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CADMIUM ROD CASK COMPLIANCE AND SHIPMENT READINESS

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ABSTRACT
The Cadmium Rod Cask (the Cask) is a 70-ton spent fuel shipping cask that contains legacy irradiated cadmium reactor safety and control rods from the Savannah River Site. The Cask has been loaded, closed, and seal welded shut since 1995. The Cask is to be shipped offsite to a permitted waste facility for treatment and disposal as an Industrial Package Type 2 (Type IP-2) carrying Low Specific Activity (LSA-II) content. This paper discusses the actions and evaluations performed to demonstrate 49 CFR compliance and prepare the Cask for offsite shipment.

INTRODUCTION
To support the offsite shipment and disposal of legacy irradiated cadmium reactor safety and control rods from the Savannah River Site (SRS), an existing 70-ton spent fuel cask (the Cask) is being utilized. The Cask was modified by removing all non-essential external features (e.g., expansion tank, lid lifting fixtures), capping and sealing all penetrations, seal welding the lid to the cask body, and outfitting the top ends of the Cask with metal clad foam impact limiters. The Cask has been loaded, closed and seal welded shut since 1995 and shipment was on hold pending identification of a disposal path and radioactive decay of the payload to levels acceptable for transport. Between 2011 and 2015 a disposal path was determined, and the Cask began to be evaluated for disposal. Initial evaluations indicated that due to elevated activity levels, the Cask would not be ready for shipment until March 2018. The transport of hazardous materials is governed by the U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA) through Title 49 of the Code of Federal Regulations (49 CFR), Subchapter C, "Hazardous Materials Regulations." This paper discusses the path taken to ensure and demonstrate 49 CFR compliance for offsite shipment and to prepare the Cask for shipment.

Background
In the 1950s, SRS designed and built several 70-ton shielded Charge/Discharge (CD) casks to be used for transferring irradiated fuel elements and other radioactive materials. The casks were used to transfer materials from the reactor areas to other facilities on Site. These heavily shielded containers have 0.5-inch thick steel outer panels, 8.5-inch thick lead shielding between the outer and inner panels, and 0.25-inch thick steel inner panels. Due to the casks' robust design, most of the original CD cask fleet is still used today to transport spent fuel onsite with the exception of the CD-1 Cask. In 1995, SRS decommissioned the remaining reactors and loaded the last of the cadmium safety and control rods from the five Site reactor facilities into the cask designated as CD-1. The cask lid was installed and welded shut. The Cask was transferred onsite to the SRS Solid Waste Management Facility (SWMF) in E-Area as radioactive mixed waste. The Cask remained in storage until a final treatment/disposal path could be agreed upon.

FIGURE 1: THE CASK ON A PAD IN SWMF

The initial evaluation of the Cask as a USA Industrial Package Type 2 (Type IP-2) container revealed that the Cask would require impact limiters to ensure the lid would meet the structural requirements of 49 CFR to be DOT compliant. It also revealed that the lifting trunnions were not designed to the required safety factor against yielding. An analysis performed in 2015 determined the radioactive payload in the Cask exceeded the requirements for Low Specific Activity (LSA) content (unshielded dose rate at 3 meters exceeded 1 rem/hr). The elevated dose rate was due to the presence of cobalt-60 (Co-60) which was produced by neutron activation of the control rod metal. It was anticipated that Co-60 would decay sufficiently in approximately 3 years (March 2018) to enable the shipment to occur.

Upon decay of the Co-60, SWMF and Savannah River National Laboratory (SRNL) personnel began preparing the Cask for shipment by railcar to a permitted waste disposal facility. The Cask will be shipped one-time, one-way as a Type IP-2 container containing LSA-II material for permanent disposal.

49 CFR COMPLIANCE

Before the Cask can leave the Site and be introduced into commerce, it must be compliant with 49 CFR. Specifically, it must be compliant with Subpart I, *Class 7 (Radioactive Materials).* In order to determine and document compliance with the applicable regulations, a comprehensive compliance summary was assembled. The compliance summary presents all the relevant 49 CFR regulations and demonstrates how the Cask abides by those regulations. In some cases, additional evaluations were required. In determining the applicable regulations, the Cask was conservatively considered to be shipped under non-exclusive use provisions. The following sections detail the pertinent regulations and how compliance was evaluated.

Type IP-2 Requirements

The Cask was to be qualified as a Type IP-2 container for offsite shipment. Relevant Type IP-2 requirements for the Cask are found primarily in 49 CFR §173.411(b)(2), which states that:
"Each Type IP-2 package must meet the general design requirement prescribed in §173.410 and when subjected to the tests specified in §173.465(c) and (d) or evaluated against these tests by any of the methods authorized by §173.461(a), must prevent: (i) Loss or dispersal of the radioactive contents; and (ii) A

significant increase in the radiation levels recorded or calculated at the external surfaces for the condition before the test."

A structural evaluation was performed in order to demonstrate compliance with the above regulation. Specifically, the Cask was evaluated for impact from 1 foot drops per §173.465(c), compression load requirements per §173.465(d), and vibration loads per §173.410(f). The evaluation concluded that the Cask will maintain its structural integrity with no bolt loosening, foam compression, or unacceptable fatigue under the effects of acceleration and vibrations that may arise during normal conditions of transport. Additionally, the evaluation concluded that Cask can withstand five times the weight of the actual package, which is the basis for the compression load requirement. Previous analysis shows that the Cask can survive 4 foot drops onto the sides, bottom, or bottom corners.

To address vulnerabilities in the Cask lid, two identical impact limiters were designed to provide cushioning during top-down and center-of-gravity-over-top-corner (CGOTC) impacts. The role of the impact limiters is to absorb top-side and top-corner impacts, directing impact loads away from the lid-to-cask joint and directly into the Cask body. The impact limiters are designed to crush nearly 6 inches, which provides very low impact G-levels. The analysis shows that the impact limiters can withstand 4 foot drops in a top-down orientation.

The impact limiters are constructed from A500 series carbon steel tubing and General Plastics FR3715 Last-a-Foam. The foam is a nuclear grade material, commonly used as energy absorbers in radioactive materials packages ranging from Type IP-1 to Type B. One limiter is installed at each end of the Cask top and weighs 1,241 pounds. The impact limiters were constructed in 2011 and have remained in storage since. Due to the amount of time that has lapsed since initial construction, there were some concerns regarding the pedigree of construction. The "as-built" condition of the impact limiters were inspected and compared against the 2011 drawing and fabrication records. SRNL personnel deemed them fit for use. The impact limiters also perform a secondary function – rendering the lifting trunnions inoperable during transport per §173.410(b). Further discussion of the lifting trunnions is provided later in this paper.

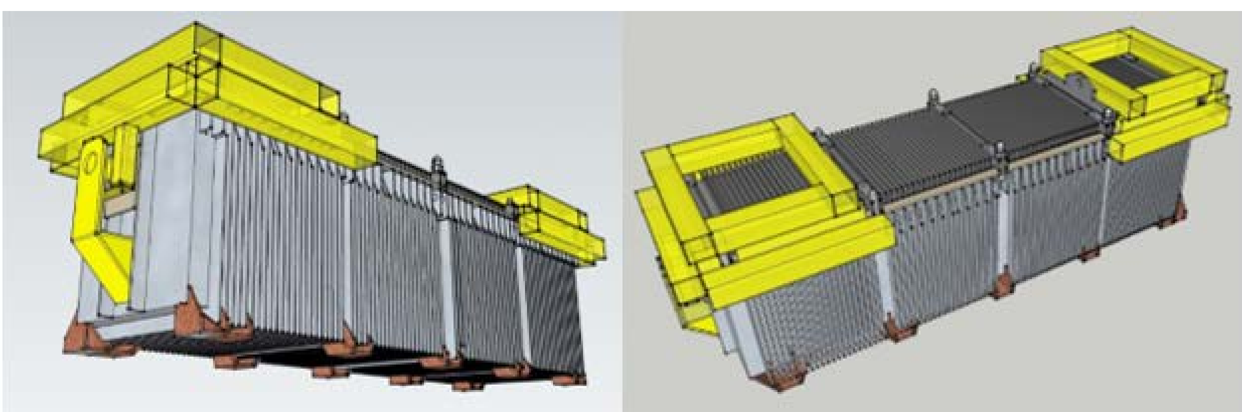

FIGURE 2: MODELLING OF IMPACT LIMITERS ON CASK

The structural evaluation did not evaluate the radiation levels at the external surfaces after test conditions. However, compliance with §173.411(b)(2)(ii) was demonstrated with reasoned analysis. The neutron activated cadmium rods result in a relatively large and distributed radiation source, which is consistent with the definition of LSA-II material. The majority of activation products reside at the ends of the irradiated rods and therefore a more intense "slab" of radiation will exist at each of the two ends of the Cask. The rods fill the length of the Cask and approximately 2/3 of this internal height. The potential for any significant movement of the rods is small. Under drop conditions, some movement of the rods can occur; however, the distributed nature of the gamma ray source in the Cask cavity will preclude any significant changes in surface dose rates. The 1-foot drop does not result in any significant deformation to the external features of the cask, so dose rates will not change significantly due to cask surface deformation. Overall it is reasoned that the dose rate at the external surface of the Cask should not significantly change due to internal shifting of the content (radiation source) or external deformation of the surface.

Lifting Trunnions and the Special Permit

During the evaluation for compliance, it was determined that the lifting trunnions on the Cask did not meet the 3:1 safety factor against yielding as required by §173.410(b); the trunnions currently have a safety factor of 2.1:1 against yielding. Therefore, the trunnions were to be rendered inoperable during transport by the impact limiters. However, there was still uncertainty about how the Cask would then be lifted from the pad it is currently stored on to the designated railcar for transportation without use of the trunnions. Although the Cask would not be in-commerce, loading a hazardous material package onto a transport vehicle falls under *Pre-transportation functions* as defined by §171.1. There were three possible solutions to this problem: (1) lift the Cask by some other means, (2) weld reinforcement onto the trunnions to meet the required safety factor, or (3) apply for a DOT Special Permit for exemption from the required safety factor against yield based on compliance with an industry standard 5:1 safety factor against ultimate tensile strength.

In order to lift the Cask in a different manner for loading onto the railcar, SRS Rigging personnel would have to use wire rope slings in a basket configuration. To accomplish this, the Cask would have to be lifted using the trunnions and the slings placed under the Cask. Due to the size and weight of the Cask, lifting it by this method could damage the heat dissipation fins surrounding the Cask and lead to a potential breach of containment. In addition, the slings would be unable to be removed from under the Cask once it is placed on the railcar. This would interfere with securing the Cask to the railcar as it is designed, leading to additional risk during transport.

Modifying the trunnions to meet the 3:1 safety factor against yielding would require significant grinding and welding that would impact fixed contamination on the Cask. This activity would be contrary to “As Low As Reasonably Achievable” (ALARA) practices for handling contaminated equipment. The grinding and welding evolution increases the risk of contamination and uptake by the involved personnel and increases the potential risk of releasing radioactive material into the environment. Grinding and welding in radiological personal protective equipment (PPE) introduces additional safety concerns for the welders, such as the risk of sparks from welding burning the radiological PPE (cotton coveralls or plastic suit).

The most safety forward option was to apply for a DOT Special Permit for exemption from the required safety factor. Disregarding the safety concerns of the other two options, there are other arguments for allowing the use of the trunnions. The Cask is a legacy container and although it was not designed to the 3:1 safety factor against yielding, the trunnions have been shown to meet a 5:1 safety factor against ultimate tensile strength which meets the SRS Rigging criteria (based on OSHA/ASME standards) for a safe lift. The Cask has been lifted by the trunnions multiple times during its life with visual inspection indicating no damage or degradation of the trunnions. After loading the Cask onto the railcar, the impact limiters will be placed on the Cask and the trunnions will be rendered inoperable for the remainder of the transport. The Cask will be shipped one-time, one-way, with no trans-loading for disposal, therefore use of the trunnions under DOT regulations will be for a single evolution.

As of the writing of this paper, the special permit application has been forwarded to the U.S. Department of Energy Headquarters (DOE-HQ) for their review and submittal to DOT. In the event that the special permit application is denied, the trunnions will be modified to allow for shipment. While welding on contaminated equipment is not normally considered good ALARA practice, it was deemed safer than attempting the alternative lifting methods.

General Requirements

The Cask was subject to several general requirements in 49 CFR. The general requirements for packaging found in §173.24 were concerned mostly with the chemical compatibility between the contents and packaging, and the integrity of the packaging and ability to maintain containment under normal conditions of transport. In addition, the Cask meets the definition of bulk packaging found in §171.8 (no intermediate form of containment, weighs more than 882 pounds, volume greater than 119 gallons) and thus is also subject to the general requirements for bulk packagings found in §173.24b. The Cask was found to be compliant with all applicable regulations in §173.24 and §173.24b.

Though the Cask is a legacy container built in the 1950s, it still needs to adhere to the general design requirements prescribed in §173.410. Compliance with several of these regulations are demonstrated through reasoning and historical records. As §173.410(b) and (f) have already been addressed, the remaining regulations are shown in Table 1 below.

TABLE 1: APPLICABLE 49 CFR §173.410 REQUIREMENTS

49 CFR Ref.	49 CFR Requirement	Acceptance Criteria
173.410(a)	The package can be easily handled and properly secured in or on a conveyance during transport.	The Cask is of a rectangular design that can be lifted and secured to a conveyance. The bottom of the Cask has engineered base feet that have been historically used for securement of the Cask to a railcar for transport using tie-down strapping or chains. A specific rail car tie-down plan is provided.
173.410(c)	The external surface, as far as practicable, will be free from protruding features and will be easily decontaminated.	The external surface of the Cask is all metal with painted surfaces that are conducive to decontamination. The protruding features of the cask (e.g., cooling fins, trunnions, impact limiters) all have function and are necessary components of the legacy cask design.
173.410(d)	The outer layer of packaging will avoid, as far as practicable, pockets or crevices where water might collect.	The external surface of the cask has no unnecessary pockets or crevices where water might collect.
173.410(e)	Each feature that is added to the package will not reduce the safety of the package.	The configuration that will be shipped is the Cask equipped with impact limiters (enhances safety) for compliance with Type IP-2 requirements. No additional features will be added to the package. Blocking, bracing, and tie-downs are ancillary (non-packaging) hardware for securement of the package to the conveyance.

173.410(g)	The materials of construction of the packaging and any components or structure will be physically and chemically compatible with each other and with the package contents. The behavior of the packaging and the package contents under irradiation will be taken into account.	The Cask structure and contents are chemically compatible. When Cask was loaded with irradiated metallic rods in L-Area basin, it was drained, removed from the basin, and inorganic desiccant material was added to the cask cavity to ensure there were no free liquids remaining. An evaluation has shown the hydrogen concentration in the Cask due to radiolytic hydrogen generation will not exceed the lower flammability limit during shipment.
173.410(h)	All valves through which the package contents could escape will be protected against unauthorized operation.	All openings in the Cask were seal welded shut. Hence there are no operable valves through which content could escape. The lid to the package was welded closed.

Transport in air is addressed in §173.410(i), which is not applicable to the Cask and therefore not included in the table. The evaluation referenced in §173.410(g) also evaluated the thermal output of the Cask and will be revisited later in this paper.

Low Specific Activity (LSA) Requirements

The cadmium safety and control rods inside the Cask were considered to be LSA-II material, and therefore needed to comply with the requirements of §173.427. LSA-II material is defined in §173.403 as “water with tritium concentration up to 0.8 TBq/L (20.0 Ci/L); or other radioactive material in which the activity is distributed throughout and the average specific activity does not exceed 10^{-4} A_2/g for solids and gases, and 10^{-5} A_2/g for liquids.” The primary relevant regulation came from §173.427(a)(1), which states that:

“In addition to the other applicable requirements specified in this subchapter, LSA material and SCO must be transported in accordance with the following conditions: (1) The external dose rate may not exceed an external radiation level of 10 mSv/h (1 rem/h) at 3 m (10 feet) from the unshielded material.”

As the Cask was loaded and seal welded shut in 1995, there was no way to measure the unshielded dose rate from the material. A content characterization was performed in 2015 to calculate the unshielded dose rate using a Dose-to-Curie (DTC) computer modelling program. The developed radionuclide characterization, physical characteristics of the Cask, and physical characteristics of the cadmium safety and control rods were used as model input parameters in order to calculate a theoretical unshielded dose at 3 meters from the material. The radionuclide characterization was developed from historical records and calculations that gave information such as the 1993 activity of Co-60 in 120 rods, number of rods in each of the 5 reactors (977 rods total), start date of decay of the rods, and the isotopic content of the rods. The isotopes present, and their respective half-lives are given in Table 2. As 20 years had passed since the loading and closing of the Cask, only Co-60, Ni-59, Fe-55, and Cd-109 were considered to be contributors to the present activity, with the main contributor being Co-60.

The evaluation concluded that the unshielded dose rate exceeded the regulatory requirements at 1,457.2 mrem/hr at three meters. However, the Co-60 would decay sufficiently to levels acceptable to transport by March 2018. It is worth noting that there were several conservatisms taken in the characterization.

TABLE 2: ISOTOPES PRESENT IN THE CADMIUM RODS AND THEIR HALF-LIVES

Isotope	Half-Life
Co-60	5.272 years
Ni-59	76,000 years
Fe-55	2.7 years
Cd-109	1.267 years
Ag-109m	59.8 sec
Cd-115m	44.6 days
Fe-59	44.5 days
Co-59	70.9 days
Cr-51	27.7 days

LSA requirements also mandate that the Cask conforms to conveyance activity limits and industrial package integrity requirements found in §173.427(e). Solid LSA-II content must be shipped in a Type IP-2 package for non-exclusive use shipments and there are no activity limits for conveyances other than by inland waterway, thus the Cask is deemed compliant. Per the LSA regulations, the Cask must comply with §173.441 and §173.443, which is addressed in the following section.

Other Requirements

There were several other 49 CFR requirements that were judged to be applicable to the Cask and thus should be included in the compliance summary, though they did not require in-depth analysis and evaluation. These dealt with radiation level limitations (§173.441), contamination control (§173.443), demonstration of compliance with tests (§173.461), and quality control for construction of packaging (§173.474). The Cask was found to be compliant with all the applicable requirements in these regulations.

Thermal limitations are addressed in §173.442 and required an evaluation of the Cask. The Cask was evaluated for radiolytic hydrogen generation (discussed in §173.410(g)), maximum heat output of the rods, and temperature of the external surfaces in the shade at ambient temperature. Using the activity levels calculated in the content characterization discussed in the LSA requirements, the maximum heat output of the cadmium rods was calculated to be 11.8 watts, while the Cask is designed to handle heat loads up to 5,600 watts. In total shade and partial shade at ambient temperature (100°F), the external surfaces of the Cask reach 101°F and 115°F, respectively, which is below the 122°F limit for non-exclusive use shipments.

SHIPMENT READINESS

The compliance summary is only one component needed to ship the Cask offsite. The compliance summary merely demonstrates that the Cask is DOT compliant, but SRS has its own Site Transportation Regulatory Authority. It ensures all applicable DOT requirements for the package have been implemented prior to the package leaving the site. Its purpose is not to impose additional regulatory requirements, but rather enforces the DOT regulations on site. The following sections discuss the additional actions and activities that are necessary to ready the Cask for shipment.

Package Authorization

Upon completion of the compliance summary, SWMF was ready to present DOT compliance documentation to the Package Review Committee (PRC). This process entailed presenting the compliance summary and any other supporting documentation to the PRC for their approval. The PRC is the Site Transportation Regulatory Authority responsible for: (1) the approval of all transportation package, and (2) maintaining the Radioactive Packaging Approval Log (RPAL). The RPAL is a current listing of packagings, approved facility procedures and other relevant information governing the loading, closure, and use of authorized packages for onsite transfers or offsite shipments. It is the control point for all radioactive material, waste, and mixed waste transfers or shipments.

Since the Cask was evaluated to have LSA-II material, the PRC needed proof that the cadmium rods did in fact fall under the LSA-II definition. Using the activities calculated in the content characterization (43.4 Ci) and the calculated weight of the cadmium rods (977 rods at 22.04 pounds each), a calculation was developed that concluded that the cadmium rods did meet the LSA-II definition. This and the compliance summary were presented to the PRC, and the PRC approved the Cask as a DOT compliant Type IP-2 container carrying LSA-II material assuming the design requirement is met through a DOT Special Permit or modification of the trunnions to meet the 3:1 safety factor against yield.

Before radioactive material can be transferred onsite or shipped offsite, the package must be approved by the PRC and placed on the RPAL. Though the Cask was qualified by the PRC, it is not authorized to be shipped until Handling and Operating Instructions (HOI) are developed and approved by the PRC, and thus is not on the RPAL.

Handling and Operating Instructions

The HOI documents the requirements for safely handling the Cask and preparing it for shipment. There are four major components of the HOI: pre-shipment verifications, handling and lifting requirements, loading and tie-down plan, and impact limiters installation. During pre-shipments verifications, the Cask is visually examined to ensure that all parts and components are present, there are no signs of obvious physical damage or breaches of containment, and that the Cask is properly closed. Pending a resolution on the special permit application submitted to DOT, the HOI has an additional step to verify that the lifting trunnions are authorized to lift the Cask onto the designated railcar per DOT Special Permit. This verification step is also present in the handling and lifting requirements, which state that hoisting and rigging activities will be as directed by Site Rigging in compliance with the SRS Hoisting and Rigging Manual.

The HOI also addresses the tie-down plan for the Cask on the railcar. The Cask will be secured to the railcar using block and clamp assemblies that will be welded onto the railcar. The block and clamp assemblies clamp and brace the engineered feet of the Cask to prevent shifting. This was considered by a loading evaluation to be the best method to properly secure the Cask to the railcar for shipment. Lastly, the HOI provides installation instructions for the impact limiters. The impact limiters are held in place by their weight but have two secondary points of securement to the Cask. A plate is secured under the lifting trunnion to two side arms coming down on the side of the Cask (visible in Figure 3). On top of the Cask, the lid lift lug is secured to the rear bumper of the impact limiter with a 5” screw (Figure 4).

The HOI, as currently written, allows use of the trunnions provided that it’s authorized per DOT Special Permit. Since authorization cannot be verified due to the special permit application still being processed by DOE-HQ, the PRC has not approved the HOI. If the special permit application is denied and the trunnions have to be modified, the HOI will be revised to reflect that change.

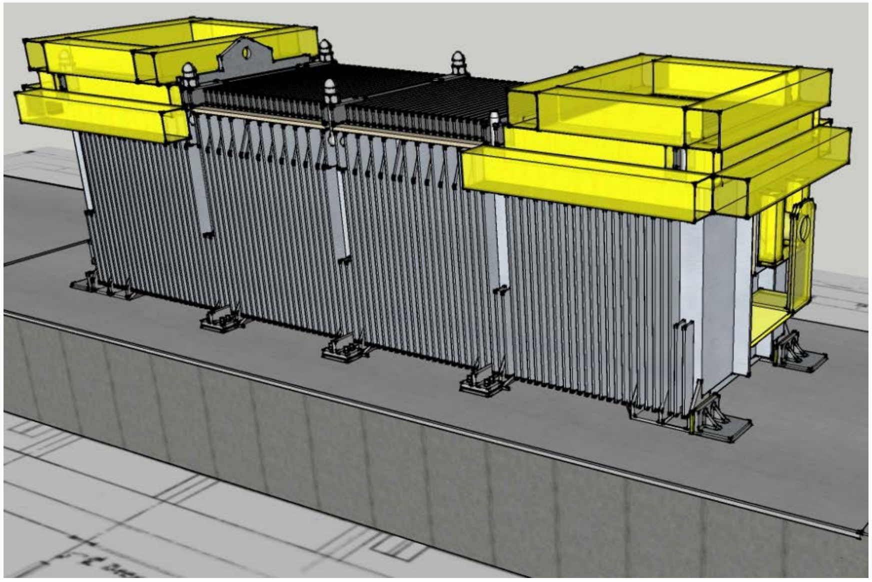

FIGURE 3: MODELLING OF THE TIE-DOWN ASSEMBLY

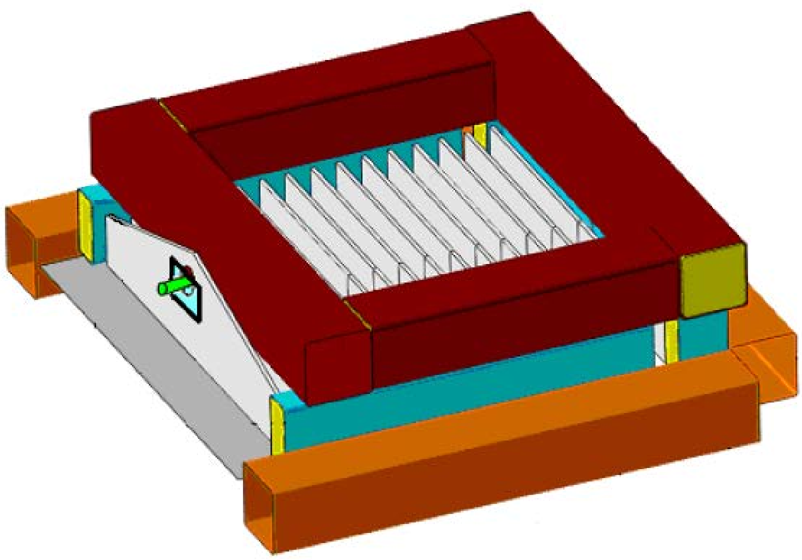

FIGURE 4: VIEW OF THE IMPACT LIMITER ATTACHMENT TO THE CASK LID LIFT LUG

Other Preparations

There are several other preparations being handled by the SWMF. Due to concerns of possible contamination on the exterior of the Cask, SRS Radiological Control requires the Cask be bagged prior to shipping offsite. The bag will be a soft-sided overpack, with cutouts at the Cask feet to allow for the implementation of the tie-down plan. The soft-sided overpack is only credited for contamination control. A statement of work for the contract has been put out to bid and includes procuring the rad bag (overpack), providing and preparing the railcar for shipment, transporting the Cask, and ultimately disposing of the Cask. Once all the final pieces are in place, the final step is making sure the Cask and/or railcar is correctly marked, labelled, and placarded in accordance with 49 CFR. These activities will be overseen by a Site Hazardous Material Transportation Representative (HMTR) to ensure compliance with all DOT requirements.

CONCLUSION

The Cask is a 70-ton spent fuel shipping cask that contains legacy irradiated cadmium reactor safety and control rods from SRS. The Cask has been loaded, closed, and seal welded shut since 1995. The Cask is to be shipped offsite to a permitted waste facility for treatment and disposal as an Industrial Package Type 2 (Type IP-2) carrying Low Specific Activity (LSA-II) content. SWMF and SRNL personnel have demonstrated Cask compliance with 49 CFR and assessed all steps necessary to prepare the Cask for shipment. The Cask currently has a planned ship date of August 2019.

There have been many challenges in getting this legacy container approved and prepared for offsite shipment. The latest SRS disposal effort for this Cask filled with legacy mixed waste has spanned the better part of ten years, and many people have taken part. Many of those people have since retired or moved to other positions. Consequently, there has been a large loss of knowledge, context, and communication that has proved to be detrimental to this project. The impact limiters were sitting in storage for seven years before being addressed. There were some serious concerns about the pedigree of construction because the shop that made them had since shut down and the fabrication records were missing. The lifting trunnions were known to not be compliant with the required safety factor against yielding from the beginning of the Cask disposal effort in 2011 but weren't addressed until 2018 due to a lack of communication. The original plan was to lift the Cask by another means, but by 2018 circumstances had changed and poor communication meant a last minute special permit application. There is still a chance the special permit application will not be reviewed in time to allow for a timely shipment and the trunnions will have to be reinforced.

Using a container already on hand may have been the best course of action in 1995, it has only caused unnecessary stress nearly 25 years later. The initial effort to prepare the Cask for cadmium rod storage and the recent effort to dispose of the Cask may have been lessened if a new container had been properly designed and fabricated to be DOT compliant. Opportunities for improvement identified during this task include considering designing and fabricating a new container in accordance with 49 CFR when shipping something of this caliber, and stressing the importance of communication and keeping good records.

REFERENCES

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[2] G-HOI-E-00001. Rev. 0. *Handling and Operating Instructions for CD-1 Cask with Cadmium Rods.* Savannah River Nuclear Solutions, Aiken, SC. March 2019.

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