owned has limited availability Need internal convenience can to contain fuel pieces. Needs shielding Approximate cost, if required, $250-500K Estimated cost for internal pig is $50K. Previously designed ANL pig estimated as ~$130K.	DOE (1) Energy Solutions (1) Need permit from the states through which this cask would travel
8-120B	12 - 18	10	175	Supplemental analysis and an application are required to DOE for an amendment to the CoC to obtain approval to use the Model 8-120B cask to ship high-burnup fuel rod segments Current shielding design would need to be evaluated for adequacy for shipment of HBU fuel segments.	Energy Solutions

ANL = Argonne National Laboratory, CoC = certificate of compliance, DOE = U.S. Department of Energy, HEU = highly enriched uranium, LEU = low enriched uranium, MOX = mixed oxide, N/A = not applicable, NRC = U.S. Nuclear Regulatory Commission, ORNL = Oak Ridge National Laboratory, PNNL = Pacific Northwest National Laboratory, RH TRU = remote handled transuranic (waste), SARP = safety analysis report for packaging, SNF = spent nuclear fuel, TRU = transuranic (waste)

5. SUMMARY AND RECOMMENDATIONS

To accommodate the transportation of high-burnup fuel segments available packages were evaluated considering a range of criteria that included cost, availability, and current authorized contents.

For packages that could ship full-length fuel rods (T-3 or the NAC-LWT) the NAC-LWT cask is currently licensed to ship HBU used fuel in segments, rods, or as an assembly. In addition to the NAC-LWT, the T-3 cask has the configuration to ship both full-length fuel rods and fuel segments. However, the T-3 would require refurbishment, modification to its SARP, new shielding analysis, and CoC modifications to accommodate either HBU full-length fuel rods or HBU fuel segments. The estimated cost to bring the T-3 back into service exceeds the cost to lease NAC-LWT casks for the foreseeable number of shipments using such casks that the UFD Program might make.

There were six packages (See Table 4.3) identified for the shipment of HBU fuel segments. Most of the packages require modification of their CoCs, SARPs, and possibly designs to accommodate HBU fuel segments. Early discussions with Energy Solutions suggest the 10-160B cask could be suitable for the transportation of used fuel segments contained in an approved shielded insert carried inside the body of the cask. According to the EnergySolutions manager responsible for maintaining the 10-160B cask’s CoC, there is the possibility that the CoC may not require modification and that the currently authorized contents for the cask may encompass the radioactive material content of several, 6- to 10-inch HBU fuel segments. The cask’s large capacity would also allow a potential shipment with sister pin fuel segments of varying lengths for multiple destinations. Therefore, the 10-160B is the cask the authors recommend the UFD project pursue as the primary option to support the sister pin segments transportation. Initial cost for EnergySolutions to confirm that the 10-160B cask’s CoC encompasses the radioactive material contents of sister-rod segments is estimated to be $56K. An additional $100K would be needed to prepare safety documentation to submit to regulators in a request for an amendment to the CoC if the current contents limits would be exceeded.

The shipment of HBU fuel contaminated cladding can be accommodated by the 9975 package without modification to its documentation or design. Transport would be $50K.

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