CANISTER DESIGN FOR DIRECT DISPOSAL OF HLW CALCINE DISPOSAL PRODUCED AT THE IDAHO NATIONAL ENGINEERING AND ENVIRONMENTAL LABORATORY

T. J. Hill, T. E. Rahl, D. K. Morton, K. C. Coughlan, J. T. Beck, M. W. Patterson
Idaho National Engineering and Environmental Laboratory
P. O. Box 1625, Idaho Falls, ID 83415

ABSTRACT

Spent nuclear fuel reprocessing was carried out for many years at what is now called the Idaho National Engineering and Environmental Laboratory (INEEL). This reprocessing effort left significant quantities of liquid high-level waste (HLW) as a by-product. A multi-year effort was successfully completed that transformed nearly all that liquid waste into a solid waste (particulate) form, referred to as calcine. One of the options being investigated by the U.S. Department of Energy's Office of Environmental Management (DOE-EM) is the direct disposal of calcine waste in a mined geologic repository. A final decision by the Office of Civilian Radioactive Waste Management (OCRWM) and DOE-EM is not expected for several years.

Numerous disposal options arose as to the choice of material form for the HLW (vitrified, mixed with alternate media, leave as is, etc.) as well as the design concept for the canister in which the calcine was to be placed. Each material form presented different transportation and disposal requirements that needed to be satisfied. Either small (24-inch-diameter) or large (66-inch-diameter) canisters could be used, each with unique geometries and wall thicknesses. Small canisters could be more easily loaded and handled and fit in with existing plans for disposal of 24-inch-diameter HLW canisters from Savannah River, West Valley, and Hanford. The drawback of small canisters for a conceptual design was the significant number of canisters needed. An alternative is to use larger canisters that reduced the canister population significantly. However, large HLW canisters require more handling care and specialized equipment, especially to support transportation to the repository. The use of a larger canister also affects OCRWM's decision to codispose DOE-EM spent nuclear fuel with the HLW in the same waste package. Therefore, multi-variable life-cycle cost estimates will be required to select the most economical and viable solution.

The design analysis for the INEEL HLW disposal canister was initiated using a process and computer codes similar to that being used to support the licensing approach for the repository for disposal of DOE-EM spent nuclear fuel. A high degree of confidence was needed that the calcine canister would not be breached during preclosure events at the repository. Analysis supports this premise for either the 24-inch or 66-inch-diameter canisters.

This paper covers the background project information, the various options available to the HLW project, including canister design, the design analysis used to support the canister selection, the pros and cons of each alternative, and the reasons for the selection of the most favorable option. This effort resulted in the decision to continue pursuing disposal of the INEEL's HLW in a 66-inch-diameter by 15-ft-long canister.

INTRODUCTION

The primary objective for this task was to develop conceptual design options for a canister that can be used to transport calcined high-level waste (HLW) (located at the Idaho Nuclear Technology and Engineering Center [INTEC]) to the repository and then be disposed. The premise for this study was that calcine would be accepted at the mined geologic repository for direct disposal in long-term storage canisters. The sequence of events leading up to long-term storage would progress as follows:

- Calcine (calcined waste) is transferred from storage bins to disposal canister.
- Disposal canister is sealed.
- Disposal canister is loaded into transportation cask.
- Cask is transported to permanent storage facility or repository.
- Disposal canister is unloaded from transportation cask and inserted into a repository waste package, which may hold several canisters.
- Waste package is placed in long-term (permanent) storage.

The scope included development of design options for a canister that will maintain structural integrity during normal operation and postulated accident events that might occur during the handling stages of the canister. All analyses and evaluations will be performed using computer modeling techniques and analytical calculations. No actual testing of the canister designs have been performed at this time.

The analytical evaluation described here is preliminary in nature and is meant to provide the HLW Project with insights into potential options available regarding canister use for the calcine material at INTEC. This is a preliminary engineering study of canister concepts and does not invoke any facility-specific design or quality assurance requirements. Once a viable path forward for the disposal of the calcine material has been determined and the Idaho National Engineering and Environmental Laboratory (INEEL) HLW Project selects a canister concept, then a more complete and rigorous design analysis will be pursued that meets all applicable requirements.

REGULATORY STATUS OF CALCINE

The U.S. Department of Energy (DOE) Idaho Operations Office issued the Environmental Management Performance Management Plan for Accelerating Cleanup of the Idaho National Engineering and Environmental Laboratory.[1] This document outlined nine different strategic initiatives for achieving this objective. One of those initiatives is to accelerate the removal of HLW calcine from the State of Idaho by 35 years. In order to accomplish this, the initiative requires revision of the INEEL HLW disposal baseline from vitrification followed by disposal to direct disposal of the calcine without further treatment or with alternative treatment prior to disposal. Other than acceleration of HLW disposal from the State of Idaho by 35 years, the objectives of this strategy include eliminating the need to construct, decontaminate, and decommission a calcine vitrification facility, for an estimated life-cycle cost savings of $6 billion.[2]

As prescribed by this strategy, the direct disposed calcine is expected to be able to comply with the Yucca Mountain repository waste acceptance criteria, relating to radioactive constituents. However, the strategy presents Resource Conservation and Recovery Act (RCRA) (42 USC 6901 et seq.) Subtitle C hazardous waste regulation issues that need to be addressed before committing resources to conceptual design of the calcine treatment facility for ultimate disposal of INEEL HLW calcine in the repository.

The INEEL HLW calcine is regulated by RCRA Subtitle C[a] because the waste exhibits the hazardous characteristic of toxicity (40 Code of Federal Regulations [CFR] 261, Subpart C), and because the waste carries RCRA-listed hazardous waste numbers (40 CFR 261, Subpart C) (see Reference 2). Waste carrying listed hazardous waste numbers must be disposed in a permitted RCRA Subtitle C facility. The waste is planned to be disposed in the monitored geologic repository, but DOE's Office of Civilian Radioactive Waste Management (OCRWM) is not planning to accept waste regulated under RCRA Subtitle C for disposal at the repository. A list of the hazardous waste codes identified for the calcine is provided in Table I.

Table 1 List of hazardous waste codes for INEEL's high-level radioactive waste

Hazardous Waste Code	Description
D004	Arsenic
D005	Barium
D006	Cadmium
D007	Chromium
D008	Lead
D009	Mercury
D010	Selenium
D011	Silver
F001	1,1,1-trichloroethane Trichloroethylene Carbon tetrachloride
F002	1,1,1-trichloroethane Trichloroethylene Carbon tetrachloride Tetrachloroethylene
F005	Benzene Carbon disulfide Pyridine Toluene
U134	Hydrogen fluoride (hydrofluoric acid)

Sources:

"Regulatory Analysis and Reassessment of U.S. Environmental Protection Agency Listed Hazardous Waste Numbers for Applicability to the INTEC Liquid Waste System," Revision 1, INEEL/EXT-98-01213, Idaho Engineering and Environmental Laboratory, February 1999.

"NWCF Calcine Emissions Inventory—Final Report for Phase IV Testing," INEEL/EXT-01-00260 Idaho Engineering and Environmental Laboratory, February 2001.

"HWMA/RCRA Part A Permit Application for the INEEL Volume I," Bechtel BWTX Idaho, LLC, Rev. 35, December 9, 2002.

Delisting is the established mechanism under the RCRA regulations for excluding a waste with listed hazardous waste numbers from RCRA Subtitle C regulation. The delisting process can be used to exclude listed wastes that are sufficiently treated so that they no longer pose a threat to human health or the environment (61 FR 32799, 1996). One of the delisting petition requirements is that the petitioned waste does not exhibit a RCRA hazardous waste characteristic following treatment. INEEL HLW calcine is known to exhibit the RCRA hazardous characteristic of toxicity. Therefore delisting, although a viable regulatory strategy for vitrified HLW, is not a viable option for direct disposed calcine.

The RCRA Land Disposal Restrictions (LDR) regulations at 40 CFR 268 require that waste planned for land disposal must meet specified LDR treatment standards, unless a treatment variance (including petitioning for a waiver of requirements) is obtained. The LDR program ensures that wastes are properly treated prior to land disposal and specifies either concentration levels or treatment methods for hazardous constituents to substantially reduce the toxicity and mobility of a waste prior to land disposal. By achieving this toxicity and mobility reduction, the likelihood that contaminants would migrate from the waste and cause land and groundwater contamination is decreased.[3]

In 2001, the Environmental Protection Agency (EPA) issued a final rule providing RCRA regulatory relief from the dual regulation of the management, storage, and disposal of mixed low-level waste (MLLW). The rule provides exemption of MLLW on two conditions: (1) the MLLW is disposed of in an Nuclear Regulatory Commission-licensed and regulated facility and (2) meets the RCRA LDR standards when disposed of (66 FR 27218; May 16, 2001). The INEEL Calcine Disposition Project is currently implementing a RCRA regulatory strategy patterned after this final rule and seeks to obtain conditional exemption of HLW calcine upon disposal in a Nuclear Regulatory Commission-licensed geologic repository at Yucca Mountain and to petition EPA for a no-migration variance from the LDR treatment requirements.

CANISTER DESIGN CONCEPTS

Four canister design concepts were evaluated and are discussed in this paper. In addition, variations of the four concepts were evaluated.

24-Inch HLW Canister

This design is similar to the 24-inch-diameter DOE spent nuclear fuel (SNF) canister design concept presented in Reference 4. Sketches of the SNF canister are shown in Figure 1. The chief differences between the HLW canister and the SNF canister would be:

- A modified top head to allow loading of calcine
- No internal impact plates
- A possible modified bottom head with no plug.

Note that the length of the 24-inch canister option is normally 180 inches long, which is similar to the SNF canister design. A variation of the 24-inch HLW canister was considered, which involved modifying the skirt, head, and shell thickness to 0.375 inches rather than 0.5 inches of the original concept.

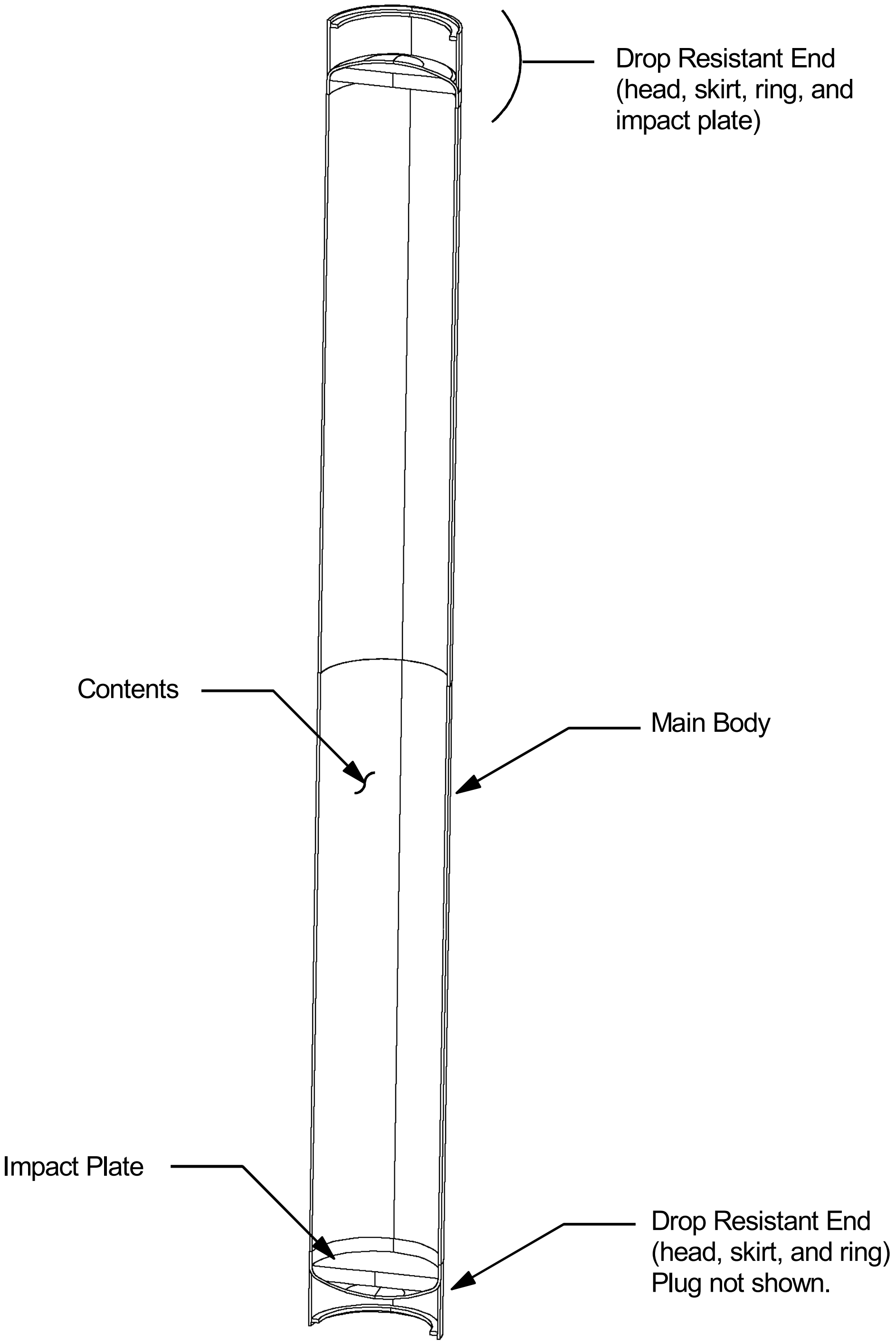

Fig. 1 Section view of 24-inch SNF canister design

66-Inch HLW Canister

This design is similar to the 24-inch option with an outside diameter of 66 inches and an overall length of 210 inches. Like the 24-inch option, there are no internal impact plates, and the top head would be designed to accommodate loading of the canister. In addition, the lifting device has not been determined yet. The current concept assumes that a device will be used that uses a lifting ring integral with the canister.

The initial concept design of the 66-inch canister was basically a 24-inch can with the key dimensions of wall thickness and diameter factored up by a value of 2.75. Four design variations were also evaluated. These variations are presented in Table II.

Table II Design variations of the 66-inch HLW canister.

Design Variation	Length (inches)	Shell Thickness (inches)	Head Thickness (inches)
Initial concept	210	1.375	1.375
Variation A	210	1.000	1.000
Variation B	210	0.750	0.750
Variation C	210	0.500	0.500
Variation D	210	0.375	0.375

66-Inch HLW Donut Canister

This design is similar to the 66-inch option with a design modification of a cylindrical opening located at the center of the canister. A solids model plot of the 66-inch HLW donut canister concept is contained in Figure 2. The center cylinder has an inside diameter of approximately 18.5 inches. This opening will permit the codisposal of a DOE Office of Environmental Management SNF canister within the HLW disposal canister. Overall length is 210 inches. Like the other options, the top head would be designed to accommodate loading of the canister. In addition, the lifting device has not been determined yet. The current concept assumes that a device would be used that uses a lifting ring integral with the canister.

The initial concept design of the 66-inch donut canister had key dimensions that corresponded directly with the 66-inch canister. The wall thickness of the center cylinder was 0.5 inches. Four design variations were also evaluated. These variations are presented in Table III.

Flat Bottom HLW Canister

This concept is similar to the Navy Long Spent Fuel Canister described in the Reference 5 document. It is a 66-inch diameter cylinder with a 1-inch shell, 15-inch top-head, and a 3.5-inch bottom head. A solids model plot of the Flat Bottom HLW canister concept is shown in Figure 3. Overall length is 210 inches. Like the other options, the top head would be designed to accommodate loading of the canister.

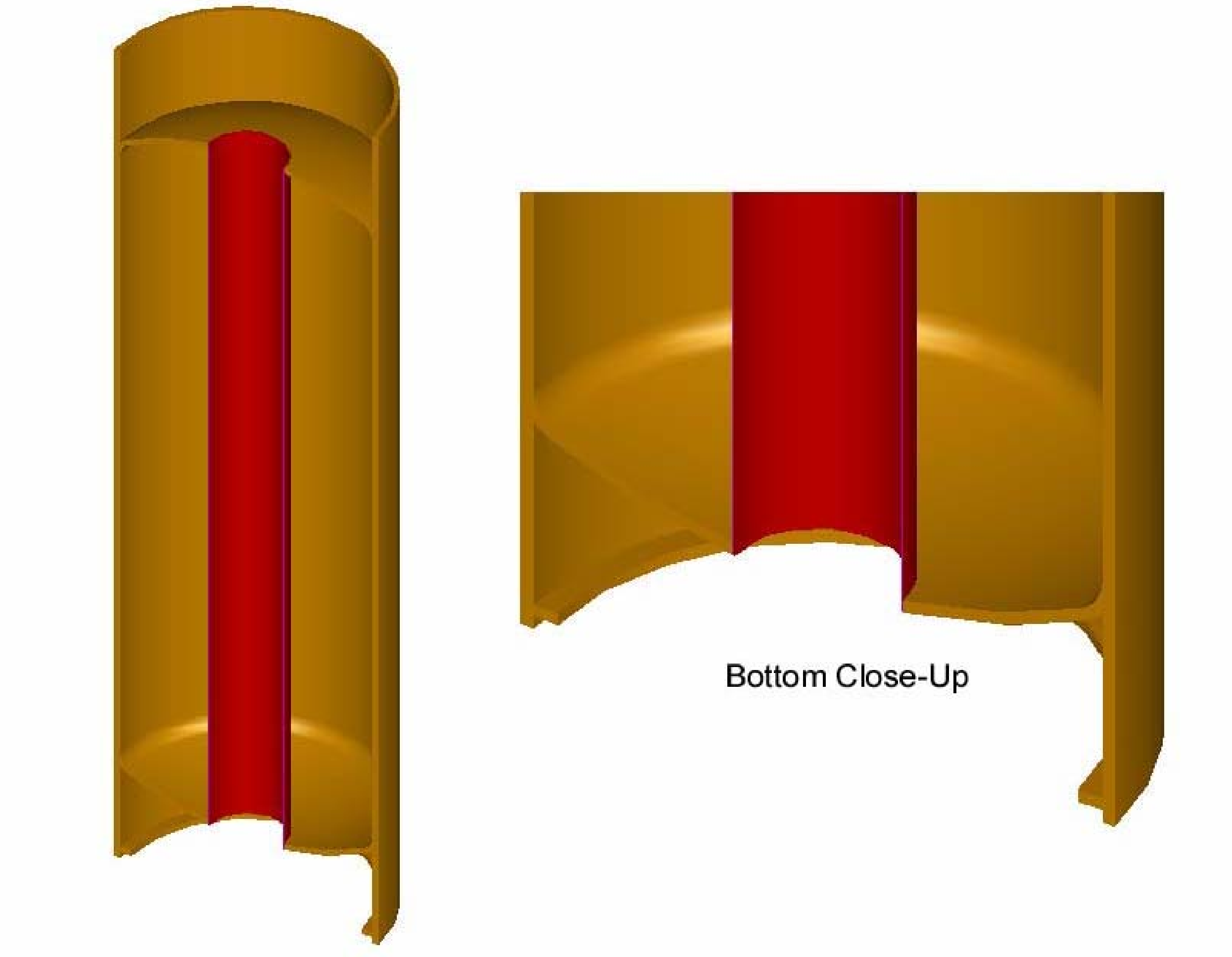

Fig. 2 66-inch HLW donut canister concept cross section

Table III. Design variations of the 66-inch HLW donut canister

Design Variation	Length (inches)	Shell Thickness (inches)	Head Thickness (inches)	Center Cylinder Wall Thickness (inches)
Initial concept	210	1.375	1.375	0.500
Variation A	210	1.000	1.000	0.500
Variation B	210	0.7500	0.7500	0.500
Variation C	210	0.5000	0.5000	0.500
Variation D	210	0.3750	0.3750	0.500

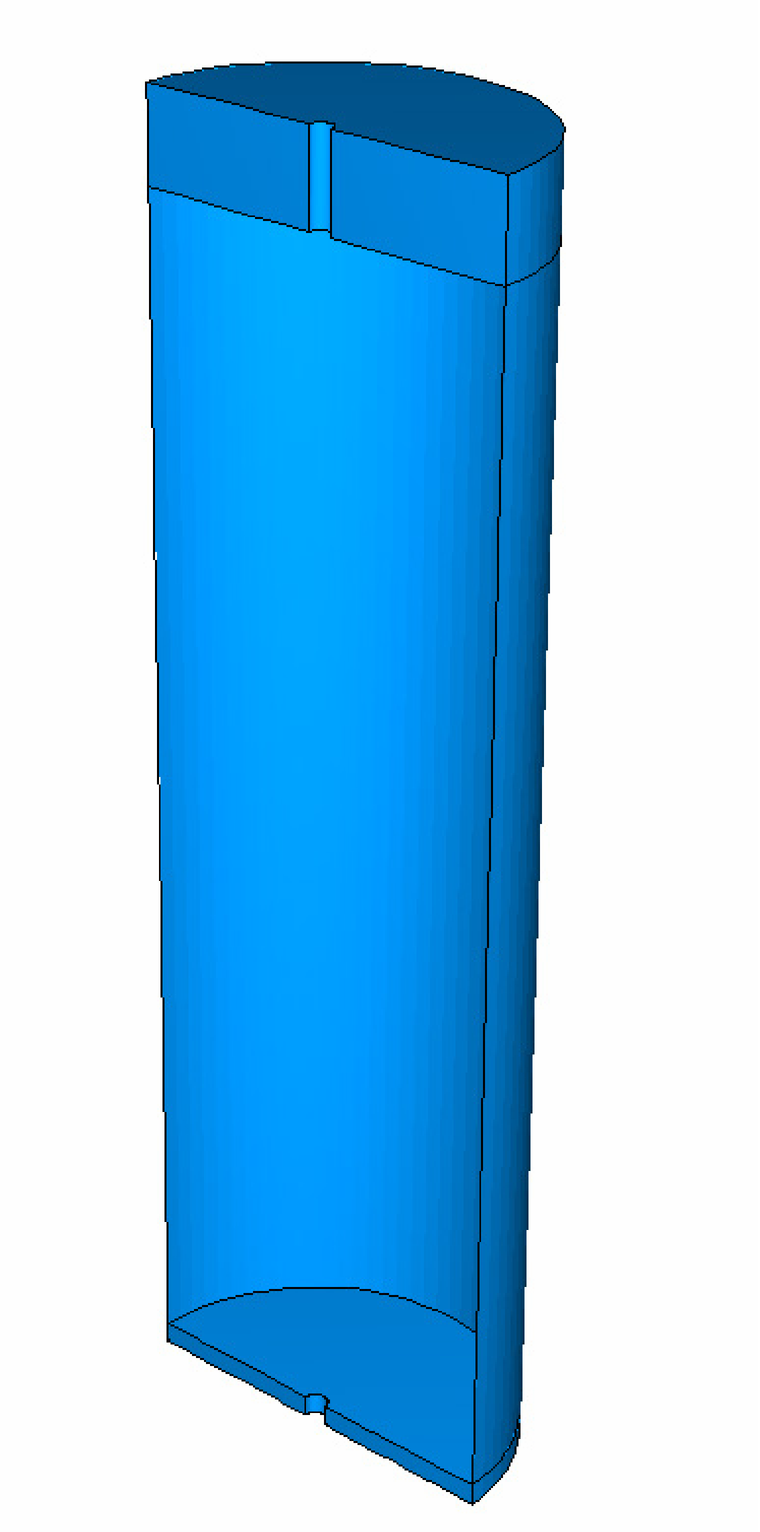

Fig. 3 66-inch HLW flat bottom concept cross section.

In addition, the lifting device has not been determined. Six design variations were also evaluated. These variations are presented in Table IV.

Table IV Design variations of the flat bottom HLW canister

Design Variation	Length (inches)	Shell Thickness (inches)	Top Head Thickness (inches)	Bottom Head Thickness (inches)
Initial concept	210	1.000	15.000	3.5
Variation B	210	0.7500	15.000	3.5
Variation C	210	0.5000	15.000	3.5
Variation C, H1	210	0.5000	15.000	3.0
Variation C, H2	210	0.5000	15.000	2.5
Variation C, H3	210	0.5000	15.000	2.0
Variation D	210	0.3750	15.000	3.5

MATERIALS CONSIDERED

The material selection for the canisters (all design concepts) was made with several factors in mind. First, the most demanding load on the canisters was expected to be the accidental drop, so a strong and ductile material is needed. Second, it is desirable to avoid the problems associated with inter-granular stress corrosion cracking, making a low carbon material (base metal and welds) a requirement. Third, the canisters could be in a moist environment, which dictates a material with high corrosion resistance. Fourth, exotic materials would be more costly than commonly available materials. A significant number of these canisters may be manufactured and the use of common materials, if they meet the structural requirements, would result in significant cost savings.

Either 304L stainless steel or 316L stainless steel would satisfy the above requirements. Because 316L has better resistance to pitting corrosion and more closely matches the material specified for the repository waste packages, it was chosen as the material to use. The material properties for 316L that were used in this evaluation are summarized below and in Table V.[6]

Young's Modulus = 28,300,000 psi
Poisson's ratio = 0.29
Weight Density = 0.283 lb/in^3

Table V Plastic stress-strain curve

Plastic Stress-Strain Curve	
Stress (psi)	Strain
45450.	0.
59900.	0.094
68200.	0.138
76800.	0.180
95500.	0.260
116000.	0.333
135700.	0.393
135700.	0.500
135700.	1.000

The current material model used for the 316L stainless steel was taken from the Reference 6 report. It represents an assumption that the dynamic stress-strain curve is approximately 20% above that obtained from low rate (static) tensile testing with the assumption that uniform elongation equaled strain.

Note that these material property values are based on actual material testing performed at room temperature. These are representative for temperatures of –20°F to 100°F. As temperatures go up these property values decrease. Because this effort is a conceptual design effort comparing different design options, these property values are appropriate and correct. If high temperature effects become a concern, they can be addressed during the final design effort of the HLW canister.

CANISTER CONTENTS AND WEIGHTS

For the purposes of this evaluation, the canisters will contain INTEC calcined HLW. According to Reference 7 and at the direction of the INEEL HLW Project, the density of the calcine used in this evaluation will be the following.
Calcine density = 1.7 gm/cm^3 (0.06142 lb/in^3)

The volume and weight of the canister contents along with the canister weights are tabulated in Table VI. These weights are based on the initial design concepts, not the variations.

Table VI Canister and calcine weights

Design Concept	Canister Weight (lb)	Calcine Volume (in^3)	Canister Volume (in^3)	% Full	Calcine Weight (lb)	Total Weight (lb)
24-inch Canister	2,050	65,440	66,860	98	4,020	6,070
66-inch Canister	20,110	481,800	526,530	92	29,600	49,710
66-inch Donut Canister	21,375	429,600	466,580	92	26,390	47,765
Flat-Bottom Canister	29,400	570,800	612,210	93	35,060	64,460

ACCIDENTAL DROP LOADS

Several accident drop orientations were considered for each of the design concepts. The orientations common for all four concepts are listed below:

- 30-foot drop on flat surface, canister oriented vertically
- 30-foot drop on flat surface, canister oriented with center-of-gravity (CG) overcorner
- 30-foot drop on flat surface, canister oriented 45 degrees off-vertical
- 30-foot drop on flat surface, canister oriented 90 degrees off-vertical (horizontal)
- 30-foot drop on flat surface, slapdown (canister oriented 60 to 80 degrees off-vertical)
- 40-inch drop on 6-inch diameter post, canister oriented 90 degrees off-vertical (horizontal).

FINITE ELEMENT MODELS

The drop simulations were performed using ABAQUS/Explicit finite element (FE) models. Solutions were obtained using ABAQUS/Explicit Versions 6.3-1 and 6.3-3. Version 6.3-1 is not an officially validated version of ABAQUS/Explicit, whereas 6.3-3 is. [8] Version 6.3-3 was not available at the time this task was begun and because of the large number of runs made for this task; the start of the effort could not be delayed in order to use only Version 6.3-3. Results from the few cases that were run with both versions agree very closely, if not identical. There were some modeling capability improvements in Version 6.3-3, but nothing that significantly affected the results or conclusions of this paper. In addition, the fact that this is a conceptual effort providing only preliminary information justifies this approach. It is recommended that a fully validated and verified version of ABAQUS/Explicit be used for the final design/analysis effort.

24-Inch HLW Canister Model

The 24-inch HLW model was created using plate elements for the heads, body, and skirts. The lifting ring located on the skirt and the calcine contents were modeled using solid elements. A half model was used with appropriate symmetry boundary conditions applied. The nozzle at the center of the bottom head has a 4-inch diameter and is 3 inches long. It represents a volume reserved for some type of fill connection that has not been designed yet. It was modeled to give perspective to deformation plots as to how much clearance might be expected during a drop event between the filling device and the impact surface, assuming the canister falls with the top oriented down. The nozzle/head configuration was also used in a weight only run to evaluate a pintel type design option for lifting the canister versus the lifting ring.

The calcine was modeled to have a weight corresponding to the weight stated in Table VI of this paper. After trying a number of different Elastic Modulus values, it was decided to use 20,000 psi as the modulus for the calcine. This provided a material that had a very small stiffness relative to the steel. Higher values might add some structural resistance that would not exist in the actual canister. This structural resistance could inadvertently add strength to the vessel wall. To further verify that the situation would not occur, the calcine was modeled in three different geometries. All three models were used in all drop orientations to determine if the calcine geometry affected the results significantly. The first model represents a solid volume of calcine. The second model referred to as “reduced calcine model #1” represents the calcine as a series of annular rings with three annular gaps present. The third model referred to as “reduced calcine model #2” contains full-length longitudinal gaps modeled in a checkerboard pattern. The intent of the reduced calcine models is to create a calcine geometry that collapses upon itself during loading and thus does not add any structural rigidity or strength to the canister wall or head.

66-Inch HLW Canister Model

The 66-inch HLW canister model was created using shell elements for the heads, body, and skirts. The lifting ring located on the skirt and the calcine contents were modeled using solid elements. A half model was used with appropriate symmetry boundary conditions applied. One version of the 66-inch HLW model includes a nozzle at the center of the head simulating a pintel type design. It was used to evaluate a pintel type design option for lifting the canister versus the lifting ring.

The calcine was modeled to have a weight corresponding to the weight stated in Table VI of this paper. The Modulus of Elasticity used was 20,000 psi. As with the 24-inch HLW model, the calcine was modeled in three different geometries. All three models were used in all drop orientations to determine if the calcine geometry affected the results significantly.

66-Inch HLW Donut Canister Model

The 66-inch HLW donut model was created using shell elements for the heads, body, skirts, and center tube. The lifting ring located on the skirt and the calcine contents were modeled using solid elements. A half model was used with appropriate symmetry boundary conditions applied.

The calcine was modeled to have a weight corresponding to the weight stated in Table VI of this paper. The Modulus of Elasticity used was 20,000 psi. For this model, the calcine was modeled in two different model geometries (“solid model” and the “reduced calcine model #2”). Both models were used in all drop orientations to determine if the calcine geometry affected the results significantly.

66-Inch Flat Bottom Canister Model

The 66-inch Flat Bottom Canister model was created using shell elements for body and solid elements for the heads and calcine contents. A half model was used with appropriate symmetry boundary conditions applied.

The calcine was modeled to have a weight corresponding to the weight stated in Table VI of this paper. The Modulus of Elasticity used was 20,000 psi. The calcine was modeled in three different geometries. All three models were used in all drop orientations to determine if the calcine geometry affected the results significantly.

COMPARISON EVALUATION

A comparison of the evaluation results has been made to aid in the selection of a preferred design. There are many different things that could be considered in a design selection. Eventually, this project could have parameters such as size or weight that have absolute limitations that would drive this design one direction or the other. For now, those driving parameters do not exist. For purposes of this selection, the following items will be considered:

- Maximum allowable design pressure
- Peak equivalent plastic strain
- Maximum deformations
- Material cost
- Total weight (indicates some measure of ease of handling)
- Handling characteristics (lifting mechanism interface).

Maximum Allowable Pressure

The maximum allowable design pressure per ASME Section VIII criteria are presented in Table VII for each design. Examination of this table demonstrates the inherent weakness of a flat head for internal pressure. Once a design pressure is absolutely defined a number of these designs would likely be eliminated.

Table VII Maximum design pressure comparison

Model	Thickness Variation (inches)	Head Design Pressure (psi)	Wall Design Pressure (psi)	Governing Pressure (psi)
24-inch Canister	$t_{wall} = t_{head} = 0.500$	392	708	392
	$t_{wall} = t_{head} = 0.375$	294	528	294
66-inch Canister and 66-inch Donut Canister	$t_{wall} = t_{head} = 1.375$	392	708	392
	$t_{wall} = t_{head} = 1.000$	285	512	285
	$t_{wall} = t_{head} = 0.750$	214	383	214
	$t_{wall} = t_{head} = 0.500$	143	255	143
	$t_{wall} = t_{head} = 0.375$	107	191	107
66-inch Flat Bottom	$t_{wall} = 1.0$ $t_{bottom\ head} = 3.5$	178	512	178
	$t_{wall} = 0.75$ $t_{bottom\ head} = 3.5$	178	383	178
	$t_{wall} = 0.50$ $t_{bottom\ head} = 3.5$	178	255	178
	$t_{wall} = 0.50$ $t_{bottom\ head} = 3.0$	127	191	127
	$t_{wall} = 0.50$ $t_{bottom\ head} = 2.5$	85	191	85
	$t_{wall} = 0.50$ $t_{bottom\ head} = 2.0$	53	191	53
	$t_{wall} = 0.375$ $t_{bottom\ head} = 3.5$	178	191	178

Peak Equivalent Plastic Strain

Maximum strains in the containment boundaries for the four canister models are compared in Table VIII. Previous testing [9] has indicated that mid-plane strain levels of approximately 40% and surface strains of 80% are acceptable levels. All models meet those requirements, with the 66-inch canister and donut modification experiencing the lowest values.

Table VIII Maximum peak equivalent plastic strain comparison

Model	Peak Equivalent Plastic Strain (%)	
	Surface	Mid-Plane
24-inch Canister	65	32
66-inch Canister	50	22
66-inch Donut Canister	48	22
66-inch Flat Bottom	72	27

Maximum Deformations

Acceptable deformations at this stage of the design have not been defined and are, therefore, somewhat subjective. As the design progresses to final stages, maximum acceptable deformations will come into being and may dictate the final design configuration. For now, the primary driver for acceptability of deformations in the 24-inch, 66-inch, and 66-inch donut models is the ability of the canister to protect the canister fill mechanism (nozzle) during an inverted drop. Figure 4 is representative of deformations obtained from the analytical model. For the flat bottom canister, acceptability is based solely on the author's subjective opinion of excessive deformation in a containment boundary.

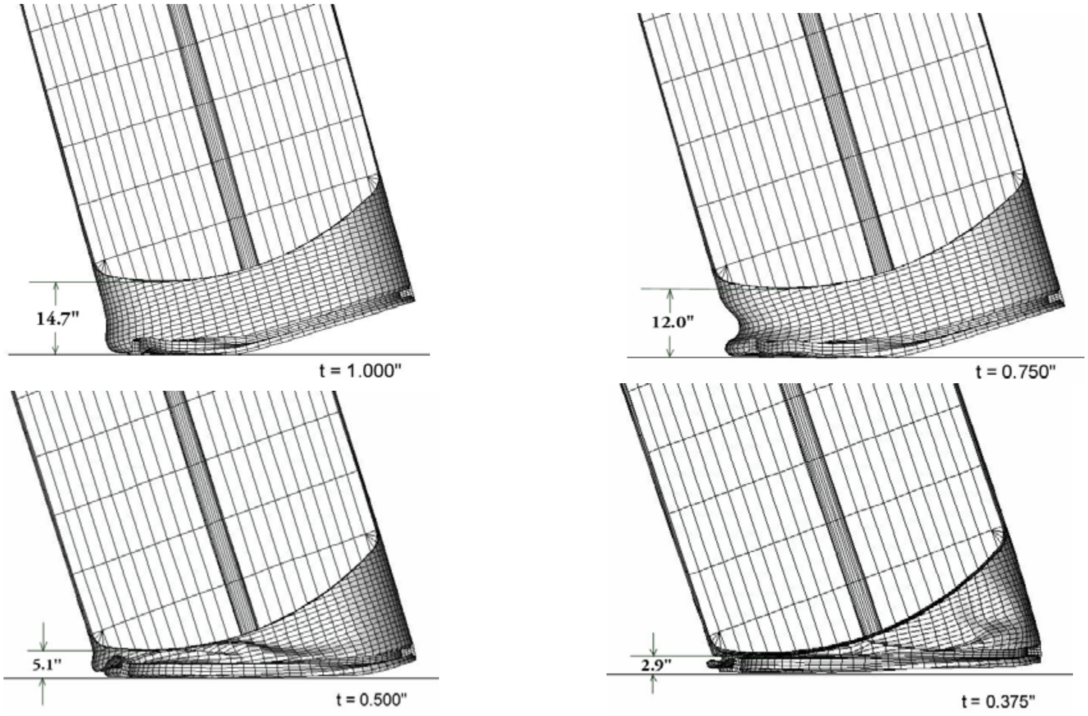

Fig. 4 Center of gravity over-corner deformed plots.

All canister designs along with the thickness variations are presented in Table IX. They are rated as either acceptable or unacceptable from the perspective of maximum deformations occurring during drop events.

Table IX Deformation acceptability

		Max Deformation	
Model	Thickness Variation	Acceptable	Not Acceptable
24-inch Canister	$t_{wall} = t_{head} = 0.500$ inches	x	
	$t_{wall} = t_{head} = 0.375$ inches	x	
66-inch Canister	$t_{wall} = t_{head} = 1.375$ inches	x	
	$t_{wall} = t_{head} = 1.000$ inches	x	
	$t_{wall} = t_{head} = 0.750$ inches	x	
	$t_{wall} = t_{head} = 0.500$ inches		x
	$t_{wall} = t_{head} = 0.375$ inches		x
66-inch Donut Canister	$t_{wall} = t_{head} = 1.375$ inches	x	
	$t_{wall} = t_{head} = 1.000$ inches	x	
	$t_{wall} = t_{head} = 0.750$ inches	x	
	$t_{wall} = t_{head} = 0.500$ inches		x
	$t_{wall} = t_{head} = 0.375$ inches		x
66-inch Flat Bottom	$t_{wall} = 1.0$ inches $t_{bottom\ head} = 3.5$ inches	x	
	$t_{wall} = 0.75$ inches $t_{bottom\ head} = 3.5$ inches	Marginal	Marginal
	$t_{wall} = 0.50$ inches $t_{bottom\ head} = 3.5$ inches		x
	$t_{wall} = 0.375$ inches $t_{bottom\ head} = 3.5$ inches		x

Material Cost

A detailed cost estimate is beyond the scope of this paper. However, some consideration can be made concerning cost. Assuming the effort and material cost required to build a specific canister is somewhat proportional to the weight of steel contained in the canister, the ratio of weight of steel to weight of calcine contained in a specific design can be determined. A comparison of these ratios can then be made to determine the most economic design to use, based strictly from the standpoint of pounds of steel required to contain a unit volume of calcine. Table I0 presents this concept. The 66-inch canister with a ¾-inch wall appears to be the best choice using this simplified approach.

Table I0 Cost ratio concept comparison

Design Concept	Wall Thickness (inches)	Canister Wt. (lb)	Calcine Wt (lb)	Total Wt. (lb)	$\frac{W_{canister}}{W_{calcine}}$
24-inch Canister	0.50	2,050	4,020	6,070	0.51
	0.375	1,550	4,020	5,570	0.39
66-inch Canister	1.375	20,110	29,600	49,710	0.68
	0.75	10,970	29,600	40,570	0.37
66-inch Donut Canister	1.375	21,375	26,390	47,765	0.81
	0.75	11,660	26,390	38,050	0.44
66-inch Flat Bottom Canister	1.00	29,400	35,060	64,460	0.84

Total Weight

The total weight of the loaded canister is definitely an issue that needs to be resolved. The heavier the canister the harder it is to handle and transport. The total weight numbers for the concepts are presented in Table I0. The 24-inch canister is obviously the easiest design to handle and transport. It is significantly lighter than the other concepts, and the weight ratio is just slightly higher than the 66-inch canister.

Considering only the larger designs, the 66-inch canister with or without the donut option is the best choice. The total weight and cost ratio for these two is significantly less than the flat bottom option.

Handling Characteristics

Although the handling approach hasn't been determined yet, it appears that the current two options are a pintel type design that would involve a center nozzle interface and a lifting ring located on the skirt of the canister. From a handling perspective it seems as if either option is about equal for the 24-inch canister. The final calcine loading interface would probably drive the choice one way or the other, although a lifting fixture would already exist for the lifting ring because of the prior existence of standardized canisters for DOE SNF. Because of the larger size of the 66-inch canister options, it seems logical that the pintel style design would be preferable. Mainly from the standpoint that the lifting mechanism to engage the lifting ring would have to be significantly bigger than a lift mechanism designed to engage a pintel.

CONCLUSIONS

24-Inch HLW Canister

The maximum containment boundary strain for the 24-inch canister (1/2-inch wall thickness) was calculated to be 65% at the surface and 32% at the mid-plane. A 4-inch diameter by 3-inches long fill equipment (nozzle) envelope was evaluated for an inverted drop. Results indicated this envelope could be expanded to 6 inches in diameter by 4 inches long. The skirt for the 24-inch can is approximately 10 inches in length.

Reducing the wall and head thicknesses of the 24-inch can to 0.375 inches was investigated and results indicated that this could be done without any dire consequences. Higher material straining would result, but maximum values would not increase significantly. Additional deformation of the can (the result of the additional strain) would occur; however, the additional deformation is not excessive and appears to be at an acceptable level. The increased fill equipment envelope (nozzle) of 6 inches by 3 inches might not be achievable in the reduced thickness design, but it is very likely that it would be. More detailed analysis would be required to determine if that was feasible. This determination could be done in the final design should the 24-inch design be chosen.

66-Inch HLW Canister

The maximum containment boundary strain for the 66-inch canister (1.375-inch wall thickness) was calculated to be 50% at the surface and 22% at the mid-plane. As with the 24-inch canister, reducing the thickness did not increase the strains significantly although they did go up some. The critical issue was deformation. Decreasing the wall/head thickness to 0.5 inches caused the deformations to experience a step change to the point of the skirt collapsing for some load cases. A wall/head thickness of 0.75 inches appears to be the best choice for this design.

Both a lift ring and pintel style lifting interface were evaluated. Both work well from a maximum stress consideration. Because of the large diameter of the 66-inch design, it seems that the pintel style interface would be easier for designing a lifting mechanism. The lifting mechanism/pintel lift system would need to be coordinated with the calcine loading system finally used. Once those two decisions are made, the pintel/head intersection could be optimized for additional stress margin.

Current analyses indicate that a 12-inch long, 12-inch diameter nozzle envelope would exist for loading hardware. As the final model is fine tuned (should this option be chosen), this envelope could quite possibly increase.

The current skirt is 27 inches long. This appears to be a good length. As the canister loading mechanism design is finalized, this number could be modified, possibly shorter, which would allow for a slight increase in calcine volume loading.

66-Inch HLW Donut Canister

The maximum containment boundary strain for the 66-inch canister (1.375-inch wall thickness) was calculated to be 48% at the surface and 22% at the mid-plane. This is similar to the 66-inch model as expected because the designs are identical except for the center tube. Maximum center tube strains were roughly 10% of those occurring in the outside wall.

The calcine loading mechanism is complicated somewhat for this design due to the center tube. The lifting mechanism would easily accommodate the lifting ring design, while a pintel (at least center pintel) would probably not work.

Deformations for the donut design are similar to the non-donut 66-inch canister.

Flat Bottom Canister

The maximum containment boundary strain for the 66-inch flat bottom canister was calculated to be 72% at the surface and 27% at the mid-plane. Because this design has no skirt, the shell sees the majority of the deformations that occurs during an accidental drop. The heads are so thick that they don't experience any significant deformation, although they do see some high local strains.

One weakness of the flat bottom concept is its resistance to internal pressure. The flat bottom canister with a 3.5-inch head can tolerate an internal pressure of 180 psi per ASME Section VIII criteria. By comparison, the 66-inch canister with a formed head thickness of 0.75 inches can tolerate an internal pressure of 214 psi.

DESIGN RECOMMENDATIONS

It is recommended that the 66-inch HLW canister (with 0.75-inch head/wall thickness) be adopted as the preferred design for transporting calcine waste. Overall the 66-inch canister and the 24-inch canister are relatively equal with the 24-inch individually easier to handle. However, the simple fact that eight 24-inch canisters have to be handled and loaded to equal the contents of one 66-inch HLW canister makes the 66-inch HLW canister the clear choice of designs. It is further recommended that a pintel-type design be used as the lifting mechanism interface between the lifting device and canister.

REFERENCES

1 Department of Energy, *Environmental Management Performance Management Plan for Accelerating Cleanup of the Idaho National Engineering and Environmental Laboratory,* DOE/ID-11006, July 2002.

2 Department of Energy, *Idaho High-*Level *Waste and Facilities Disposition Draft Environmental Impact Statement*, DOE/EIS-0287D, December 1999.

3 Environmental Protection Agency, *Land Disposal Restrictions: Summary of Requirements,* EPA530-R-01-007, August 2001.

4 Department of Energy, *Preliminary Design Specification for Department of Energy Standardized Spent Nuclear Fuel Canisters*, DOE/SNF/REP-011, Revision 3, Volume I and II, August 17, 1999.

5 U.S. Nuclear Regulatory Commission, *Safety Evaluation Report for the Navy Spent Fuel Canister System Storage*, Docket No. 72-33.

6 American Society of Mechanical Engineers, ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, "Rules for Construction of Pressure Vessels," 1998 Edition, 2000 Addenda, July 1, 2000.

7 E-mail from Christine M. Frazee on October 9, 2002, @ 04:49 PM, Subject: Calcine Characteristics.

8 S. D. Snow, DOE/SNF/REP-085, Rev. 2, Software Report for ABAQUS/Explicit Version 6.3-3, June 2003.

9 D. K. Morton, S.D. Snow, T.E. Rahl, *FY1999 Drop Testing Report for the 18-Inch Standardized DOE SNF Canister*, EDF-NSNF-007, Revision 2, September 5, 2002.

FOOTNOTES

[a] The State of Idaho is authorized to implement the RCRA Subtitle C hazardous waste program, including delisting, in lieu of the federal program. Pursuant to the (Idaho) Hazardous Waste Management Act of 1983 (§§ 39-4401 et seq., Idaho Code), the implementing regulations are provided in the Idaho Department of Environmental Quality Rules, IDAPA 58.01.05, "Rules and Standards for Hazardous Waste," in the Idaho Administrative Code.