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STATUS OF THE BENEFICIAL USES SHIPPING SYSTEM CASK (BUSS)*

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NOTICE/DISCLAIMER

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Abstract

The Beneficial Uses Shipping System cask is a Type B packaging developed by Sandia National Laboratories for the U. S. Department of Energy. The cask is designed to transport special form radioactive source capsules (cesium chloride and strontium fluoride) produced by the Department of Energy's Hanford Waste Encapsulation and Storage Facility. This paper describes the cask system and the analyses performed to predict the response of the cask in impact, puncture, and fire accident conditions as specified in the regulations. The cask prototype has been fabricated and Certificates of Compliance have been obtained.

INTRODUCTION

This paper presents a status report on the development of the Beneficial Uses Shipping System (BUSS) cask. The purpose of U. S. Department of Energy's (DOE) Beneficial Uses of Nuclear Byproducts Program is to develop and encourage beneficial uses of nuclear byproduct isotopes such as cesium-137 and strontium-90. Applications include the use of gamma irradiation to improve the quality of certain food products, to disinfect municipal sewage sludge, and to sterilize medical products.

The transportation of cesium chloride or strontium fluoride capsules produced by the DOE Waste Encapsulation and Storage Facility (WESF) at Hanford, WA, to and from commercial licensed facilities is performed in a Type B packaging (cask) certified by the U. S. Nuclear Regulatory Commission (NRC). Sandia National Laboratories was funded by the DOE to develop the BUSS cask to support transportation of these sources.

The BUSS cask was designed to maximize payload within prescribed weight and size limits established by WESF and to serve as a safe, reliable, and efficient alternative to existing transportation systems. The cask design must be consistent with DOE policies for containment and as low as reasonably achievable radiation exposure and must comply with applicable regulations. A major goal of the BUSS cask development program was to obtain regulatory approval of the design through verification by means of state-of-the-art analysis techniques.

CONTENTS DESCRIPTION

The approved contents to be transported in the BUSS cask are special form capsules of either melt-cast cesium chloride or press-filled strontium fluoride [1,2]. Each source is doubly encapsulated with a 316-L stainless-steel outer layer and an inner steel capsule made from Hastelloy C-276 for the strontium fluoride or from 316-L for the cesium chloride. The capsule assemblies are about 7 cm in diameter, 53 cm long, and weigh about 8 kg. A cutaway sketch of a typical capsule is

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shown in Figure 1. Containment for the BUSS cask is provided by the special form nature of the source capsules.

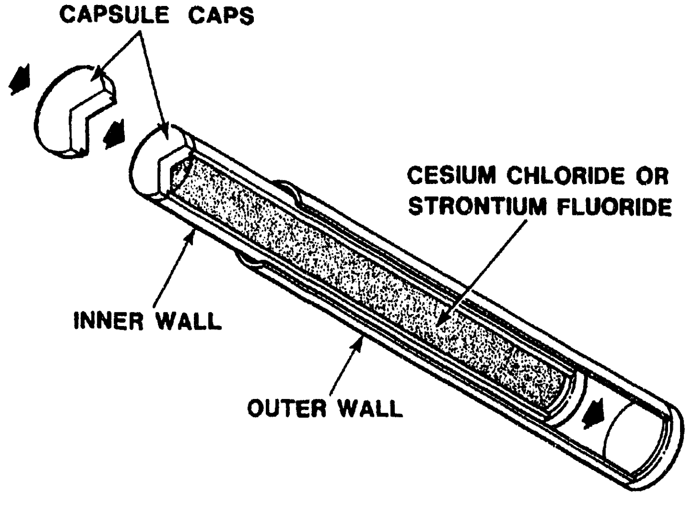

Figure 1. Schematic of a typical Waste Encapsulation and Storage Facility capsule.

CASK DESCRIPTION

The major components of the BUSS cask system include the cask body and lid, basket, impact limiters, personnel barrier, and shipping skid. Figure 2 shows an exploded view of the BUSS cask.

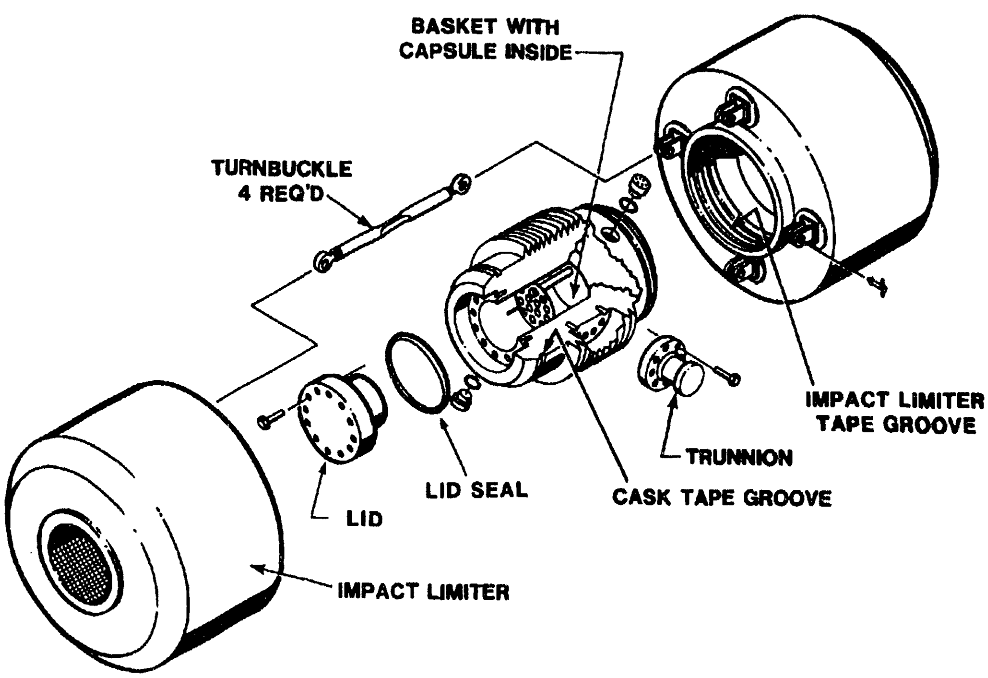

Figure 2. Exploded view of the BUSS cask.

The cask body is constructed from a one-piece 304 stainless-steel cylindrical forging. The wall and end of the cask body are a minimum of 33 cm thick. Eleven integral circumferential fins are machined on the outer surface of the cask body for heat dissipation. The cask closure is a one-piece, 33-cm-thick 304 stainless-steel forged lid, weighing about 680 kg. The lid is bolted through the 10-cm-thick lid flange to the cask body with 12 ASME SA-286 steel 1-1/2 in. (3.81-cm) dia bolts. All openings into the cask interior are fitted with bolted-on lids, each having a combination metallic-elastomeric double seal. The inner containment seals used in the cask closure and port lid covers are high-temperature copper Helicoflex seals rated for a 450° C operating temperature [3]. The outer elastomeric seal serves to provide the test volume for leak testing.

The cask's contents (capsules) are carried in one of four removable solid stainless-steel basket configurations. An example of a 16-hole basket is shown in Figure 3.

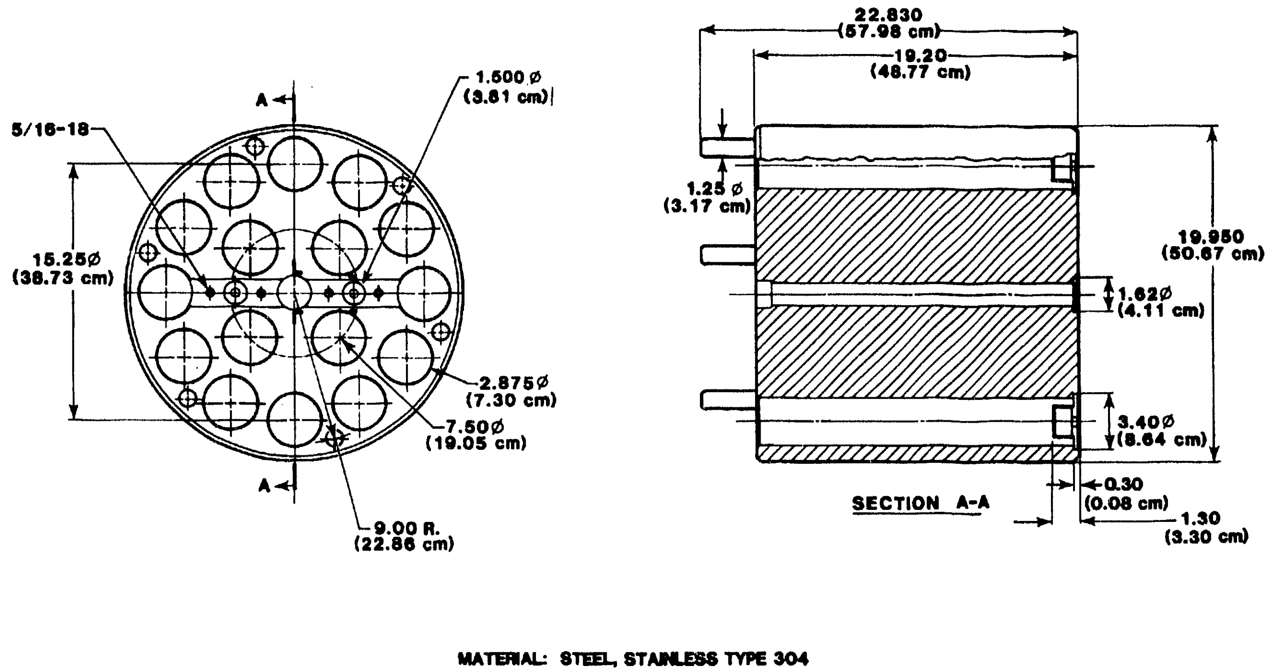

Figure 3. Typical basket configuration (16-capsule CsCl).

Depending on the thermal power level of cesium or strontium capsules to be transported, one of four different basket configurations may be used (see Table 1 for cask content limits).

Table 1. Beneficial Uses Shipping System Cask Radioactive Material Limits

Capsule Type	Basket Capacity/Maximum Capsule Thermal Power [no. of capsules (W)]		Thermal Power (kW)	Activity (millions of Ci)*
Cesium chloride	16	(250)	4.0	0.85
(Cs-137)	12	(333)	4.0	0.85
Strontium fluoride	6	(650)	3.9	0.65
(Sr-90)	4	(850)	3.4	0.56

* 1 Ci = 37 GBq.

Steel-encased polyurethane-foam impact limiters are attached to each end of the cask body to provide impact protection to the cask system. These impact limiters are retained by four turnbuckles and two tape joints [4]. The turnbuckles are used to secure the impact limiters to the cask body during normal handling operations. The tape joints become effective during accident environments to hold the limiters onto the cask body during impact. These tape joints are loose fitting and do not take effect until large forces are imposed on the impact limiters. The tape joints are unique in cask design and are normally found in applications required to withstand large shear loads. Because of the near one-to-one aspect ratio of the cask body, the ends of the cask do not extend into the impact limiters sufficiently to produce large resisting forces to counteract the moments developed on the impact limiters during side drops. It was determined analytically that these moments may be practically resisted through devices which generate large shear forces such as tape joints.

The assembled cask with impact limiters is transported on its shipping skid as shown in Figure 4. A personnel barrier is used to prevent unauthorized access to the hot surfaces of the loaded cask. The weight of the loaded cask including its shipping skid and personnel barrier is approximately 15,310 kg. The cask can be dry- or wet-loaded and unloaded, depending on the facility.

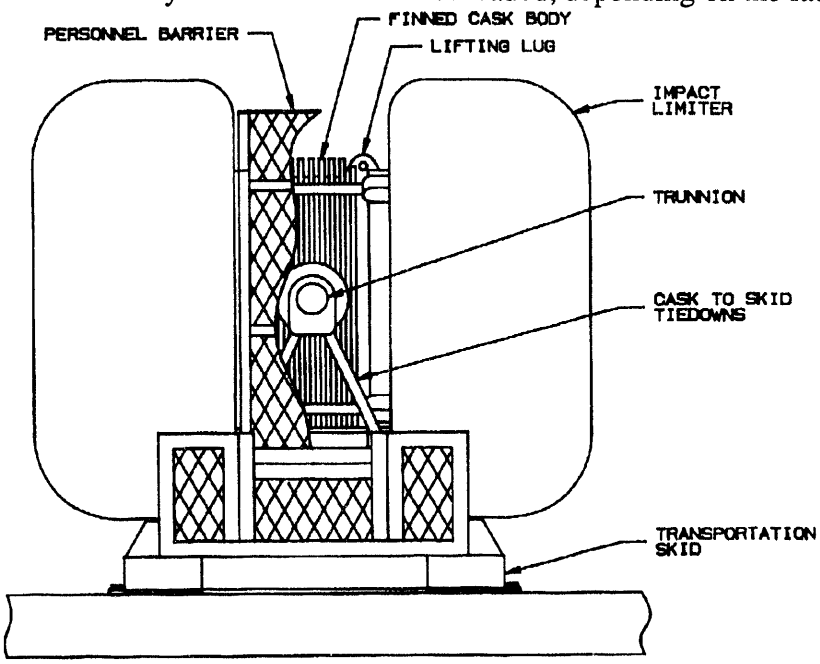

Figure 4. Cask assembly showing personnel barrier and shipping skid.

CASK DESIGN AND DEVELOPMENT

The design process included shielding, structural, and thermal analyses of the BUSS response to regulatory normal and hypothetical accident conditions. Results of these analyses for the final design were incorporated in the Safety Analysis Report for Packaging (SARP) [5].

The principal design criteria for structural integrity and shielding used during development of the BUSS cask were specified in 10 CFR Part 71 [6]. Of those conditions, the hypothetical accident conditions are the most stringent. They include 9-m drop, 1-m puncture, 30-minute thermal, and water immersion tests.

Shielding Analysis

We performed detailed shielding analyses of the BUSS cask loaded with 16 cesium chloride capsules to determine the radiation environment external to the package. The 16-capsule cask was found to be a more extreme shielding problem than the system loaded with six strontium fluoride capsules. The shielding assessments included multienergy group discrete ordinates and Monte Carlo computer analyses [7,8,9]. The radiation transport analyses of the BUSS cask were performed (1) to evaluate the shielding capabilities of the package for both normal and accident conditions, and (2) to determine the energy deposition profiles in the container for use in the thermal evaluation of the system. Separate one-, two-, and three-dimensional (1-D, 2-D, 3-D) finite-difference models were developed for both cases. Table 2 gives the calculated results for normal operation and post-accident radiation levels for the BUSS cask loaded with 16 cesium chloride capsules as well as maximum levels specified by the regulations.

Table 2. Summary of Radiation Levels (mrem/hr) for the Beneficial Uses Shipping System

	Normal Conditions				Accident Condition	
Source	Package Surface		2 m from Surface		1 m from Surface	
	End	Side	End	Side	End	Side
Gamma**	64	29	2.9	1.2	11	4.6
10CFR71 Regulation	200		10		1000	

As shown above, the cask meets the applicable shielding performance requirements specified in 10 CFR Part 71.

Structural Analysis

The principal structural members of the BUSS cask include the body, lid, and the impact limiters. The integrity of the system is assured for both normal operation and accidents by the performance of the structural members and the presence of high-quality metallic seals at every opening into the cask interior. In combination with the impact limiters, we show that this boundary is virtually unaffected by the normal and hypothetical accident conditions specified in 10 CFR Part 71.

9 Meter Free-Drop

We evaluated the performance and structural integrity of a BUSS cask subjected to the hypothetical accident free-drop test with 2-D and 3-D finite-element analysis techniques. Three orientations at impact were evaluated: (1) end, (2) side, and (3) center of gravity over corner. The finite-element models were generated by using QMESH [10] and PATRAN [11]; they were analyzed with Hondo II [12] and DYNA3D [13]. The deformed shapes and stress distributions were plotted with MOVIE BYU [14]. Accelerations were also obtained to evaluate lid integrity.

Table 3 shows the predicted values for impact limiter crush, cask body acceleration, and von Mises equivalent stress in the cask for three impact orientations at the most severe operating temperature condition.

Table 3. Predicted Foam Crush and Peak von Mises Stress for the Beneficial Uses Shipping System Cask in the Hypothetical Accident 9 Meter Free-Drop at -40° C

Orientation	Crush (cm)	Acceleration (g)	Stress (MPa)
End	15.5	105	59.3
Side	19.1	97	15.2
Corner	28.7	75	20.0

As shown above, the cask wall is stressed to values significantly less than yield during the 9-m drop event. Evaluation of the bolting arrangement using deceleration values on the cask lid

**Corresponds to the total dose rate since contents do not include neutron-emitting materials.

indicated that the seal will maintain its integrity in all impact orientations. Thus, the cask body is essentially undamaged when subjected to the second event of the hypothetical accident sequence, the 1-m drop onto a mild-steel pin.

1 Meter Puncture

We determined the structural response of the BUSS cask to the hypothetical accident puncture test with analyses similar to that used for the drop. To ensure analysis of the most severe accident, we evaluated puncture in three orientations: (1) cask impacting the punch on its side, (2) corner of the cask directly below the center of gravity impacting the punch, and (3) closure end impacting the punch. Each analysis was performed without the impact limiter in place to produce maximum damage to the cask. For the side punch, the cooling fins were not modeled.

In every case, we found that either the cask body or lid during closure end impact would be plastically deformed near the impact point. The damage would be limited to a shallow circular indentation corresponding to the cross-sectional dimensions of the end of the puncture bar. Elsewhere in the cask, the bulk of the material remains elastic (The average stress is 15 MPa or less).

Since the cask body is only moderately stressed and retains its containment and structural integrity, the cask body configuration (geometry) when subjected to the hypothetical accident thermal test is virtually unchanged.

Thermal Analysis

We evaluated the thermal responses of the BUSS cask for normal conditions of transport and hypothetical accidents with finite-difference modeling techniques and pre- and post-processing software. From the geometric description of the cask, we used PATRAN to generate a 2-D finite-element mesh into finite-difference data and Q/TRAN [15] to analyze the finite-difference model.

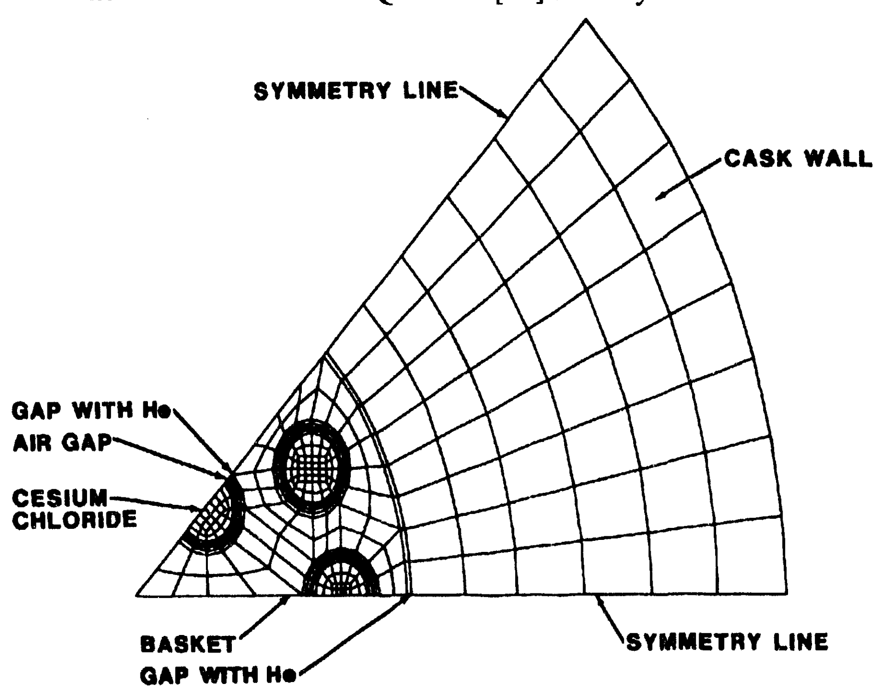

Figure 5. Cask thermal analysis model (16 capsule basket).

Once the model was analyzed, an inverse translator was used to convert the data back into a finite-element representation for post-processing. We used PATRAN to post-process the analysis data.

The finite-difference models used for the evaluation of normal and accident conditions were similar. The model used in the hypothetical thermal accident evaluation was essentially the same as the normal condition model except that the exterior boundary condition was changed to simulate thermal input from the fire as defined by the regulations. We modeled the body, basket, capsules, cooling fins, and the effects of the circumferential gaps between the body components (Figure 5). We conservatively assumed that heat was transported across the gaps only by conduction and radiation. Omitting convective transport across the gaps ensures greater predicted temperatures for the cask interior than expected under actual conditions. Heat loss from the exterior surface of the cask was modeled by assuming free convection and thermal radiation.

The thermal load of the cesium-137 in the BUSS cask was distributed throughout the interior portions of the cask based on the energy-deposition profile. About 50% of the decay energy is transported to and absorbed by the cladding, the basket, or the cask wall. The remainder of the heat released during the radioactive decay of cesium-137 was deposited within the cesium chloride.

Heat released by the decay of the strontium was assumed as absorbed entirely by the strontium fluoride. This assumption is justified since strontium-90 and its daughters emit betas which deposit their energy quickly. Such an assumption overestimates the capsule temperatures; some energy is actually deposited elsewhere in the the cask by gamma and bremsstrahlung radiation. The results of the thermal analyses (both normal and accident) indicate the temperatures of the cask body, basket, seals, and the cesium chloride and strontium fluoride contents. The temperatures in the capsules are less than the design allowables of 450°C at the cesium/metal capsule interface and 800°C at the strontium material centerline. Helium is used in the cask cavity to reduce capsule temperatures and thus increases the margin of safety during transport.

Containment

The containment of the special form contents is provided by the rugged double encapsulation of the radioactive materials. This encapsulation is supplemented by the cask structure and seals tested to a leak rate of 1×10^{-4} atm-cm^3/s. Essentially there are triple barriers to the release of the radioactive contents.

The primary function of the cask structure and seals is to retain helium for cavity heat-transfer purposes under normal transport conditions. Under these conditions, a design basis leakage limit of 1×10^{-4} atm-cm^3/s is low enough to ensure adequate helium retention during the transport period.

SUMMARY

The design of the cask system and the analyses performed to predict the response of the cask in impact, puncture, and fire accident conditions as specified in the regulations have been described. We have demonstrated in a SARP that the integrity of the BUSS cask system is maintained during normal and hypothetical accident conditions of 10 CFR Part 71. A cask prototype has been fabricated, and Certificates of Compliance have been obtained from both the DOE and the NRC.

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