A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

ORNL/CSD/TM--237

DE86 015990

**SCOPING STUDY OF CASKS SHIPPED FROM THE MRS
FACILITY TO VARIOUS REPOSITORY SITES**

J. A. Bucholz

Date Issued: August 1986

**Computing and Telecommunications Division
at
Oak Ridge National Laboratory
Post Office Box X
Oak Ridge, Tennessee 37831**

**MARTIN MARIETTA ENERGY SYSTEMS, INC.
operating the
Oak Ridge Gaseous Diffusion Plant Oak Ridge National Laboratory
Oak Ridge Y-12 Plant Paducah Gaseous Diffusion Plant
under contract No. DE-AC05-84OR21400
for the
U.S. Department of Energy**

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EAB

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A04; Microfiche A01

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

TABLE OF CONTENTS

	PAGE
LIST OF FIGURES	v
LIST OF TABLES	vii
ACKNOWLEDGMENTS	ix
ABSTRACT	xi
1. INTRODUCTION	1
2. DESCRIPTION OF PACKAGES TO BE TRANSPORTED INSIDE THE SHIPPING CASKS	1
2.1 SALT REPOSITORY WASTE PACKAGE CONFIGURATIONS	1
2.2 TUFF REPOSITORY WASTE PACKAGE CONFIGURATIONS	4
2.3 BASALT REPOSITORY WASTE PACKAGE CONFIGURATIONS	4
3. GENERIC DESCRIPTION OF CASKS TO BE USED	7
4. METHODOLOGY	11
4.1 INITIAL ANALYSIS	11
4.2 SHIELDING REASSESSMENT	12
4.3 HEAT TRANSFER CONSIDERATIONS	12
5. RESULTS	15
6. CONCLUSIONS	26
REFERENCES	29
APPENDIX	31

LIST OF FIGURES

FIGURE	PAGE
1. Salt reference design for a segmented steel canister containing consolidated fuel rods from 12 PWR assemblies or 30 BWR assemblies	2
2. Thick carbon steel overpack in the Salt reference design	3
3. Tuff reference design for an overpack and canister containing consolidated fuel rods from 6 PWR assemblies	5
4. Tuff reference design for an overpack and canister containing consolidated fuel rods from 14 BWR assemblies	5
5. Generic description of a typical shipping cask, as modeled in this study	8
6. Removable aluminum inserts for casks containing 1-12 cylindrical waste packages	10
7. A Simplified 2-D KENO IV model of a large U-shielded cask containing 100 consolidated PWR fuel assemblies in 25 thin-walled steel canisters	25

LIST OF TABLES

TABLE	PAGE
1. Basalt reference designs for thin-walled carbon steel canisters containing consolidated fuel rods from 1, 2, 3, or 4 PWR assemblies and/or 2, 4, 7, or 9 BWR assemblies	6
2. Thicknesses of the main structural components in each type of cask	9
3. Initial capacities, weights, shield thicknesses, and dose rates for 30 representative casks that were selected for more detailed multigroup, 1-D, discrete ordinates shielding analyses	13
4. Final capacities, weights, shield thicknesses, and dose rates for 30 representative casks that were selected for more detailed multigroup, 1-D, discrete ordinates shielding analyses	14
5. Number of consolidated PWR fuel assemblies that may be shipped in 200,000-lb and 300,000-lb casks	16
6. Number of consolidated BWR fuel assemblies that may be shipped in 200,000-lb and 300,000-lb casks	16
7. Gross weight of Salt repository casks vs the number of waste packages	17
8. Gross weight of Tuff repository casks vs the number of waste packages	18
9. Gross weight of Basalt repository casks vs the number of waste packages	19
A.1. Salt reference design; overpack and canister with 12 PWR assemblies/package	32
A.2. Salt reference design; overpack and canister with 30 BWR assemblies/package	32
A.3. Salt reference design; bare canister with 12 PWR assemblies/package	33
A.4. Salt reference design; bare canister with 30 BWR assemblies/package	33
A.5. Tuff reference design; overpack and canister with 6 PWR assemblies/package	34
A.6. Tuff reference design; overpack and canister with 14 BWR assemblies/package	34
A.7. Tuff reference design; bare canister with 6 PWR assemblies/package	35
A.8. Tuff reference design; bare canister with 14 BWR assemblies/package	35
A.9. Basalt reference design; overpack only, with 4 PWR assemblies/package	36
A.10. Basalt reference design; overpack only, with 9 BWR assemblies/package	37

LIST OF TABLES (continued)

TABLE	PAGE
A.11. Basalt reference design; canister only, with 1 PWR assembly/package	38
A.12. Basalt reference design; canister only, with 2 BWR assemblies/package	39
A.13. Basalt reference design; canister only, with 2 PWR assemblies/package	40
A.14. Basalt reference design; canister only, with 4 BWR assemblies/package	41
A.15. Basalt reference design; canister only, with 3 PWR assemblies/package	42
A.16. Basalt reference design; canister only, with 7 BWR assemblies/package	43
A.17. Basalt reference design; canister only, with 4 PWR assemblies/package	44
A.18. Basalt reference design; canister only, with 9 BWR assemblies/package	45

ACKNOWLEDGMENTS

This study was performed for the Office of Storage and Transportation Systems (OSTS) in the Office of Civilian Radioactive Waste Management (OCRWM), U.S. Department of Energy.

The final manuscript was prepared by Lindy Norris of the Computing and Telecommunications Division at Oak Ridge National Laboratory.

ABSTRACT

The objective of this study was to determine the maximum number of specialized repository waste packages that could be shipped from the Monitored Retrievable Storage (MRS) facility in Pb-, Fe-, and U-shielded casks weighing 200,000 or 300,000 lbs. The study included 18 different waste packages designed for the Salt, Tuff, and Basalt repositories. Nine of these contained consolidated PWR fuel pins, and nine contained consolidated BWR fuel pins. Discrete ordinates calculations were performed to determine the neutron and gamma shield thicknesses that would ensure a dose rate of 10 millirem/hr, 10 ft from the centerline of the cask(s). Over 100 casks of particular interest have been identified, while preliminary design information is also given for 522 casks of potential interest.

Relative to the 200,000-lb casks, 50-100% more fuel may be shipped in the larger 300,000-lb casks. Placing the spent fuel canisters in overpacks prior to shipment from the MRS will reduce the net payload by 30-50%. The highest-capacity cask/waste package combination studied corresponds to a 300,000-lb U-shielded cask containing 84 consolidated PWR fuel assemblies in 21 canisters, or 171 consolidated BWR fuel assemblies in 19 canisters. Criticality analyses have shown these high-capacity casks to be safely subcritical—even if all the canisters were loaded with unirradiated LWR fuel containing 3.4 wt% U-235.

1. INTRODUCTION

One of the fundamental purposes for establishing a Monitored Retrievable Storage (MRS) facility is to process spent fuel and repackage it in such a way as to reduce the number of shipments to, and handling requirements at, the chosen repository site.

In order to evaluate the benefits of repackaging the spent fuel at the MRS, it is necessary to determine the net carrying capacity of shipping casks that could be designed for the various types of waste packages used to transfer spent fuel to the repository. Two packaging options exist: (a) the fuel could be disassembled at the MRS, rod-by-rod, and placed in high quality steel canisters; and (b) these canisters might be placed in an overpack before shipment to a repository. Use of overpacks would permit the packages to be placed directly in the geologic repository without any additional processing.

Spent fuel could move from the MRS facility to repositories located in salt, tuff, or basalt formations. Each geologic medium would require a different size canister and a different overpack, if one is to be used. Given the size, weight, and capacity of the canisters and overpacks that would be used for the various repositories, this study employed the Shipping Cask Optimization and Parametric Evaluation (SCOPE) code¹ to determine the amount of spent fuel that could be shipped in casks weighing 200,000 and 300,000 lbs. The spent fuel was assumed to be ten years old; and the gamma shielding in the casks could be lead, steel, or depleted uranium metal.

2. DESCRIPTION OF PACKAGES TO BE TRANSPORTED INSIDE THE SHIPPING CASKS

2.1 SALT REPOSITORY WASTE PACKAGE CONFIGURATIONS

Packages for the Salt repository may consist of (a) a 1-cm-thick carbon steel canister containing spent fuel or (b) a 10-cm-thick carbon steel overpack containing a 1-cm-thick carbon steel canister with spent fuel. In either case, the thin-walled steel canister has an outside diameter of 62 cm and an inside diameter of 60 cm. Canisters containing consolidated fuel rods from 12 PWR assemblies are 400 cm long (including lifting pintle) and weigh 8390 kg fully loaded, while canisters containing consolidated fuel rods from 30 BWR assemblies are 435 cm long (including lifting pintle) and weigh 8810 kg fully loaded. In each case, the canister is internally divided into six pie-shaped segments which receive the spent fuel rods (see Fig. 1). The internally segmented canister serves several functions: it facilitates the handling of rods during the consolidation operation; it enhances heat transfer from the center, radially outward; and it enables retrieval of waste after emplacement. The steel overpacks into which the canisters may be placed prior to shipment have an outside diameter of 84.5 cm and an inside diameter of 64.5 cm. Overpacks containing a canister of PWR spent fuel are 446.5 cm long (including lifting pintle) and weigh 17,600 kg fully loaded, while overpacks containing a canister of BWR spent fuel are 481.5 cm long (including lifting pintle) and weigh 18,700 kg fully loaded (see Fig. 2). Scoping calculations were performed to determine the net carrying capacity of 200,000-lb and 300,000-lb Pb-, Fe-, and U-shielded shipping casks containing:

- (a) overpacks with canisters containing the equivalent of 12 PWR fuel assemblies,
- (b) overpacks with canisters containing the equivalent of 30 BWR fuel assemblies,
- (c) bare canisters containing the equivalent of 12 PWR fuel assemblies, and
- (d) bare canisters containing the equivalent of 30 BWR fuel assemblies.

ORNL-DWG 85-18134

Fig. 1. Salt reference design for a segmented steel canister containing consolidated fuel rods from 12 PWR assemblies or 30 BWR assemblies.

ORNL-DWG 85-18133

Fig. 2. Thick carbon steel overpack in the Salt reference design.

2.2 TUFF REPOSITORY WASTE PACKAGE CONFIGURATIONS

Packages for the Tuff repository may consist of (a) a 1-cm-thick stainless steel canister containing spent fuel or (b) a 1-cm-thick stainless steel overpack containing a 1-cm-thick stainless steel canister with spent fuel. In each case, the fuel-bearing canister has an outside diameter of 63 cm and an inside diameter of 61 cm. Canisters containing consolidated fuel rods from 6 PWR assemblies are 400 cm long (including lifting pintle) and weigh 5466 kg fully loaded, while canisters containing consolidated fuel rods from 14 BWR assemblies are 435 cm long (including lifting pintle) and weigh 6426 kg fully loaded. Canisters for PWR spent fuel are internally divided into three square-shaped segments containing fuel rods (see Fig. 3) while canisters for BWR spent fuel are internally divided into seven square-shaped segments containing fuel rods (see Fig. 4). This 1-cm-thick stainless steel internal structure provides additional mechanical stability and enhances heat transfer. It also provides room for internal poison rods to ensure against criticality. The stainless steel overpacks into which the canisters may be placed prior to shipment have an outside diameter of 70 cm and an inside diameter of 68 cm. Overpacks containing a canister of PWR spent fuel are 416.5 cm long (including the 16.5-cm-long lifting pintle) and weigh 6700 kg fully loaded, while overpacks containing a canister of BWR spent fuel are 491.5 cm long (including the 16.5-cm-long lifting pintle) and weigh 7900 kg fully loaded (see Figs. 3 and 4). Scoping calculations were performed to determine the carrying capacity of 200,000-lb and 300,000-lb Pb-, Fe-, and U-shielded shipping casks containing:

- (a) overpacks with canisters containing the equivalent of 6 PWR fuel assemblies,
- (b) overpacks with canisters containing the equivalent of 14 BWR fuel assemblies,
- (c) bare canisters containing the equivalent of 6 PWR fuel assemblies, and
- (d) bare canisters containing the equivalent of 14 BWR fuel assemblies.

2.3 BASALT WASTE PACKAGE CONFIGURATIONS

Packages for the Basalt repository may be one of two general types: (a) an 8.3-cm-thick carbon steel overpack (with no inner canister) containing consolidated fuel rods from 4 PWR assemblies or 9 BWR assemblies, or (b) various types of 0.5-cm-thick carbon steel canisters containing consolidated fuel rods from 1, 2, 3, or 4 PWR assemblies or 2, 4, 7, or 9 BWR assemblies. The thick-walled overpacks have an outside diameter of 50.3 cm and an inside diameter of 33.7 cm. Overpacks containing PWR fuel are 405 cm long (including lifting pintle) and weigh 7000 kg fully loaded, while overpacks containing BWR fuel are 440 cm long (including lifting pintle) and weigh 7400 kg fully loaded. The four different thin-walled canisters included in the reference calculations are described in Table 1. Scoping calculations were performed to determine the carrying capacity of 200,000-lb and 300,000-lb Pb-, Fe-, and U-shielded shipping casks containing:

- (a) overpacks (with no internal canister) containing the equivalent of 4 PWR fuel assemblies,
- (b) overpacks (with no internal canister) containing the equivalent of 9 BWR fuel assemblies,
- (c) bare 17.5 cm-diam canisters containing the equivalent of 1 PWR fuel assembly,
- (d) bare 17.5-cm-diam canisters containing the equivalent of 2 BWR fuel assemblies,
- (e) bare 23.3-cm-diam canisters containing the equivalent of 2 PWR fuel assemblies,

ORNL-DWG 85-18138

Fig. 3. Tuff reference design for an overpack and canister containing consolidated fuel rods from 6 PWR assemblies.

ORNL-DWG 85-18138A

Fig. 4. Tuff reference design for an overpack and canister containing consolidated fuel rods from 14 BWR assemblies.

Table 1. Basalt reference designs for thin-walled carbon steel canisters containing consolidated fuel rods from 1, 2, 3, or 4 PWR assemblies and/or 2, 4, 7, or 9 BWR assemblies

OD (cm)	ID (cm)	Canister of PWR fuel ^a		Canister of BWR Fuel ^b	
		N _{asys}	Weight (kg)	N _{asys}	Weight (kg)
17.5	16.5	1	750	2	795
23.3	22.3	2	1439	4	1525
28.9	27.9	3	2129	7	2256
33.0	32.0	4	2511	9	2661

^aLength = 400 cm, including lifting pintle

^bLength = 435 cm, including lifting pintle

- (f) bare 23.3-cm-diam canisters containing the equivalent of 4 BWR fuel assemblies,
- (g) bare 28.9-cm-diam canisters containing the equivalent of 3 PWR fuel assemblies,
- (h) bare 28.9-cm-diam canisters containing the equivalent of 7 BWR fuel assemblies,
- (i) bare 33.0-cm-diam canisters containing the equivalent of 4 PWR fuel assemblies, and
- (j) bare 33.0-cm-diam canisters containing the equivalent of 9 BWR fuel assemblies.

3. GENERIC DESCRIPTION OF CASKS TO BE USED

Scoping calculations were performed to determine the net carrying capacity of Pb-, Fe-, and U-shielded casks designed for each of the 18 different types of waste packages described in Sect. 2. Figure 5 shows a generic diagram of the type of shipping casks considered when estimating the overall loaded weight. The gamma shield may be Pb, Fe, or U-metal between an inner steel shell and an outer steel shell. The neutron shield between the outer steel shell and the outer steel barrel was assumed to be 28.5 vol% water (1.0 g/cc), 66.0 vol% ethylene glycol (1.11 g/cc; HOCH₂CH₂OH), and 5.5 vol% potassium tetraborate (1.74 g/cc; K₂B₄O₇·8H₂O) made with natural boron. This common mixture of water and antifreeze contains ~1 wt% boron. The thicknesses of the inner steel shell, the outer steel shell, and the outer steel barrel, are given in Table 2 for each type of cask considered. The nominal neutron and gamma shield thicknesses shown in Table 2 are based on an extensive series of weight optimization studies for large casks containing 10-year-cooled PWR spent fuel irradiated to 33,000 MWd/MTIHM.* These optimization studies are described in Sect. IV and Table F.1 of ref. 1. The procedure followed there assures a dose rate of 10 millirem/hr at a point 10 ft from the cask centerline. Recognizing that the steel canisters and/or thick-walled steel overpacks in the Salt, Tuff, and Basalt waste packages provide a significant amount of shielding, the actual gamma shield thicknesses used in the present study were correspondingly reduced relative to the nominal thicknesses shown in Table 2. The neutron shield thicknesses were assumed to be unaffected. Additional details are provided in Sect. 4.2 and the Appendix of this report. In every case, the thicknesses of the main structural components on either end were assumed to be the same as in the radial direction.

In a few cases involving larger payloads, circumferential cooling fins (spaced every 4 in. axially) were required to prevent the external surface temperature from exceeding 250°F when the outside ambient temperature was assumed to be 130°F.[†] Such fins were only required in about 5–10% of the cases studied. The dimensions of the stainless steel fins, when required, are shown in the Appendix.

Within the cask, the cylindrical waste packages were assumed to be placed in separate cavities of a removable aluminum insert. Inserts for casks containing 1–12 cylindrical canisters are illustrated in Fig. 6. The thickness (t) of the insert between canisters was assumed to be 1 in., as was the outer wall thickness (w) of the insert between the outermost canister and the inner wall of the cask (see Fig. 6). The diameter (D_i) of the holes containing the canisters was assumed to be 0.25 in. greater than that of the corresponding waste package. The inner diameter of the cask was generally assumed to be 0.25 in. greater than the outside diameter of the insert. (For casks

*Megawatt-days per metric tonne of initial heavy metal.

[†]The internal decay heat load associated with the 10-year-cooled spent fuel was 524 watts per PWR fuel assembly and 168 watts per BWR fuel assembly. BWR fuel assemblies are considerably smaller than PWR assemblies and are typically irradiated to 27,500 MWd/MTIHM.

Fig. 5. Generic description of a typical shipping cask, as modeled in this study.

Table 2. Thicknesses^a of the main structural components in each type of cask

	Fe Cask	Pb Cask	U Cask
Inner steel shell	0.375	1.5	0.75
Gamma shield	9.49 ^b	4.04 ^b	2.49 ^b
Outer steel shell	0.375	2.0	2.0
Neutron shield	3.75	4.25	3.47
Outer steel barrel	0.75	0.75	0.75

^aAll thicknesses are given in inches.

^bThe actual gamma shield thicknesses used in the present study were reduced relative to this nominal value to account for the shielding provided by the thin-walled steel canisters and/or the thick-walled steel overpacks in the Salt, Tuff, and Basalt waste packages.

ORNL-DWG 85-18135

Fig. 6. Removable aluminum inserts for casks containing 1-12 cylindrical waste packages.

containing a single waste package, no insert was used, and the inner diameter of the cask was assumed to be 0.25 in. greater than the outside diameter of the waste package.) The length of the cavity inside the cask was always assumed to be 1 in. greater than that of the corresponding waste package.

4. METHODOLOGY

The objective of this study was to determine the maximum number of waste packages or equivalent spent fuel assemblies that could be shipped in Pb-, Fe-, and U-shielded casks having a gross loaded weight of 200,000 or 300,000 lbs. This determination was to be made for each of the 18 waste packages described in Sect. 2. To accomplish this, a modified version of the SCOPE code was prepared in which the internal cavity of the cask was defined as being 1 in. longer than the prescribed waste package. Adjusted gamma shield thicknesses which accounted for the shielding provided by the thin-walled steel canisters and/or thick-walled steel overpacks were used in the initial SCOPE analysis of the various casks. This initial analysis provided a rough estimate of the net carrying capacity for each of the various cask/waste package combinations. Thirty representative casks of potential interest were then selected for more detailed multigroup shielding analyses using the XSDRNPM and XSDOSE 1-D, discrete ordinates, radiative transport codes.^{2,3} Based on these results, second-order adjustments were made to the gamma shield thicknesses of the various casks; and another series of 1-D shielding calculations were performed to ensure that the final gamma shield thicknesses did, in fact, yield a dose rate of 10 millirem/hr, 10 ft from the centerline. A final series of SCOPE analyses were then performed (using the finalized gamma shield thicknesses) to determine the net carrying capacity for each of the various cask/waste package combinations. Because the results for casks containing compacted BWR spent fuel were considered of marginal importance in this initial study, the gamma shield thicknesses for the BWR casks were assumed to be the same as those for similar PWR casks.

4.1 INITIAL ANALYSIS

The SCOPE code¹ requires, as input, the thickness of the neutron and gamma shields as a function of the number of waste packages each type of cask. Because of the large amount of consolidated spent fuel contained in these particular casks and the spatial self-shielding afforded by the fuel itself, it was anticipated that the actual neutron and gamma shield thicknesses would be relatively insensitive to the number of waste packages in the cask. These parameters were therefore treated as constants in the initial analysis. Nominal neutron and gamma shield thicknesses based on a cask containing 26, 10-year-cooled PWR assemblies are given in Table 2. These thicknesses are based on an extensive series of weight optimization studies¹ for large casks containing 10-year-cooled PWR spent fuel irradiated to 33,000 MWd/MTIHM. These optimization studies used the XSDRNPM and XSDOSE 1-D discrete ordinates shielding codes^{2,3} and are described in Sect. IV and Table F.1 of ref. 1. The resulting shield thicknesses typically yield a dose rate of 10 millirem/hr at a point 10 ft from the centerline of the cask. Recognizing that the steel canisters and/or thick-walled steel overpacks comprising the Salt, Tuff, or Basalt waste packages may provide a significant amount of shielding, the actual Fe gamma shield thicknesses used in this study were correspondingly reduced relative to the nominal thicknesses shown in Table 2. Likewise, the Pb shields were reduced by the equivalent amount of Pb (1.0 cm Fe = 0.598 cm Pb), and the U-metal shields were reduced by the equivalent amount of U-metal (1.0 cm Fe = 0.331 cm U-metal). The neutron shield thicknesses were assumed to be unaffected. This procedure was expected to maintain a dose rate of approximately 10 millirem/hr at a point 10 ft from the cask centerline. [The nominal neutron and gamma shield thicknesses for the BWR casks were assumed to be the same as those for similar PWR casks. In practice, casks containing BWR spent fuel may require slightly less shielding (see Tables C.1 and C.2 of ref. 1).]

4.2 SHIELDING REASSESSMENT

Using the approximate gamma shield thicknesses described in Sect. 4.1, the SCOPE code was used to survey a large number of 200,000-lb and 300,000-lb Pb-, Fe-, and U-shielded casks for each of the 18 waste packages described in Sect. 2. From the large field of casks surveyed, 30 representative cask/waste package configurations were selected for more detailed shielding analyses. Table 3 describes each of the 30 cask/waste package configurations selected. It also shows the number of waste packages contained in each given cask; the overall weight of the loaded cask; the actual thickness of the gamma shield resulting from the initial approximations described in Sect. 4.1; and the actual calculated dose rate, 10 ft from the centerline of the cask. These calculated dose rates were determined using the SCALE system⁴ Shielding Analysis Sequence number 1 (i.e., the SASI control module⁵), the SCALE 22n-18 γ cross-section library with the ANSI standard flux-to-dose conversion factors, and the neutron and gamma source spectra for 10-year-cooled PWR spent fuel irradiated to 33,000 MWd/MTIHM, as given in Appendix C of ref. 1. The SASI control module employs the XSDRNPM discrete ordinates code² to perform the radiation transport calculation throughout the cask and employs the XSDOSE code³ to calculate the resulting dose rate at the midplane of the cask, 10 ft from the centerline.

It can be seen from Table 3 that the approximate gamma shield thicknesses used in the initial analysis yielded dose rates that were generally between 6 and 9 millirem/hr, although some were as low as 4.7 millirem/hr and others were as high as 13.2 millirem/hr. So that comparisons of net carrying capacities could be made on a fair basis among the various casks, second-order adjustments of the various gamma shields were then made so that each cask yielded a dose rate of 10 millirem/hr. To accomplish this, the dose rate was assumed to vary as $D = D_0 \exp[-\Sigma_\gamma \Delta r]$, where Σ_γ is the differential dose attenuation coefficient for the gamma shield; and Δr is the change in the gamma shield thickness. From earlier gamma shield sensitivity studies for similar casks (see Sect. IV, Appendix D, and Tables D.7-D.9 of ref. 1), it was estimated that for Fe, $\Sigma_\gamma = 0.9976/\text{in.}$; for Pb, $\Sigma_\gamma = 1.5378/\text{in.}$; and for U metal, $\Sigma_\gamma = 2.7909/\text{in.}$ Second-order adjustments to the actual gamma shield thicknesses were then made using these data. For the four Salt repository casks containing a single waste package, the gamma shield thicknesses could be reduced by about 0.5 in. In the other 26 cases studied, the required second-order adjustments ranged from -0.26 in. to +0.13 in. These revised gamma shield thicknesses were then used in the SCOPE code to determine their effect on the gross loaded weight of the various casks. The multigroup discrete ordinates shielding analysis was also repeated for each of these 30 casks, using the revised gamma shield thicknesses. The results of this reevaluation are shown in Table 4. Note that the gross weight of most casks changed by no more than 3000-5000 lbs and that the dose rates in each case were found to be between 9.8 and 10.2 millirem/hr, 10 ft from the centerline.

4.3 HEAT TRANSFER CONSIDERATIONS

Heat transfer considerations were generally considered an ancillary part of this initial scoping study. The SCOPE code¹ does, however, calculate the steady-state temperature distribution throughout the cask; it also performs a complete 1-D space/time transient thermal analysis following a postulated 30-min. fire. The results of these calculations are reported in the Appendix. It should be noted, however, that the algorithm used by the code for calculating the maximum fuel pin temperatures may be very conservative when applied to consolidated spent fuel. The code assumes, for example, that the fuel pins are dispersed within the canister or overpack in a square array, and calculates the maximum fuel pin temperature using the Wootton-Epstein correlation in which the primary mode of heat transfer is thermal radiation, with a small correction for thermal convection within the fuel bundle. For tightly compacted spent fuel (and for canisters with radial conductors, as in the Salt waste canister), the Wootton-Epstein equation will yield a very conservative result, such that the calculated fuel pin clad temperatures are well above those that one would

Table 3. Initial capacities, weights, shield thicknesses, and dose rates for 30 representative casks that were selected for more detailed, multigroup, 1-D, discrete ordinates shielding analyses

Repository design	Type of package	Fe cask				Pb cask				U cask												
		n - wvw.w - t.tt - d.dd ^a				n - wvw.w - t.tt - d.dd ^a				n - wvw.w - t.tt - d.dd ^a												
Salt design																						
(12 PWRs/pkg)	Overpack & canister	1	-	93.4	-	5.16	-	5.76	1	-	90.4	-	1.45	-	4.72	1	-	84.5	-	1.05	-	5.11
(12 PWRs/pkg)	Overpack & canister	3	-	268.4	-	5.16	-	8.62	3	-	263.0	-	1.45	-	6.96	3	-	252.4	-	1.05	-	7.50
(12 PWRs/pkg)	Canister only	1	-	86.7	-	9.10	-	5.54	1	-	71.2	-	3.80	-	5.50	1	-	66.6	-	2.36	-	5.50
(12 PWRs/pkg)	Canister only	3	-	209.8	-	9.10	-	9.01	3	-	191.0	-	3.80	-	8.90	3	-	177.9	-	2.36	-	9.06
Tuff design																						
(6 PWRs/pkg)	Overpack & canister	5	-	294.1	-	8.70	-	7.95	5	-	274.2	-	3.57	-	7.58	5	-	255.4	-	2.23	-	7.84
(6 PWRs/pkg)	Canister only	5	-	258.5	-	9.10	-	7.90	5	-	238.6	-	3.80	-	7.83	5	-	220.7	-	2.36	-	8.03
Basalt design																						
(4 PWRs/pkg)	Overpack only	10	-	327.0	-	6.22	-	7.91	10	-	317.8	-	2.09	-	6.53	10	-	305.1	-	1.41	-	6.90
(4 PWRs/pkg)	Canister only	10	-	209.1	-	9.29	-	9.56	10	-	192.0	-	3.92	-	9.49	10	-	180.4	-	2.43	-	9.60
(4 PWRs/pkg)	Canister only	15	-	272.9	-	9.29	-	11.53	17	-	278.2	-	3.92	-	12.25	19	-	274.5	-	2.43	-	13.78
(1 PWR/pkg)	Canister only	54	-	286.2	-	9.29	-	11.00	59	-	295.7	-	3.92	-	11.41	66	-	296.0	-	2.43	-	12.24

- ^a n = number of waste packages in the given cask.
w = overall weight of the loaded cask (268.4 = 268,400 lbs).
t = thickness of the gamma shield in inches.
d = calculated dose rate, 10 ft from the centerline (millirem/hr).

Table 4. Final capacities, weights, shield thicknesses, and dose rates for 30 representative casks that were selected for more detailed, multigroup, 1-D, discrete ordinates shielding analyses

Repository design	Type of package	Pu cask	Pb cask	U cask
		n - wvw.w - t.tt - d.dd ^a	n - wvw.w - t.tt - d.dd ^a	n - wvw.w - t.tt - d.dd ^a
Salt Design				
(12 PWRs/pkg)	Overpack & canister	1 - 38.2 - 4.58 - 9.87	1 - 84.4 - 0.94 - 10.10	1 - 80.0 - 0.79 - 10.10
(12 PWRs/pkg)	Overpack & canister	3 - 265.6 - 5.01 - 9.93	3 - 256.6 - 1.20 - 10.17	3 - 248.1 - 0.94 - 10.02
(12 PWRs/pkg)	Canister only	1 - 81.5 - 0.48 - 9.82	1 - 71.9 - 3.37 - 9.84	1 - 63.2 - 2.11 - 10.00
(12 PWRs/pkg)	Canister only	3 - 208.1 - 8.99 - 10.00	3 - 191.5 - 3.72 - 9.90	3 - 176.8 - 2.32 - 9.95
Tuff design				
(6 PWRs/pkg)	Overpack & canister	5 - 289.1 - 8.46 - 9.95	5 - 268.8 - 3.37 - 9.98	5 - 251.3 - 2.13 - 9.97
(6 PWRs/pkg)	Canister only	5 - 253.7 - 8.85 - 9.98	5 - 234.2 - 3.62 - 10.00	5 - 217.4 - 2.27 - 9.94
Basalt design				
(4 PWRs/pkg)	Overpack only	10 - 322.3 - 5.98 - 9.91	10 - 310.2 - 1.80 - 9.98	10 - 299.1 - 1.26 - 10.12
(4 PWRs/pkg)	Canister only	10 - 208.3 - 9.24 - 10.02	10 - 191.2 - 3.88 - 10.01	10 - 179.8 - 2.41 - 10.04
(4 PWRs/pkg)	Canister only	15 - 275.6 - 9.44 - 10.02	17 - 281.9 - 4.07 - 10.09	19 - 279.3 - 2.56 - 9.89
(1 PWR/pkg)	Canister only	54 - 288.0 - 9.39 - 10.01	59 - 298.3 - 4.02 - 9.98	66 - 299.5 - 2.52 - 9.97

^a n = number of waste packages in the given cask.

w = overall weight of the loaded cask (265.6 = 265,600 lbs).

t = thickness of the gamma shield in inches.

d = calculated dose rate, 10 ft from the centerline (millirem/hr).

realistically expect. Even so, the calculated steady-state temperatures are generally well below the limit at which oxidation of the fuel becomes a significant problem. In those few cases where the calculated temperatures do approach this limit (see the Salt case, with canisters only, with 12 PWR assemblies per canister), a more rigorous thermal analysis may show the actual temperatures to be well below the limit.

5. RESULTS

Table 5 shows the number of consolidated PWR fuel assemblies that may be shipped in 200,000-lb and 300,000-lb Pb-, Fe-, and U-shielded casks utilizing the various repository waste packages described in Sect. 2, the cask configurations described in Sect. 3, and the refined gamma shield thicknesses described in Sect. 4. Table 6 shows the number of consolidated BWR fuel assemblies that may be shipped in similar casks whose waste packages (that is, canisters and/or overpacks) have been designed for BWR fuel. [Because these latter results were deemed of secondary importance, the corresponding gamma shield thicknesses were conservatively assumed to be the same as those for casks containing PWR spent fuel.] In general, it should be noted that (a) 50-100% more spent fuel may be shipped in the larger 300,000-lb casks; (b) placing the spent fuel canisters in overpacks prior to shipment from the MRS will reduce the net carrying capacity by about 30-50%; (c) for the higher capacity packages used by the Salt and Tuff repositories, the Pb and U metal casks offer equal carrying capacities, while that of the Fe casks is generally less; and (d) for the smaller packages used by the Basalt repository, the U metal casks can carry more spent fuel than the Pb casks which, in turn, can carry more spent fuel than the Fe casks. [Even for the larger packages used by the Salt and Tuff repositories, the U metal casks generally weigh somewhat less than a Pb cask of equal capacity.] With respect to specific cask/waste package configurations, two points should be noted: (a) In the case of the larger overpacks used in the Salt and Tuff designs, the combined weight of two casks, each containing one waste package and each weighing less than 100,000 lbs, would be less than that of a conventional cylindrical cask containing two waste packages (see Tables 7 and 8). Further reductions in the overall weight might therefore be realized through the use of a rectangular or elliptically shaped cask containing two such waste packages. (b) The highest capacity cask/waste package combination studied corresponds to a 300,000-lb U-shielded cask containing 84 PWR fuel assemblies in 21 thin-walled steel canisters, or 171 BWR fuel assemblies in 19 thin-walled steel canisters. As noted below, KENO IV⁶ Monte Carlo criticality analyses have shown these high-capacity casks to be safely subcritical-even if all of the canisters were loaded with unirradiated PWR fuel pins containing 3.4 wt% U-235.

The information contained in Tables 5 and 6 is useful but incomplete. Because of elementary geometric constraints on the internal loading pattern, the inside diameter of a cask and its overall weight are nonuniform functions of the number of waste packages contained therein. Slight increases in the allowable weight of a cask may have a significant effect on the net carrying capacity in some cases while having no effect in other cases. Tables 7, 8, and 9 therefore show the gross (loaded) weight of Salt, Tuff, and Basalt repository casks as a function of the number of waste packages in the cask and the equivalent number of consolidated fuel assemblies in the cask. They also show the actual amount of Pb, Fe, or U-metal shielding finally used for each of the 18 waste package configurations described in Sect. 2. From this more detailed information it may be seen that a U-metal cask of a given capacity will always weigh less than a Pb cask of the same capacity, and that a Pb cask will always weigh less than an Fe cask. While two casks may have the same net carrying capacity, the differences in the gross weight may be significant in some cases. It should also be noted that two U-shielded casks, each carrying one Salt overpack, would have a combined weight of 160,000 lbs while a single, cylindrically shaped U-shielded cask carrying two Salt overpacks would have a weight of 206,200 lbs. Presumably a single, rectangular or elliptically shaped U-shielded cask carrying two Salt overpacks would weigh less than 160,000 lbs.

Tables 7, 8, and 9 briefly describe 522 casks of potential interest corresponding to the 18 repository waste packages defined in Sect. 2. Tables A.1 A.18 of the Appendix show the more detailed

Table 5. Number of consolidated PWR fuel assemblies that may be shipped in 200,000-lb and 300,000-lb casks

Repository design	Type of package	200,000-lb casks			300,000-lb casks		
		Fe	Pb	U	Fe	Pb	U
Salt design							
(12 PWRs/pkg)	Overpack & canister	24 ^a	24 ^a	24 ^x	36	36	48
(12 PWRs/pkg)	Canister only	24 ^a	36	36	60	60	72
Tuff design							
(6 PWRs/pkg)	Overpack & canister	12 ^a	18	18	30	30	42
(6 PWRs/pkg)	Canister only	18	24	24	42	42	48
Basalt design							
(4 PWRs/pkg)	Overpack only	20	20	24	36	36	40
(4 PWRs/pkg)	Canister only	36	40	48	68	76	84
(3 PWRs/pkg)	Canister only	36	39	42	63	69	75
(2 PWRs/pkg)	Canister only	34	38	42	62	68	76
(1 PWR/pkg)	Canister only	31	34	39	55	61	69

^aUses 2 casks, each containing 1 waste package, and each weighing less than 100,000 lbs; alternately, one may use a single rectangular or elliptically shaped cask containing 2 waste packages.

Table 6. Number of consolidated BWR fuel assemblies that may be shipped in 200,000-lb and 300,000-lb casks

Repository design	Type of package	200,000-lb casks			300,000-lb casks		
		Fe	Pb	U	Fe	Pb	U
Salt design							
(30 BWRs/pkg)	Overpack & canister	60 ^a	60 ^a	60 ^a	90	90	90
(30 BWRs/pkg)	Canister only	60 ^a	90	90	150	150	150
Tuff design							
(14 BWRs/pkg)	Overpack & canister	28 ^a	28 ^a	28 ^a	56	56	70
(14 BWRs/pkg)	Canister only	28 ^a	42	42	70	98	98
Basalt design							
(9 BWRs/pkg)	Overpack only	45	45	45	72	81	81
(9 BWRs/pkg)	Canister only	72	81	99	144	153	171
(7 BWRs/pkg)	Canister only	70	84	91	140	154	161
(4 BWRs/pkg)	Canister only	60	68	80	120	128	140
(2 BWRs/pkg)	Canister only	56	64	70	110	112	126

^aUses 2 casks, each containing 1 waste package, and each weighing less than 100,000 lbs; alternately, one may use a single rectangular or elliptically shaped cask containing 2 waste packages.

Table 7. Gross weight of Salt repository casks vs the number of waste packages^a

Type of package - overpack & canister					
12 PWR assemblies/package			30 BWR assemblies/package		
5.01-in. Fe shield	1.20-in. Pb shield	0.94-in. U shield	5.01-in. Fe shield	1.20-in. Pb shield	0.94-in. U shield
1 - 12 - 88.2 ^{b,c}	1 - 12 - 84.4 ^{b,d}	1 - 12 - 80.0 ^{b,e}	1 - 30 - 93.9 ^c	1 - 30 - 89.9 ^d	1 - 30 - 85.2 ^e
2 - 24 - 222.6 ^b	2 - 24 - 214.2 ^b	2 - 24 - 206.2 ^b	2 - 60 - 237.0	2 - 60 - 228.1	2 - 60 - 219.7
3 - 36 - 265.6 ^b	3 - 36 - 256.6 ^b	3 - 36 - 248.1 ^b	3 - 90 - 282.4	3 - 90 - 273.0	3 - 90 - 264.0
4 - 48 - 323.7	4 - 48 - 313.7	4 - 48 - 304.4	4 - 120 - 344.1	4 - 120 - 333.6	4 - 120 - 323.7
		5 - 60 - 367.2			
Type of package - canister only					
12 PWR assemblies/package			30 BWR assemblies/package		
8.99-in. Fe shield	3.72-in. Pb shield	2.32-in. U shield	8.99-in. Fe shield	3.72-in. Pb shield	2.32-in. U shield
1 - 12 - 81.5 ^{b,f}	1 - 12 - 71.9 ^{b,g}	1 - 12 - 63.2 ^{b,h}	1 - 30 - 87.1 ^f	1 - 30 - 76.8 ^g	1 - 30 - 67.6 ^h
2 - 24 - 182.6 ^b	2 - 24 - 166.8 ^b	2 - 24 - 152.8 ^b	2 - 60 - 194.7	2 - 60 - 178.0	2 - 60 - 163.2
3 - 36 - 208.1 ^b	3 - 36 - 191.5 ^b	3 - 36 - 176.8 ^b	3 - 90 - 221.5	3 - 90 - 203.9	3 - 90 - 188.4
4 - 48 - 244.5	4 - 48 - 231.5	4 - 48 - 214.7	4 - 120 - 259.9	4 - 120 - 240.9	4 - 120 - 224.2
5 - 60 - 290.8	5 - 60 - 271.3	5 - 60 - 253.1	5 - 150 - 303.1	5 - 150 - 282.5	5 - 150 - 264.3
6 - 72 - 335.2	6 - 72 - 314.1	6 - 72 - 294.4	6 - 180 - 349.6	6 - 180 - 327.3	6 - 180 - 312.8
	7 - 84 - 326.4	7 - 84 - 307.6			7 - 210 - 324.2
		8 - 96 - 352.9			

^aThe n-mm-vvv.v format used to present the data gives:

n - the number of waste packages in the cask

m - the equivalent number of consolidated fuel assemblies in the cask

v - the loaded weight of the cask, where 222.6 = 222,600 lbs

^bCalculated dose rate 10 ft from centerline was 9.8-10.2 millirem/hr.

^cException - $t_y = 4.58$ in. of Fe.

^dException - $t_y = 0.94$ in. of Pb.

^eException - $t_y = 0.79$ in. of U.

^fException - $t_y = 8.48$ in. of Fe.

^gException - $t_y = 3.37$ in. of Pb.

^hException - $t_y = 2.11$ in. of U.

Table 8. Gross weight of Tuff repository casks vs the number of waste packages^a

Type of package - overpack & canister					
6 PWR assemblies/package			14 BWR assemblies/package		
8.46-in. Fe shield	3.37-in. Pb shield	2.13-in. U shield	8.46-in. Fe shield	3.37-in. Pb shield	2.13-in. U shield
1 - 6 - 86.1	1 - 6 - 75.8	1 - 6 - 66.6	1 - 14 - 99.4	1 - 14 - 87.7	1 - 14 - 77.3
2 - 12 - 191.0	2 - 12 - 174.8	2 - 12 - 160.8	2 - 28 - 219.7	2 - 28 - 201.6	2 - 28 - 185.9
3 - 18 - 213.2	3 - 18 - 196.1	3 - 18 - 181.3	3 - 42 - 245.2	3 - 42 - 226.1	3 - 42 - 209.6
4 - 24 - 248.4 ^b	4 - 24 - 229.8 ^b	4 - 24 - 213.8 ^b	4 - 56 - 285.7	4 - 56 - 264.9	4 - 56 - 247.0
5 - 30 - 289.1	5 - 30 - 268.8 ^b	5 - 30 - 251.3 ^b	5 - 70 - 332.3	5 - 70 - 309.7	5 - 70 - 290.3
6 - 36 - 333.7	6 - 36 - 311.6	6 - 36 - 292.5		6 - 84 - 358.8	6 - 84 - 337.7
7 - 42 - 338.7	7 - 42 - 316.6	7 - 42 - 297.6			
		8 - 48 - 342.1			

Type of package - canister only					
6 PWR assemblies/package			14 BWR assemblies/package		
8.85-in. Fe shield	3.62-in. Pb shield	2.27-in. U shield	8.85-in. Fe shield	3.62-in. Pb shield	2.27-in. U shield
1 - 6 - 79.0	1 - 6 - 60.6	1 - 6 - 59.5	1 - 14 - 85.9	1 - 14 - 74.9	1 - 14 - 65.3
2 - 12 - 170.0	2 - 12 - 154.2	2 - 12 - 140.6	2 - 28 - 184.5	2 - 28 - 167.8	2 - 28 - 153.4
3 - 18 - 189.0	3 - 18 - 172.4	3 - 18 - 158.1	3 - 42 - 206.0	3 - 42 - 189.4	3 - 42 - 173.3
4 - 24 - 219.1 ^b	4 - 24 - 201.1 ^b	4 - 24 - 185.7 ^b	4 - 56 - 239.3	4 - 56 - 220.3	4 - 56 - 204.0
5 - 30 - 253.7	5 - 30 - 234.2 ^b	5 - 30 - 217.4 ^b	5 - 70 - 277.4	5 - 70 - 256.8	5 - 70 - 239.1
6 - 36 - 291.6	6 - 36 - 270.4	6 - 36 - 252.2	6 - 84 - 319.0	6 - 84 - 296.6	6 - 84 - 277.5
7 - 42 - 296.1	7 - 42 - 274.8	7 - 42 - 256.7	7 - 98 - 324.9	7 - 98 - 302.3	7 - 98 - 283.4
8 - 48 - 336.7	8 - 48 - 313.7	8 - 48 - 294.1		8 - 112 - 345.3	8 - 112 - 324.6
		9 - 54 - 334.0			

^aThe n-mm-wvv.v format used to present the data gives:

n - the number of waste packages in the cask,

m - the equivalent number of consolidated fuel assemblies in the cask, and

v - the loaded weight of the cask, where 191.0 = 191,000 lbs.

^bCalculated dose rate 10 ft from centerline was 9.8-10.2 millirem/hr.

Table 9. Gross weight of Basalt repository casks vs the number of waste packages^a

Type of package - overpack only					
4 PWR assemblies/package			9 BWR assemblies/package		
5.98-in. Fe shield	1.80-in. Pb shield	1.26-in. U shield	5.98-in. Fe shield	1.80-in. Pb shield	1.26-in. U shield
1 - 4 - 53.3	1 - 4 - 48.8	1 - 4 - 44.1	1 - 9 - 57.0	1 - 9 - 52.2	1 - 9 - 47.2
2 - 8 - 116.2	2 - 8 - 109.0	2 - 8 - 102.0	2 - 18 - 124.2	2 - 18 - 116.5	2 - 18 - 109.1
3 - 12 - 135.5	3 - 12 - 127.8	3 - 12 - 120.5	3 - 27 - 144.5	3 - 27 - 136.4	3 - 27 - 128.7
4 - 16 - 161.3	4 - 16 - 153.0	4 - 16 - 145.2	4 - 36 - 171.9	4 - 36 - 163.1	4 - 36 - 154.8
5 - 20 - 189.9	5 - 20 - 180.9	5 - 20 - 172.4	5 - 45 - 202.3	5 - 45 - 192.7	5 - 45 - 183.7
6 - 24 - 220.5	6 - 24 - 210.6	6 - 24 - 201.4	6 - 54 - 234.7	6 - 54 - 224.3	6 - 54 - 214.5
7 - 28 - 231.0	7 - 28 - 221.1	7 - 28 - 211.9	7 - 63 - 245.7	7 - 63 - 235.2	7 - 63 - 225.5
8 - 32 - 263.2	8 - 32 - 252.5	8 - 32 - 242.6	8 - 72 - 279.9	8 - 72 - 268.6	8 - 72 - 258.1
9 - 36 - 297.0	9 - 36 - 285.5	9 - 36 - 274.8	9 - 81 - 315.8	9 - 81 - 303.6	9 - 81 - 292.3
10 - 40 - 322.3 ^b	10 - 40 - 310.2 ^b	10 - 40 - 299.1 ^b		10 - 90 - 329.8	10 - 90 - 318.1
	11 - 44 - 330.1	11 - 44 - 318.7			11 - 99 - 338.8
		12 - 48 - 339.7			

Table 9 (continued)

Type of package - canister only					
1 PWR assembly/package			2 BWR assemblies/package		
9.39-in. Fe shield	4.02-in. Pb shield	2.52-in. U shield	9.39-in. Fe shield	4.02-in. Pb shield	2.52-in. U shield
27 - 27 - 185.2	32 - 32 - 190.1	35 - 35 - 187.2	24 - 48 - 185.9	28 - 56 - 185.9	32 - 64 - 187.7
28 - 28 - 189.9	33 - 33 - 195.4	35 - 36 - 192.2	25 - 50 - 189.7	29 - 58 - 190.3	33 - 66 - 193.2
29 - 29 - 194.2	34 - 34 - 198.2	37 - 37 - 193.2	26 - 52 - 194.2	30 - 60 - 193.0	34 - 68 - 196.0
30 - 30 - 196.9	35 - 35 - 202.2	38 - 38 - 196.5	27 - 54 - 198.7	31 - 62 - 194.1	35 - 70 - 200.1
31 - 31 - 197.9	36 - 36 - 207.3	39 - 39 - 200.4	28 - 56 - 202.7	32 - 64 - 203.0	36 - 72 - 205.4
32 - 32 - 206.7	37 - 37 - 208.4	40 - 40 - 205.2	29 - 58 - 207.3	33 - 66 - 208.7	37 - 74 - 206.5
33 - 33 - 212.3	38 - 38 - 211.8	41 - 41 - 208.5	30 - 60 - 210.1	34 - 68 - 211.6	38 - 76 - 210.0
34 - 34 - 215.1	39 - 39 - 215.8	42 - 42 - 214.7	31 - 62 - 211.2	35 - 70 - 215.8	39 - 78 - 214.1
35 - 35 - 219.2	40 - 40 - 220.7	43 - 43 - 221.1	32 - 64 - 220.5	36 - 72 - 221.3	40 - 80 - 219.2
.	.	.	.	.	41 - 82 - 222.7
.	.	.	.	.	.
.	.	.	.	.	.
.	.	.	.	.	.
50 - 50 - 275.9	55 - 55 - 269.8	62 - 62 - 287.3	46 - 92 - 278.2	54 - 108 - 280.8	55 - 110 - 264.2
51 - 51 - 279.6	56 - 56 - 290.8	63 - 63 - 288.3	47 - 94 - 283.2	55 - 110 - 281.9	56 - 112 - 285.4
52 - 52 - 280.7	57 - 57 - 296.2	64 - 64 - 292.7	48 - 96 - 287.1	56 - 112 - 304.1	57 - 114 - 290.9
53 - 53 - 281.7	58 - 58 - 297.2	65 - 65 - 295.9	49 - 98 - 289.3	57 - 114 - 309.7	58 - 116 - 292.0
54 - 54 - 288.0 ^b	59 - 59 - 298.3 ^b	66 - 66 - 299.5 ^b	50 - 100 - 294.0	58 - 116 - 310.8	60 - 120 - 294.2
55 - 55 - 289.1	60 - 60 - 299.3	67 - 67 - 300.6	51 - 102 - 298.0	59 - 118 - 311.9	61 - 122 - 297.4
56 - 56 - 305.6	61 - 61 - 302.5	68 - 68 - 301.6	52 - 104 - 299.0	60 - 120 - 313.0	62 - 124 - 301.4
57 - 57 - 316.7	62 - 62 - 306.4	69 - 69 - 303.7	53 - 106 - 300.1	61 - 122 - 316.3	63 - 126 - 302.5
58 - 58 - 317.7	63 - 63 - 307.5	70 - 70 - 313.3	54 - 108 - 301.2	62 - 124 - 320.5	64 - 124 - 307.2
59 - 59 - 318.8	64 - 64 - 312.0	71 - 71 - 318.1	55 - 110 - 302.3	63 - 126 - 321.5	65 - 130 - 310.5
60 - 60 - 319.8	65 - 65 - 315.3	72 - 72 - 319.1	56 - 112 - 325.5	64 - 128 - 326.4	66 - 132 - 314.3
61 - 61 - 323.1	66 - 66 - 319.1	73 - 73 - 320.2			68 - 136 - 316.5
62 - 62 - 327.2	67 - 67 - 320.1	74 - 74 - 327.1			69 - 138 - 317.6
					70 - 140 - 328.9

Table 9. (continued)

Type of package - canister only					
2 PWR assemblies/package			4 BWR assemblies/package		
9.39-in. Fe shield	4.02-in. Pb shield	2.52-in. U shield	9.39-in. Fe shield	4.02-in. Pb shield	2.52-in. U shield
15 - 30 - 183.7	17 - 34 - 183.5	19 - 38 - 181.8	14 - 56 - 188.4	16 - 64 - 187.6	18 - 72 - 188.3
16 - 32 - 191.3	18 - 36 - 190.5	20 - 40 - 190.2	15 - 60 - 196.0	17 - 68 - 195.9	19 - 76 - 190.5
17 - 34 - 199.5	19 - 38 - 192.6	21 - 42 - 196.8	16 - 64 - 204.2	18 - 72 - 203.3	20 - 80 - 199.3
18 - 36 - 206.8	20 - 40 - 201.2	22 - 44 - 205.8	17 - 68 - 212.9	19 - 76 - 205.5	21 - 84 - 206.2
19 - 38 - 208.9	21 - 42 - 207.9	23 - 46 - 212.3	18 - 72 - 220.6	20 - 80 - 214.7	22 - 88 - 215.7
20 - 40 - 217.9	22 - 44 - 217.1	24 - 48 - 218.4	.	21 - 84 - 221.9	23 - 92 - 222.5
.	.	.	.	.	.
.	.	.	.	.	.
29 - 58 - 285.1	32 - 64 - 285.6	35 - 70 - 286.6	27 - 108 - 284.6	30 - 120 - 282.9	33 - 132 - 289.3
30 - 60 - 289.7	33 - 66 - 294.1	36 - 72 - 294.5	28 - 112 - 291.0	31 - 124 - 285.1	34 - 136 - 294.1
31 - 62 - 291.8	34 - 68 - 298.8	37 - 74 - 296.6	29 - 116 - 298.2	32 - 128 - 298.7	35 - 140 - 300.7
32 - 64 - 305.2	35 - 70 - 305.2	38 - 76 - 303.1	30 - 120 - 303.0	33 - 132 - 307.6	36 - 144 - 309.1
33 - 66 - 314.0	36 - 72 - 313.5	39 - 78 - 309.5	31 - 124 - 305.2	34 - 136 - 312.5	37 - 148 - 311.3
34 - 68 - 318.9	37 - 74 - 315.6	40 - 80 - 317.2	32 - 128 - 319.3	35 - 140 - 319.3	38 - 152 - 317.0

Type of package - canister only					
3 PWR assemblies/package			7 BWR assemblies/package		
9.39-in. Fe shield	4.02-in. Pb shield	2.52-in. U shield	9.39-in. Fe shield	4.02-in. Pb shield	2.52-in. U shield
10 - 30 - 184.8	12 - 36 - 186.3	13 - 39 - 186.4	9 - 63 - 185.3	11 - 77 - 189.5	12 - 84 - 184.0
11 - 33 - 193.3	13 - 39 - 197.3	14 - 42 - 197.0	10 - 70 - 197.3	12 - 84 - 198.9	13 - 91 - 195.3
12 - 36 - 202.5	14 - 42 - 208.2	15 - 45 - 206.2	11 - 77 - 206.2	13 - 91 - 210.6	14 - 98 - 206.4
13 - 39 - 213.9	15 - 45 - 217.6	16 - 48 - 216.1	12 - 84 - 216.0	14 - 98 - 222.1	15 - 105 - 216.1
.	.	.	.	.	.
.	.	.	.	.	.
20 - 60 - 287.2	22 - 66 - 290.4	24 - 72 - 289.5	19 - 133 - 287.3	21 - 147 - 290.2	22 - 154 - 285.4
21 - 63 - 296.9	23 - 69 - 299.7	25 - 75 - 298.2	20 - 140 - 300.3	22 - 154 - 303.6	23 - 161 - 299.7
22 - 66 - 310.2	24 - 72 - 308.4	26 - 78 - 306.9	21 - 147 - 310.6	23 - 161 - 313.3	24 - 168 - 308.7
23 - 69 - 319.8	25 - 75 - 316.2	27 - 81 - 315.9	22 - 154 - 324.5	24 - 168 - 322.5	25 - 175 - 316.8

Table 9 (continued)

Type of package - canister only					
4 PWR assemblies/package			9 BWR assemblies/package		
9.44-in. Fe shield	4.07-in. Pb shield	2.56-in. U shield	9.44-in. Fe shield	4.07-in. Pb shield	2.56-in. U shield
8 - 32 - 176.2 ^c	9 - 36 - 178.6 ^d	10 - 40 - 179.8 ^{b,e}	7 - 63 - 168.0 ^c	8 - 72 - 171.6 ^d	9 - 81 - 175.4 ^e
9 - 36 - 195.2 ^c	10 - 40 - 191.2 ^{b,d}	11 - 44 - 189.5 ^e	8 - 72 - 188.1 ^c	9 - 81 - 190.8 ^d	10 - 90 - 188.3 ^e
10 - 40 - 208.3 ^{b,c}	11 - 44 - 205.8 ^g	12 - 48 - 200.1 ^h	9 - 81 - 208.3 ^c	10 - 90 - 204.1 ^d	11 - 99 - 198.4 ^e
11 - 44 - 218.7 ^f	12 - 48 - 216.8 ^g	13 - 52 - 213.1 ^k	10 - 90 - 222.2 ^c	11 - 99 - 214.7 ^g	12 - 108 - 209.6 ^h
12 - 48 - 230.1 ⁱ	13 - 52 - 230.4 ^j	14 - 56 - 226.1 ^k	.	.	13 - 117 - 223.3 ^k
.	.	.	.	.	.
15 - 60 - 275.6 ^b	17 - 68 - 281.9 ^b	19 - 76 - 279.3 ^b	14 - 126 - 275.1	16 - 144 - 280.4	17 - 153 - 275.4
16 - 64 - 288.1	18 - 72 - 293.3	20 - 80 - 293.1	15 - 135 - 288.1	17 - 153 - 294.6	18 - 162 - 292.5
17 - 68 - 301.4	19 - 76 - 296.4	21 - 84 - 304.9	16 - 144 - 301.2	18 - 162 - 306.6	19 - 171 - 296.8
18 - 72 - 313.3	20 - 80 - 310.9	22 - 88 - 319.7	17 - 153 - 315.2	19 - 171 - 310.2	20 - 180 - 311.3
19 - 76 - 316.7	21 - 84 - 323.2	23 - 92 - 331.5	18 - 162 - 327.7	20 - 180 - 325.1	21 - 189 - 322.8

^aThe n-mm-ww.v format used to present the data gives:

n - the number of waste packages in the cask,

m - the equivalent number of consolidated fuel assemblies in the cask, and

v - the loaded weight of the cask, where 195.2 = 195,200 lbs.

^bCalculated dose rate 10 ft from centerline was 9.8-10.2 millirem/hr.

^cException - t_y = 9.24 in. of Fe.

^dException - t_y = 3.88 in. of Pb.

^eException - t_y = 2.41 in. of U.

^fException - t_y = 9.28 in. of Fe.

^gException - t_y = 3.92 in. of Pb.

^hException - t_y = 2.44 in. of U.

ⁱException - t_y = 9.32 in. of Fe.

^jException - t_y = 3.96 in. of Pb.

^kException - t_y = 2.48 in. of U.

SCOPE output corresponding to each of these 522 individual cases. For each case, they give the actual neutron and gamma shield thicknesses; the gross loaded weight of the cask; the overall inside and outside dimensions of the cask (including external circumferential fins, when required); the steady-state temperature distribution; and the maximum transient temperature in certain key components during and after the postulated 30-min. fire.

Most (90-95%) of the casks surveyed do not require external cooling fins. Some, however, do require 2-in.-high circumferential fins in order to maintain an external surface temperature of 250°F, given an outside ambient temperature of 130°F. The worst case of practical interest corresponds to the large U-shielded cask for the Basalt repository which contains 84 PWR fuel assemblies in 21 thin-walled steel canisters. In this case, 4-in.-high x 0.25-in.-thick stainless-steel fins were required every 4 in. along the outer surface of the cask. (The internal decay heat load associated with the 10-year-cooled spent fuel was 524 watts per PWR fuel assembly, and 168 watts per BWR fuel assembly.) In no case does the external diameter of a cask exceed 120 in., including the cooling fins.

Except for the steady-state and transient fuel pin temperatures, the other calculated temperatures shown in the Appendix are considered fairly accurate. To calculate the maximum fuel pin cladding temperatures, the SCOPE code¹ assumes the fuel pins are dispersed within the canister or overpack in a square array. It then calculates the maximum fuel pin cladding temperature using the Wootton-Epstein correlation in which the primary mode of heat transfer is thermal radiation, with a small correction for thermal convection within the fuel bundle. For tightly compacted spent fuel (and for canisters with radial conductors, as in the Salt waste canister), the Wootton-Epstein equation will yield a very conservative result, such that the calculated temperatures are well above those that one would realistically expect. Even so, the calculated steady-state fuel pin clad temperatures are generally well below the point at which oxidation of the fuel becomes a significant problem. In those few cases where the calculated temperatures do approach this limit, a more rigorous thermal analysis may show the actual temperatures to be well below the limit. One obvious exception to this is the large U-shielded cask for the Basalt repository which contains 84 PWR fuel assemblies in 21 thin-walled steel canisters. In this case, the steady-state temperature on the innermost portion of the removable aluminum insert may approach 500°F (260°C). While the maximum fuel pin temperature will be substantially less than the 718°F (381°C) shown in Table A.17, it will obviously be greater than that of the surrounding insert (500°F or 260°C). In such cases it may be desirable to provide an inert atmosphere within the canister to prevent excessive oxidation of the fuel.

The detailed SCOPE output in the Appendix indicates that a few of the larger Pb casks containing more than 70 PWR fuel assemblies may experience some melting of the Pb gamma shield during or after the hypothetical fire ($T_{\text{melt}}^{\text{Pb}} = 620^\circ\text{F}$). However, several points should be noted: (a) Because of the lower decay heat loads, none of the casks containing BWR spent fuel experienced any melting of the Pb shield. (b) Of the several Pb-shielded PWR casks in the Appendix which exhibit some melting of the gamma shield, most weigh in excess of 300,000 lbs; and only one actually appears in Table 5 [that is, the Pb cask containing 76 PWR assemblies in 19 thin-walled canisters designed for the Basalt repository]. (c) The accident scenario used in the SCOPE code is unusually conservative insofar as it assumes that the cask is allowed to attain a new (elevated) state of thermal equilibrium after the loss of the neutron shield and prior to the start of the 30-min. fire. In a more conventional scenario, one typically assumes that the 30-min. fire begins concurrently with the loss of the neutron shield. Under the more conventional scenario, the gamma shield temperature at the start of the transient would be much lower; and it is doubtful that any significant melting would occur during or after the 30-min. fire. While more detailed transient thermal analyses of the high-capacity Pb casks should be performed as the final mechanical designs evolve, the development of such casks should not be aborted prematurely based on the preliminary transient thermal analyses reported here.

Shipping large numbers of consolidated fuel assemblies in a single large cask raises some interesting possibilities. Such systems must, however, be examined with respect to criticality safety. The highest capacity cask reported in this study is a 300,000-lb U-shielded cask containing 84 consolidated PWR fuel assemblies in 21 thin-walled steel canisters designed for the Basalt repository. As noted below, a slightly more reactive variation of this particular cask has been analyzed and found to have a generation-to-generation neutron multiplication factor (k_{eff}) no greater than 0.536 ± 0.002 , even if one assumes that the PWR fuel is unirradiated and contains 3.4 wt% U-235. The low neutron multiplication factor in these highly specialized casks stems from several factors: (a) the consolidated fuel pins have a small pitch-to-diameter ratio, (b) the fuel is shipped dry in canisters that are hermetically sealed at the MRS facility, and (c) the solid aluminum insert between the canisters effectively displaces any interstitial water that might be in the cask during loading (or in the event of a transportation accident). While the other lower-capacity casks reported in this study should eventually be analyzed in a similar fashion, it would appear, based on this preliminary evaluation, that all of the other casks would also be safely subcritical.

The criticality safety analysis referenced above was performed using Criticality Safety Analysis Sequence no. 2 (CSAS2) as incorporated in the NRC-sponsored SCALE system for Standardized Computer Analyses for Licensing Evaluation.^{4,7} That particular analytical sequence employs the NITAWL resonance self-shielding code,⁸ the XSDRNPM discrete ordinates transport code² for cell-averaging the multigroup cross sections, and the KENO IV Monte Carlo criticality program.⁶ The SCALE system's 27-group ENDF-IV cross-section library was also used. The analysis assumes that 816 unirradiated zircalloy-clad PWR fuel pins from four Westinghouse 15 x 15 fuel assemblies* are placed in a thin-walled carbon steel canister having an inside diameter of 32 cm and an outside diameter of 33 cm. The fuel pins contain 3.4 wt% U-235, and have an outside rod diameter of 1.0719 cm; a clad thickness of 0.0617 cm; a fuel pellet diameter of 0.9294 cm; and a UO_2 density of 10.41 g/cc. Within the given canister, the compacted fuel pins were assumed to be spaced on a close-packed triangular pitch of 1.2318 cm. [The 1056 0.95-cm-diam. fuel rods from four of the newer Westinghouse 17 x 17 assemblies would yield a slightly tighter lattice pitch, but would contain essentially the same amount of UO_2 per canister and have approximately the same k_{eff} as long as the canister is dry.] For an infinite lattice of such fuel pins, the one-dimensional XSDRNPM code yielded a k_{eff} of 0.6797. A simplified KENO IV model was then created which accounts for interstitial moderation by the aluminum insert and reflection by the inner walls of the cask (see Fig. 7). An homogenized mixture representing the unirradiated fuel pins was placed inside a 0.45-cm-thick carbon steel canister whose outside dimensions measured 29.25 cm x 29.25 cm. (These dimensions preserve the amount of fuel and the amount of steel in the cylindrical canisters previously described.) The steel canister was then surrounded by a 1.27-cm-thick aluminum canister whose outside dimensions measured 31.79 cm x 31.79 cm. Twenty-five of these composite canisters were arranged in a tight-fitting 5 x 5 array which was surrounded on four sides by materials representing the inner walls of the U-shielded cask--that is, 1.905 cm of stainless steel, 6.5024 cm of depleted uranium metal, and another 5.08 cm of stainless steel. Mirror-like boundary conditions were applied to the two axial ends of the model, resulting in the conservative 2-D representation depicted in Fig. 7. Subsequent KENO IV analysis of this (dry) system showed it to be safely subcritical, with a k_{eff} of 0.536 ± 0.002 .

*Each assembly contains 204 fuel pins and 21 guide tubes to accommodate the movable control rod clusters.

Fig. 7. A simplified 2-D KENO IV model of a large U-shielded cask containing 100 consolidated PWR fuel assemblies in 25 thin-walled steel canisters.

6. CONCLUSIONS

The objective of this study was to determine the maximum number of repository waste packages that could be shipped in Pb-, Fe-, and U-shielded casks having a gross loaded weight of 200,000 or 300,000 lbs. This determination was made for each of 18 different waste packages defined by requirements at the Salt, Tuff, and Basalt repositories. The waste packages were comprised of thin-walled steel canisters, thick-walled steel overpacks, or overpacks containing a single canister. Depending on the particular repository and the particular design, each waste package contained 1-12 consolidated PWR fuel assemblies or 2-30 consolidated BWR fuel assemblies (see Sect. 2).

Subsequent to the initial scoping analysis but prior to the final scoping analysis, discrete ordinates shielding calculations were performed for 30 cases of potential interest. The object of these calculations was to determine the actual neutron and gamma shield thicknesses that would yield a dose rate of 10 millirem/hr at a point 10 ft from the centerline of the cask, assuming that the consolidated PWR fuel had been irradiated to 33,000 MWd/MTIHM and allowed to cool for 10 years. While somewhat conservative, these same neutron and gamma shield thicknesses were also assumed to apply to casks containing consolidated BWR fuel irradiated to 27,500 MWd/MTIHM.

Tables 5 and 6 show the number of consolidated PWR and BWR fuel assemblies that may be shipped in 200,000-lb and 300,000-lb Pb-, Fe-, and U-shielded casks designed to accommodate the 18 repository waste packages previously described. The 108 particular cask designs associated with these limits are a subset of a larger group of 522 potentially interesting cask designs for which more detailed information is also given. This information includes the gross weight of the casks as a function of the number of waste packages or consolidated fuel assemblies, the overall cask dimensions, the actual neutron and gamma shield thicknesses, the internal temperature distribution under nominal steady-state conditions, and the maximum temperature in key components during and after a 30-min. fire. In general it should be noted that:

- (a) Relative to the 200,000-lb casks, 50-100% more fuel may be shipped in the larger 300,000-lb casks.
- (b) Placing the spent fuel canisters in overpacks prior to shipment from the MRS will reduce the net payload by about 30-50%.
- (c) For a given payload, the U-shielded cask will weigh less than a Pb-shielded cask, which will weigh less than an Fe-shielded cask.
- (d) For the high capacity waste packages used at the Salt and Tuff repositories, the Pb- and U-shielded casks will offer equal payload capacities, with the only tangible difference being the overall weight. For the smaller waste packages used at the Basalt repository, the U-shielded casks do offer a noticeable payload advantage.
- (e) Most (i.e., 90-95%) of the casks surveyed do not require external cooling fins. Some of the higher-capacity casks, however, may require 2- to 4-in.-high circumferential cooling fins. In no case does the external diameter of a cask exceed 120 in., including cooling fins.
- (f) Use of some of the higher-capacity casks may require that the thin-walled canisters be filled with an inert atmosphere if excessive oxidation of the fuel is to be avoided.
- (g) The highest capacity cask/waste package combination studied corresponds to a 300,000-lb U-shielded cask containing 84 consolidated PWR fuel assemblies in 21 thin-walled steel canisters, or 171 consolidated BWR fuel assemblies in 19 thin-walled steel canisters. Preliminary KENO IV criticality analyses have shown these high-capacity casks to be safely subcritical--even if all of the canisters were loaded with unirradiated PWR fuel pins containing 3.4 wt% U-235.

27/28

Based on these findings, one may conclude that the total number of required shipments between the MRS and the various repositories may be substantially reduced through the use of larger casks especially designed for the various repository waste packages.

REFERENCES

1. J. A. Bucholz, *Scoping Design Analyses for Optimized Shipping Casks Containing 1-, 2-, 3-, 5-, 7-, or 10-Year-Old PWR Spent Fuel*, ORNL/CSD/TM-149, Martin Marietta Energy Systems, Inc., Oak Ridge Nat. Lab., January 1983.
2. N. M. Greene and L. M. Petrie, "XSDRNPM-S: A One-Dimensional Discrete Ordinates Code for Transport Analysis," Section F3 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vol. 2, Rev. 2, U.S. Nuclear Regulatory Commission, June 1983.
3. J. A. Bucholz, "XSDOSE: A Module for Calculating Fluxes and Dose Rates at Points Outside a Shield," Section F4 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vol. 2, Rev. 2, U.S. Nuclear Regulatory Commission, June 1983.
4. Staff of Technical Applications, Computing and Telecommunications Division at ORNL, *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vols. 1-3, U.S. Nuclear Regulatory Commission (originally issued July 1980, reissued January 1982, Revision 1 issued July 1982, Revision 2 issued June 1983, Revision 3 issued December 1984), .
5. J. R. Knight, C. V. Parks, L. M. Petrie, "SASI: A One-Dimensional Shielding Analysis Module," Section S1 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vol. 1 (to be published by U.S. Nuclear Regulatory Commission).
6. L. M. Petrie and N. F. Landers, "KENO IV/S - An Improved Monte Carlo Criticality Program," Section F5 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vol. 2, U.S. Nuclear Regulatory Commission, January 1982.
7. J. A. Bucholz, "CSAS2: A Multidimensional Criticality Safety Analysis Module," Section C2 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vol. 1, U.S. Nuclear Regulatory Commission, January 1982.
8. R. M. Westfall et al., "NITAWL-S: SCALE System Module for Performing Resonance Shielding and Working Library Production," Section F2 of *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Vol. 2, U.S. Nuclear Regulatory Commission, January 1982.

APPENDIX

Tables A.1–A.18 show the actual SCOPE output for all of the cases summarized in Sect. 5. For each cask/waste package configuration, they give the actual neutron and gamma shield thicknesses, the gross loaded weight of the cask, the overall inside and outside dimensions of the cask (including external cooling fins, when required), the steady-state temperature distribution, and the maximum transient temperature in certain key components during and after the postulated 30-min. fire. This information is tabulated for each type of cask as a function of the number of waste packages (i.e., canisters) in the cask. The 18 tables in this Appendix may be briefly described as follows:

- Table A.1. Salt reference design; overpack and canister with 12 PWR assemblies/package
- Table A.2. Salt reference design; overpack and canister with 30 BWR assemblies/package
- Table A.3. Salt reference design; bare canister with 12 PWR assemblies/package
- Table A.4. Salt reference design; bare canister with 30 BWR assemblies/package
- Table A.5. Tuff reference design; overpack and canister with 6 PWR assemblies/package
- Table A.6. Tuff reference design; overpack and canister with 14 BWR assemblies/package
- Table A.7. Tuff reference design; bare canister with 6 PWR assemblies/package
- Table A.8. Tuff reference design; bare canister with 14 BWR assemblies/package
- Table A.9. Basalt reference design; overpack only, with 4 PWR assemblies/package
- Table A.10. Basalt reference design; overpack only, with 9 BWR assemblies/package
- Table A.11. Basalt reference design; canister only, with 1 PWR assembly/package
- Table A.12. Basalt reference design; canister only, with 2 BWR assemblies/package
- Table A.13. Basalt reference design; canister only, with 2 PWR assemblies/package
- Table A.14. Basalt reference design; canister only, with 4 BWR assemblies/package
- Table A.15. Basalt reference design; canister only, with 3 PWR assemblies/package
- Table A.16. Basalt reference design; canister only, with 7 BWR assemblies/package
- Table A.17. Basalt reference design; canister only, with 4 PWR assemblies/package
- Table A.18. Basalt reference design; canister only, with 9 BWR assemblies/package

Table A.1. Salt Reference Design: Overpack and Canister with 12 FWR Assemblies/Package

FUEL NO. AGE	NO. CANS	MATERIALS			THICKNESS IN INCHES		CASK WEIGHT (KILOS)	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F		
		INSERT	CAN. SHLD	HEUT SHLD	CAN. SHLD	HEUT SHLD	ID	OD	LENGTH	PIN HT.	PIN THK.	FUEL PIN	INSERT MATL	CANNA SHLD	CASK SURF.	FUEL PIN	INSERT MATL	CANNA SHLD	
10.0	1	AL	PB	H2O	0.94	4.25	84.4	33.5	52.4	195.7	0.0	0.0	590	197	196	189	831	463	462
10.0	2	AL	PB	H2O	1.20	4.25	214.2	70.3	89.7	196.2	0.0	0.0	652	279	204	196	770	419	446
10.0	3	AL	PB	H2O	1.20	4.25	256.6	75.6	95.0	196.2	0.0	0.0	690	320	227	217	827	490	493
10.0	4	AL	PB	H2O	1.20	4.25	313.7	84.6	104.0	196.2	0.0	0.0	716	361	244	232	859	532	522
10.0	1	AL	FE	H2O	4.50	3.75	88.2	33.5	53.2	196.4	0.0	0.0	507	195	194	188	790	421	421
10.0	2	AL	FE	H2O	5.01	3.75	222.6	70.3	90.0	197.3	0.0	0.0	650	277	203	195	762	410	411
10.0	3	AL	FE	H2O	5.01	3.75	265.6	75.6	96.2	197.3	0.0	0.0	688	325	226	216	817	480	459
10.0	4	AL	FE	H2O	5.01	3.75	323.7	84.6	105.1	197.3	0.0	0.0	713	358	242	230	849	521	489
10.0	1	AL	U	H2O	0.79	3.47	80.0	33.5	49.0	192.3	0.0	0.0	592	201	200	193	859	493	492
10.0	2	AL	U	H2O	0.94	3.47	206.2	70.3	86.1	192.6	0.0	0.0	654	281	207	199	775	424	469
10.0	3	AL	U	H2O	0.94	3.47	240.1	75.6	91.5	192.6	0.0	0.0	692	330	231	221	832	497	516
10.0	4	AL	U	H2O	0.94	3.47	304.4	84.6	100.4	192.6	0.0	0.0	718	363	248	236	864	530	545
10.0	5	AL	U	H2O	0.94	3.47	367.2	94.5	110.3	192.6	0.0	0.0	736	387	260	247	884	565	566

Table A.2. Salt Reference Design: Overpack and Canister with 30 FWR Assemblies/Package

FUEL NO. AGE	NO. CANS	MATERIALS		THICKNESS IN INCHES		CASK WEIGHT (KLS)	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
		INSERT SHLD	CAN. SHLD	HEUT SHLD	CAN. SHLD	HEUT SHLD	ID	OD	LENGTH	PIN HT.	PIN THK.	FUEL PIN	INSERT MATL	CANNA SHLD	CASK SURF.	FUEL PIN	INSERT MATL	CANNA SHLD	
10.0	1	AL	PB	H2O	0.94	4.25	89.9	33.5	52.4	209.5	0.0	0.0	500	183	182	176	732	433	432
10.0	2	AL	PB	H2O	1.20	4.25	220.1	70.3	89.7	210.0	0.0	0.0	551	247	188	182	662	374	414
10.0	3	AL	PB	H2O	1.20	4.25	273.0	75.6	95.0	210.0	0.0	0.0	582	286	207	199	711	436	455
10.0	4	AL	PB	H2O	1.20	4.25	333.6	84.6	104.0	210.0	0.0	0.0	604	313	220	211	739	471	480
10.0	1	AL	FE	H2O	4.50	3.75	93.9	33.5	53.2	210.2	0.0	0.0	499	181	181	176	691	392	391
10.0	2	AL	FE	H2O	5.01	3.75	237.0	70.3	90.8	211.1	0.0	0.0	549	245	187	182	654	366	379
10.0	3	AL	FE	H2O	5.01	3.75	282.4	75.6	96.2	211.1	0.0	0.0	580	283	206	198	702	426	420
10.0	4	AL	FE	H2O	5.01	3.75	344.1	84.6	105.1	211.1	0.0	0.0	602	310	219	210	730	461	446
10.0	1	AL	U	H2O	0.79	3.47	85.2	33.5	49.0	206.1	0.0	0.0	503	186	185	179	760	462	462
10.0	2	AL	U	H2O	0.94	3.47	219.7	70.3	86.1	206.4	0.0	0.0	552	248	191	185	666	379	437
10.0	3	AL	U	H2O	0.94	3.47	264.0	75.6	91.5	206.4	0.0	0.0	584	288	211	203	716	442	477
10.0	4	AL	U	H2O	0.94	3.47	323.7	84.6	100.4	206.4	0.0	0.0	605	315	220	215	745	477	503

Table A.3. Salt Reference Design; Bare Canister with 12 FWR Assemblies/Package

										STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F					
MATERIALS				THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES												
FUEL NO. AGE	CAN.	INSERT	CAN. SHLD	HEUT SHLD	ID		OD	LENGTH	FIN HT.	FIN THK.	FUEL FIN	INSERT MATL	GAMMA SHLD	CASE SURF.	FUEL FIN	INSERT MATL	GAMMA SHLD		
10.0	1	AL	PS	H2O	3.37	4.25	71.9	24.7	48.4	182.2	0.0	0.0	681	209	207	196	864	465	462
10.0	2	AL	PS	H2O	3.72	4.25	166.8	52.6	77.0	182.9	0.0	0.0	725	326	221	209	849	478	462
10.0	3	AL	PS	H2O	3.72	4.25	191.5	56.5	81.0	182.9	0.0	0.0	771	389	251	234	913	562	517
10.0	4	AL	PS	H2O	3.72	4.25	231.5	63.2	91.6	182.9	2.0	0.25	782	404	238	211	951	618	572
10.0	5	AL	PS	H2O	3.72	4.25	271.3	70.6	99.0	182.9	2.0	0.25	803	432	251	229	974	442	596
10.0	6	AL	PS	H2O	3.72	4.25	314.1	78.2	106.7	182.9	2.0	0.25	819	454	261	237	989	664	614
10.0	7	AL	PS	H2O	3.72	4.25	326.4	78.2	108.7	182.9	3.0	0.25	849	493	270	243	1048	727	654*
10.0	1	AL	FE	H2O	0.48	3.75	81.5	24.7	51.1	185.9	0.0	0.0	636	202	201	191	793	389	405
10.0	2	AL	FE	H2O	0.99	3.75	182.6	52.6	81.0	187.0	0.0	0.0	721	320	216	205	829	455	424
10.0	3	AL	FE	H2O	0.99	3.75	208.1	56.5	85.0	187.0	0.0	0.0	766	381	244	229	889	535	479
10.0	4	AL	FE	H2O	0.99	3.75	244.5	63.2	91.7	187.0	0.0	0.0	794	422	265	246	927	586	515
10.0	5	AL	FE	H2O	0.99	3.75	298.8	70.6	103.0	187.0	2.0	0.25	798	425	245	224	949	614	554
10.0	6	AL	FE	H2O	0.99	3.75	335.2	78.2	110.7	187.0	2.0	0.25	814	447	255	232	967	639	573
10.0	1	AL	U	H2O	2.11	3.47	63.2	24.7	42.0	176.6	0.0	0.0	646	217	215	205	895	499	498
10.0	2	AL	U	H2O	2.32	3.47	152.8	52.6	71.1	177.1	0.0	0.0	729	331	228	216	858	490	487
10.0	3	AL	U	H2O	2.32	3.47	176.8	56.5	75.1	177.1	0.0	0.0	775	394	259	243	923	574	543
10.0	4	AL	U	H2O	2.32	3.47	214.7	63.2	85.0	177.1	2.0	0.25	785	407	244	225	960	621	601
10.0	5	AL	U	H2O	2.32	3.47	253.1	70.6	93.1	177.1	2.0	0.25	806	435	257	236	982	652	624
10.0	6	AL	U	H2O	2.32	3.47	294.4	78.2	100.0	177.1	2.0	0.25	821	457	267	245	997	673	641
10.0	7	AL	U	H2O	2.32	3.47	307.6	78.2	104.0	177.1	4.0	0.25	849	493	273	247	1052	741	691
10.0	8	AL	U	H2O	2.32	3.47	352.9	86.1	114.6	177.1	5.0	0.25	856	503	278	250	1058	750	709

Table A.4. Salt Reference Design; Bare Canister with 30 FWR Assemblies/Package

							DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
		MATERIALS		THICKNESS IN INCHES		CASE WEIGHT (LBS)													
FUEL NO. AGE	CAN.	INSERT SHLD	CAN. SHLD	HEUT SHLD	CAN. SHLD		ID	OD	LENGTH	FIN HT.	FIN THK.	FUEL FIN	INSERT MATL	GAMMA SHLD	CASE SURF.	FUEL FIN	INSERT MATL	GAMMA SHLD	
10.0	1	AL	PS	H2O	3.37	4.25	76.8	24.7	48.4	196.0	0.0	0.0	542	192	190	182	756	431	429
10.0	2	AL	PS	H2O	3.72	4.25	178.0	52.6	77.0	196.7	0.0	0.0	610	283	202	192	720	424	425
10.0	3	AL	PS	H2O	3.72	4.25	203.9	56.5	81.0	196.7	0.0	0.0	649	334	225	213	784	495	472
10.0	4	AL	PS	H2O	3.72	4.25	240.9	63.2	97.6	196.7	0.0	0.0	675	368	242	220	817	538	503
10.0	5	AL	PS	H2O	3.72	4.25	282.5	70.6	95.0	196.7	0.0	0.0	694	393	255	239	838	567	535
10.0	6	AL	PS	H2O	3.72	4.25	327.3	78.2	102.7	196.7	0.0	0.0	708	412	266	240	853	588	542
10.0	1	AL	PS	H2O	0.48	3.75	87.1	24.7	52.1	199.7	0.0	0.0	537	186	186	178	687	358	373
10.0	2	AL	PS	H2O	0.99	3.75	194.7	52.6	81.0	200.7	0.0	0.0	607	279	198	189	708	401	388
10.0	3	AL	PS	H2O	0.99	3.75	221.5	56.5	85.0	200.7	0.0	0.0	644	328	220	209	761	476	435
10.0	4	AL	PS	H2O	0.99	3.75	259.9	63.2	91.7	200.7	0.0	0.0	670	362	237	223	794	513	467
10.0	5	AL	PS	H2O	0.99	3.75	303.1	70.6	99.0	200.7	0.0	0.0	689	386	250	234	817	543	490
10.0	6	AL	PS	H2O	0.99	3.75	349.6	78.2	106.7	200.7	0.0	0.0	703	405	260	243	834	565	508
10.0	1	AL	U	H2O	2.11	3.47	67.6	24.7	42.0	190.4	0.0	0.0	540	190	197	189	786	464	463
10.0	2	AL	U	H2O	2.32	3.47	163.2	52.6	71.1	190.8	0.0	0.0	613	287	207	190	737	434	449
10.0	3	AL	U	H2O	2.32	3.47	188.4	56.5	75.1	190.8	0.0	0.0	652	338	232	220	794	507	498
10.0	4	AL	U	H2O	2.32	3.47	224.2	63.2	85.0	190.8	0.0	0.0	678	373	250	236	826	550	528
10.0	5	AL	U	H2O	2.32	3.47	264.3	70.6	89.1	190.8	0.0	0.0	697	398	263	247	847	578	550
10.0	6	AL	U	H2O	2.32	3.47	312.8	78.2	100.0	190.8	2.0	0.25	691	389	239	221	860	592	589
10.0	7	AL	U	H2O	2.32	3.47	324.2	78.2	100.0	190.8	2.0	0.25	719	426	253	233	905	647	618

Table A.5. Tuff Reference Design: Overpack and Canister with 6 FWS Assemblies/Package

												STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
MATERIALS				THICKNESS IN INCHES		CASK WEIGHT (KLSB)	DIMENSIONS IN INCHES						FUEL PIN	INSERT MAYL	GAMMA SHELD	CASK SURF.	FUEL PIN	INSERT MAYL	GAMMA SHELD
FUEL NO. AGE	NO. CANS	INERT CAN. SHELD	NEUT SHELD	GAM. SHELD	NEUT SHELD		ID	OD	LENGTH	FIN HT.	FIN THK.								
10.0	1	AL	PB	N20	3.37	4.25	5.8	27.8	51.5	188.7	0.0	0.0	399	171	170	165	596	378	377
10.0	2	AL	PB	N20	3.37	4.25	174.8	58.9	82.6	188.7	0.0	0.0	447	228	177	172	558	343	370
10.0	3	AL	PB	N20	3.37	4.25	196.1	63.3	87.1	188.7	0.0	0.0	475	262	193	185	596	397	405
10.0	4	AL	PB	N20	3.37	4.25	229.8	70.8	94.5	188.7	0.0	0.0	495	286	205	195	622	428	427
10.0	5	AL	PB	N20	3.37	4.25	268.8	79.1	102.8	188.7	0.0	0.0	509	303	213	203	638	449	443
10.0	6	AL	PB	N20	3.37	4.25	311.6	87.7	111.4	188.7	0.0	0.0	520	316	220	209	649	463	456
10.0	7	AL	PB	N20	3.37	4.25	316.6	87.7	111.4	188.7	0.0	0.0	543	343	232	220	686	505	479
10.0	1	AL	FB	N20	0.46	3.75	86.1	27.8	55.2	192.4	0.0	0.0	396	167	167	162	529	310	324
10.0	2	AL	FB	N20	0.46	3.75	191.0	58.9	86.3	192.4	0.0	0.0	442	225	175	169	532	324	334
10.0	3	AL	FB	N20	0.46	3.75	213.2	63.3	90.7	192.4	0.0	0.0	472	259	190	183	576	376	368
10.0	4	AL	FB	N20	0.46	3.75	248.4	70.8	98.2	192.4	0.0	0.0	491	282	201	193	603	408	392
10.0	5	AL	FB	N20	0.46	3.75	289.1	79.1	106.5	192.4	0.0	0.0	505	298	210	200	628	429	409
10.0	6	AL	FB	N20	0.46	3.75	333.7	87.7	115.1	192.4	0.0	0.0	516	312	217	206	633	445	422
10.0	7	AL	FB	N20	0.46	3.75	338.8	87.7	115.1	192.4	0.0	0.0	539	339	228	216	666	484	446
10.0	1	AL	U	N20	2.13	3.47	66.6	27.8	46.0	183.2	0.0	0.0	403	175	174	169	622	407	406
10.0	2	AL	U	N20	2.13	3.47	168.8	58.9	77.1	183.2	0.0	0.0	449	231	181	175	557	350	392
10.0	3	AL	U	N20	2.13	3.47	181.3	63.3	81.5	183.2	0.0	0.0	478	266	198	190	604	406	427
10.0	4	AL	U	N20	2.13	3.47	213.8	70.8	89.0	183.2	0.0	0.0	497	279	209	200	629	437	449
10.0	5	AL	U	N20	2.13	3.47	251.3	79.1	97.3	183.2	0.0	0.0	512	305	218	208	646	457	466
10.0	6	AL	U	N20	2.13	3.47	292.5	87.7	105.9	183.2	0.0	0.0	523	319	225	215	657	471	478
10.0	7	AL	U	N20	2.13	3.47	297.6	87.7	105.9	183.2	0.0	0.0	546	347	238	226	694	514	502
10.0	8	AL	U	N20	2.13	3.47	342.1	96.5	114.7	183.2	0.0	0.0	552	355	242	230	696	518	509

Table A.6. Tuff Reference Design: Overpack and Canister with 14 FWS Assemblies/Package

												STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
MATERIALS					THICKNESS IN INCHES		CASK WEIGHT (KLSB)	DIMENSIONS IN INCHES											
FUEL NO.	INSERT	GAM.	NEUT		GAM.	NEUT		ID	OD	LENGTH	FIN	FIN	FUEL	INSERT	GAMMA	CASK	FUEL	INSERT	GAMMA
AGE	CANS	SHELD	SHELD		SHELD	SHELD				HT.	THK.	PIN	MATL	SHELD	SURF.	PIN	MATL	SHELD	
10.0	1	AL	FB	N20	3.37	4.25	87.7	27.8	51.5	218.2	0.0	0.0	329	158	158	154	515	352	352
10.0	2	AL	FB	N20	3.37	4.25	201.6	58.9	82.6	218.2	0.0	0.0	362	197	163	159	456	299	341
10.0	3	AL	FB	N20	3.37	4.25	226.1	63.3	87.1	218.2	0.0	0.0	382	220	174	169	493	341	367
10.0	4	AL	FB	N20	3.37	4.25	264.9	70.8	94.5	218.2	0.0	0.0	396	237	182	176	513	365	385
10.0	5	AL	FB	N20	3.37	4.25	309.7	79.1	102.8	218.2	0.0	0.0	407	249	189	182	526	380	398
10.0	6	AL	FB	N20	3.37	4.25	358.8	87.7	111.4	218.2	0.0	0.0	415	258	193	186	534	390	407
10.0	1	AL	FB	N20	0.46	3.75	99.4	27.8	55.2	221.9	0.0	0.0	327	156	156	152	449	285	299
10.0	2	AL	FB	N20	0.46	3.75	219.7	58.9	86.3	221.9	0.0	0.0	360	195	161	157	438	280	305
10.0	3	AL	FB	N20	0.46	3.75	245.2	63.3	90.7	221.9	0.0	0.0	380	218	172	167	474	321	332
10.0	4	AL	FB	N20	0.46	3.75	285.7	70.8	98.2	221.9	0.0	0.0	394	234	180	174	494	345	350
10.0	5	AL	FB	N20	0.46	3.75	332.3	79.1	106.5	221.9	0.0	0.0	404	246	186	179	508	361	374
10.0	1	AL	U	N20	2.13	3.47	77.3	27.8	46.0	212.7	0.0	0.0	331	161	161	157	541	379	378
10.0	2	AL	U	N20	2.13	3.47	187.9	58.9	77.1	212.7	0.0	0.0	363	198	165	161	462	305	361
10.0	3	AL	U	N20	2.13	3.47	209.6	63.3	81.5	212.7	0.0	0.0	384	222	177	172	500	349	388
10.0	4	AL	U	N20	2.13	3.47	247.0	70.8	89.0	212.7	0.0	0.0	398	239	185	179	520	373	406
10.0	5	AL	U	N20	2.13	3.47	290.3	79.1	97.3	212.7	0.0	0.0	409	251	192	185	532	387	418
10.0	6	AL	U	N20	2.13	3.47	337.7	87.7	105.9	212.7	0.0	0.0	417	261	197	190	540	397	428

Table A.7. Tuff Reference Design; Bare Canister with 6 FW Assembly/Package

FUEL NO. AGE	CAN.	MATERIALS		THICKNESS IN INCHES		CAST	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
												FUEL PIN	INSERT MATEL	GAMMA SHLD	CASK SURF.	FUEL PIN	INSERT MATEL	GAMMA SHLD	
		INSERT SHLD	CAN. SHLD	HEUT SHLD	GAM. SHLD	HEUT SHLD	W. LGHT (KLSB)	ID	OD	LENGTH	FIN WT.	FIN THK.	FUEL PIN	INSERT MATEL	GAMMA SHLD	CASK SURF.	FUEL PIN	INSERT MATEL	GAMMA SHLD
10.0	1	AL	PS	H2O	3.62	4.25	68.6	25.0	49.3	102.7	0.0	0.0	424	174	173	167	621	305	303
10.0	2	AL	PS	H2O	3.62	4.25	154.2	53.3	77.6	102.7	0.0	0.0	477	239	181	175	584	359	378
10.0	3	AL	PS	H2O	3.62	4.25	172.4	57.4	81.6	102.7	0.0	0.0	507	276	199	190	631	417	415
10.0	4	AL	PS	H2O	3.62	4.25	201.1	64.1	88.4	102.7	0.0	0.0	528	302	211	201	659	450	439
10.0	5	AL	PS	H2O	3.62	4.25	234.2	71.6	95.9	102.7	0.0	0.0	544	321	221	209	676	473	456
10.0	6	AL	PS	H2O	3.62	4.25	270.4	79.4	103.6	102.7	0.0	0.0	555	336	229	216	689	488	470
10.0	7	AL	PS	H2O	3.62	4.25	274.8	79.4	103.6	102.7	0.0	0.0	580	365	242	227	726	532	494
10.0	8	AL	PS	H2O	3.62	4.25	313.7	87.3	111.6	102.7	0.0	0.0	587	373	247	232	729	530	502
10.0	1	AL	PS	H2O	0.05	3.75	79.0	25.0	53.2	106.7	0.0	0.0	420	170	169	164	552	313	329
10.0	2	AL	PS	H2O	0.05	3.75	170.0	53.3	81.5	106.7	0.0	0.0	474	235	170	172	56	330	341
10.0	3	AL	PS	H2O	0.05	3.75	189.8	57.4	85.6	106.7	0.0	0.0	504	272	195	187	649	393	378
10.0	4	AL	PS	H2O	0.05	3.75	219.1	64.1	92.3	106.7	0.0	0.0	524	297	205	197	637	427	403
10.0	5	AL	PS	H2O	0.05	3.75	253.7	71.6	99.0	106.7	0.0	0.0	539	316	217	206	656	451	421
10.0	6	AL	PS	H2O	0.05	3.75	291.5	79.4	107.6	106.7	0.0	0.0	551	330	224	212	670	468	436
10.0	7	AL	PS	H2O	0.05	3.75	296.1	79.4	107.6	106.7	0.0	0.0	575	359	237	223	704	509	460
10.0	8	AL	PS	H2O	0.05	3.75	336.7	87.3	115.5	106.7	0.0	0.0	582	368	242	227	710	517	469
10.0	1	AL	U	H2O	2.27	3.47	59.5	25.0	43.5	177.0	0.0	0.0	427	179	178	172	649	414	413
10.0	2	AL	U	H2O	2.27	3.47	140.6	53.3	71.0	177.0	0.0	0.0	479	242	185	179	591	360	400
10.0	3	AL	U	H2O	2.27	3.47	150.1	57.4	75.9	177.0	0.0	0.0	510	287	204	195	640	427	438
10.0	4	AL	U	H2O	2.27	3.47	185.7	64.1	82.6	177.0	0.0	0.0	531	306	217	207	668	461	462
10.0	5	AL	U	H2O	2.27	3.47	217.4	71.6	90.1	177.0	0.0	0.0	547	325	227	216	685	482	479
10.0	6	AL	U	H2O	2.27	3.47	252.2	79.4	97.9	177.0	0.0	0.0	558	339	234	222	696	497	493
10.0	7	AL	U	H2O	2.27	3.47	256.7	79.4	97.9	177.0	0.0	0.0	583	369	248	234	735	542	510
10.0	8	AL	U	H2O	2.27	3.47	294.1	87.3	105.0	177.0	0.0	0.0	590	377	253	239	737	547	525
10.0	9	AL	U	H2O	2.27	3.47	334.0	95.4	113.9	177.0	0.0	0.0	595	384	257	243	740	550	532

Table A.8. Tuff Reference Design; Bare Canister with 14 FW Assembly/Package

FUEL NO. AGE	CAN.	MATERIALS		THICKNESS IN INCHES		CASK WEIGHT (KILBS)	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
												FUEL PIN	INSERT MATL	GAMMA SHLD	CASK SURF.	FUEL PIN	INSERT MATL	GAMMA SHLD	
		HEUT SHLD	GAM. SHLD	ID	OD	LENGTH	FIN WT.	PIN THK.	PIN	MATL	SHLD	SURF.	PIN	MATL	SHLD				
10.0	1	AL	PS	H2O	3.62	4.25	74.9	25.0	49.3	196.5	0.0	0.0	351	162	161	157	539	359	350
10.0	2	AL	PS	H2O	3.62	4.25	167.8	53.3	77.6	196.5	0.0	0.0	391	209	168	163	489	317	349
10.0	3	AL	PS	H2O	3.62	4.25	180.4	57.4	81.6	196.5	0.0	0.0	414	237	181	175	529	363	378
10.0	4	AL	PS	H2O	3.62	4.25	220.3	64.1	88.4	196.5	0.0	0.0	430	256	190	183	551	390	397
10.0	5	AL	PS	H2O	3.62	4.25	256.8	71.6	95.9	196.5	0.0	0.0	443	271	198	189	565	407	412
10.0	6	AL	PS	H2O	3.62	4.25	296.6	79.4	103.0	196.5	0.0	0.0	452	282	204	195	575	419	422
10.0	7	AL	PS	H2O	3.62	4.25	302.6	79.4	103.6	196.5	0.0	0.0	471	304	213	203	607	456	443
10.0	8	AL	PS	H2O	3.62	4.25	345.3	87.3	111.6	196.5	0.0	0.0	476	311	217	207	609	460	449
10.0	1	AL	PS	H2O	0.05	3.75	85.9	25.0	53.2	200.5	0.0	0.0	349	159	159	155	471	289	305
10.0	2	AL	PS	H2O	0.05	3.75	184.5	53.3	81.5	200.5	0.0	0.0	389	207	166	161	470	296	312
10.0	3	AL	PS	H2O	0.05	3.75	206.0	57.4	85.6	200.5	0.0	0.0	411	234	170	172	508	341	382
10.0	4	AL	PS	H2O	0.05	3.75	239.3	64.1	92.3	200.5	0.0	0.0	427	253	187	180	530	368	362
10.0	5	AL	PS	H2O	0.05	3.75	277.4	71.6	99.0	200.5	0.0	0.0	439	267	195	186	546	386	377
10.0	6	AL	PS	H2O	0.05	3.75	319.0	79.4	107.6	200.5	0.0	0.0	449	278	200	192	557	400	389
10.0	7	AL	PS	H2O	0.05	3.75	324.9	79.4	107.6	200.5	0.0	0.0	467	300	210	200	586	433	409
10.0	1	AL	U	H2O	2.27	3.47	65.3	25.0	43.5	190.7	0.0	0.0	354	166	165	161	565	386	386
10.0	2	AL	U	H2O	2.27	3.47	153.4	53.3	71.0	190.7	0.0	0.0	393	211	171	166	494	324	369
10.0	3	AL	U	H2O	2.27	3.47	173.3	57.4	75.9	190.7	0.0	0.0	417	240	185	179	537	372	400
10.0	4	AL	U	H2O	2.27	3.47	204.0	64.1	82.6	190.7	0.0	0.0	433	260	195	187	560	399	419
10.0	5	AL	U	H2O	2.27	3.47	239.1	71.6	90.1	190.7	0.0	0.0	445	274	202	194	573	416	433
10.0	6	AL	U	H2O	2.27	3.47	277.5	79.4	97.9	190.7	0.0	0.0	454	285	208	199	582	427	444
10.0	7	AL	U	H2O	2.27	3.47	283.4	79.4	97.9	190.7	0.0	0.0	474	308	218	200	615	465	465
10.0	8	AL	U	H2O	2.27	3.47	324.6	87.3	105.0	190.7	0.0	0.0	479	314	222	212	616	468	471

Table A.9. Basalt Reference Design; Overpack Only, with 4 PWR Assemblies/Package

FUEL NO.	AGE	MATERIALS		THICKNESS		CASE	DIMENSIONS					STEADY STATE				MAX FIRE-TEST			
				IN INCHES			IN INCHES					TEMPERATURES				TEMPERATURES			
		INSRT	GAM.	WEVT	GAM.	WEVT	WEIGHT	ID	OD	LENGTH	PIN	PIN	FUEL	INSRT	GAMMA	CASE	FUEL	INSRT	GAMMA
CASES	SHELD	SHELD	SHELD	SHELD	(LBS)				HT.	THR.	PIN	MATL	SHELD	SHELD	SHELD	PIN	MATL	SHELD	
10.0	1	AL	PS	H2O	1.00	4.25	40.0	20.0	40.6	101.1	0.0	0.0	434	166	165	161	649	393	392
10.0	2	AL	PS	H2O	1.00	4.25	109.0	43.3	63.9	101.1	0.0	0.0	478	220	173	160	507	343	376
10.0	3	AL	PS	H2O	1.00	4.25	127.0	46.6	67.2	101.1	0.0	0.0	503	252	107	101	629	393	400
10.0	4	AL	PS	H2O	1.00	4.25	153.0	52.1	72.7	101.1	0.0	0.0	520	273	190	190	652	422	429
10.0	5	AL	PS	H2O	1.00	4.25	180.9	58.1	70.7	101.1	0.0	0.0	533	289	206	190	666	441	444
10.0	6	AL	PS	H2O	1.00	4.25	210.6	64.4	65.0	101.1	0.0	0.0	543	302	213	204	675	454	455
10.0	7	AL	PS	H2O	1.00	4.25	221.1	64.4	65.0	101.1	0.0	0.0	563	326	224	213	700	493	477
10.0	8	AL	PS	H2O	1.00	4.25	252.5	70.0	91.4	101.1	0.0	0.0	569	334	220	217	710	497	484
10.0	9	AL	PS	H2O	1.00	4.25	285.5	77.3	97.9	101.1	0.0	0.0	574	340	232	221	711	500	490
10.0	10	AL	PS	H2O	1.00	4.25	310.2	81.2	101.0	101.1	0.0	0.0	582	350	237	226	721	512	499
10.0	11	AL	PS	H2O	1.00	4.25	330.1	83.0	104.4	101.1	0.0	0.0	592	363	244	231	735	529	510
10.0	1	AL	FE	H2O	5.90	3.75	53.3	20.0	42.5	102.9	0.0	0.0	432	164	164	160	590	333	333
10.0	2	AL	FE	H2O	5.90	3.75	116.2	43.3	65.0	102.9	0.0	0.0	476	210	171	167	573	327	334
10.0	3	AL	FE	H2O	5.90	3.75	135.5	46.6	69.1	102.9	0.0	0.0	501	249	186	179	612	376	367
10.0	4	AL	FE	H2O	5.90	3.75	161.3	52.1	74.5	102.9	0.0	0.0	510	270	196	189	635	405	380
10.0	5	AL	FE	H2O	5.90	3.75	189.9	58.1	68.6	102.9	0.0	0.0	530	286	204	196	651	424	405
10.0	6	AL	FE	H2O	5.90	3.75	229.5	64.4	66.9	102.9	0.0	0.0	540	290	211	202	661	430	417
10.0	7	AL	FE	H2O	5.90	3.75	231.0	64.4	66.9	102.9	0.0	0.0	560	322	221	211	691	475	439
10.0	8	AL	FE	H2O	5.90	3.75	263.2	70.0	93.3	102.9	0.0	0.0	566	330	226	215	696	481	447
10.0	9	AL	FE	H2O	5.90	3.75	297.0	77.3	99.0	102.9	0.0	0.0	570	336	229	219	699	486	454
10.0	10	AL	FE	H2O	5.90	3.75	322.3	81.2	103.7	102.9	0.0	0.0	579	346	235	223	709	499	464
10.0	1	AL	U	H2O	1.26	3.47	44.1	20.0	36.5	176.9	0.0	0.0	437	170	169	165	677	423	423
10.0	2	AL	U	H2O	1.26	3.47	102.0	43.3	59.0	176.9	0.0	0.0	479	223	176	171	594	350	399
10.0	3	AL	U	H2O	1.26	3.47	120.5	46.6	63.1	176.9	0.0	0.0	505	255	191	185	637	403	432
10.0	4	AL	U	H2O	1.26	3.47	145.2	52.1	60.5	176.9	0.0	0.0	523	276	202	195	660	432	453
10.0	5	AL	U	H2O	1.26	3.47	172.4	58.1	74.6	176.9	0.0	0.0	535	292	211	202	673	449	460
10.0	6	AL	U	H2O	1.26	3.47	201.4	64.4	60.9	176.9	0.0	0.0	545	305	217	200	682	461	479
10.0	7	AL	U	H2O	1.26	3.47	211.9	64.4	60.9	176.9	0.0	0.0	565	329	229	210	716	502	501
10.0	8	AL	U	H2O	1.26	3.47	242.6	70.0	67.3	176.9	0.0	0.0	571	337	233	222	717	505	500
10.0	9	AL	U	H2O	1.26	3.47	274.0	77.3	93.0	176.9	0.0	0.0	576	343	237	226	710	507	514
10.0	10	AL	U	H2O	1.26	3.47	299.1	81.2	97.7	176.9	0.0	0.0	584	353	242	230	727	519	523
10.0	11	AL	U	H2O	1.26	3.47	310.7	83.0	100.2	176.9	0.0	0.0	595	366	249	236	741	536	534
10.0	12	AL	U	H2O	1.26	3.47	339.7	86.6	103.1	176.9	0.0	0.0	604	377	254	241	752	550	543

Table A.10. Basalt Reference Design: Overpack Only, with 9 SWH Assemblies/Package

FUEL NO. ATB		MATERIALS			THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES				STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
												FUEL				MAX FIRE-TEST			
		INSERT	CAN.	HEUT	CAN.	HEUT		ID	OD	LENGTH	FIN	FIN	PIN	INSERT	CANNA	CASE	FUEL	INSERT	CANNA
CANS	SHLD	SHLD	SHLD	SHLD	SHLD				WT.	THK.				SURF.	PIN	MATL	SHLD		
10.0	1	AL	FE	H2O	1.00	0.25	52.2	20.0	40.6	190.0	0.0	0.0	353	156	155	152	557	369	368
10.0	2	AL	FE	H2O	1.00	0.25	116.5	43.3	63.9	190.0	0.0	0.0	303	193	161	157	405	303	309
10.0	3	AL	FE	H2O	1.00	0.25	136.4	46.6	67.2	190.0	0.0	0.0	402	216	171	167	519	343	373
10.0	4	AL	FE	H2O	1.00	0.25	163.1	52.1	72.7	190.0	0.0	0.0	415	232	179	174	537	365	309
10.0	5	AL	FE	H2O	1.00	0.25	192.7	58.1	78.7	190.0	0.0	0.0	425	243	185	179	548	379	401
10.0	6	AL	FE	H2O	1.00	0.25	224.3	64.4	85.0	190.0	0.0	0.0	433	252	190	183	554	388	409
10.0	7	AL	FE	H2O	1.00	0.25	235.2	64.4	85.0	190.0	0.0	0.0	440	271	190	190	503	421	427
10.0	8	AL	FE	H2O	1.00	0.25	268.6	70.8	91.4	190.0	0.0	0.0	452	276	201	193	503	422	433
10.0	9	AL	FE	H2O	1.00	0.25	303.6	77.3	97.9	190.0	0.0	0.0	456	281	204	196	503	423	437
10.0	10	AL	FE	H2O	1.00	0.25	329.0	81.2	101.0	190.0	0.0	0.0	463	289	200	200	590	433	445
10.0	1	AL	FE	H2O	5.90	3.75	57.0	20.0	42.5	196.7	0.0	0.0	351	150	154	151	499	310	310
10.0	2	AL	FE	H2O	5.90	3.75	124.2	43.3	65.0	196.7	0.0	0.0	302	192	160	156	471	289	307
10.0	3	AL	FE	H2O	5.90	3.75	144.5	46.6	69.1	196.7	0.0	0.0	401	214	170	165	503	326	331
10.0	4	AL	FE	H2O	5.90	3.75	171.9	52.1	74.5	196.7	0.0	0.0	413	229	177	172	521	349	348
10.0	5	AL	FE	H2O	5.90	3.75	202.3	58.1	80.6	196.7	0.0	0.0	423	241	183	170	533	363	361
10.0	6	AL	FE	H2O	5.90	3.75	234.7	64.4	86.9	196.7	0.0	0.0	431	250	180	182	544	373	371
10.0	7	AL	FE	H2O	5.90	3.75	245.7	64.4	86.9	196.7	0.0	0.0	445	260	196	189	566	403	389
10.0	8	AL	FE	H2O	5.90	3.75	279.9	70.8	93.3	196.7	0.0	0.0	450	273	199	192	569	407	395
10.0	9	AL	FE	H2O	5.90	3.75	315.0	77.3	99.0	196.7	0.0	0.0	454	278	202	195	570	410	400
10.0	1	AL	U	H2O	1.26	3.47	47.2	20.0	36.5	190.7	0.0	0.0	354	150	150	155	505	397	397
10.0	2	AL	U	H2O	1.26	3.47	109.1	43.3	59.0	190.7	0.0	0.0	305	195	163	159	491	310	371
10.0	3	AL	U	H2O	1.26	3.47	120.7	46.6	63.1	190.7	0.0	0.0	404	210	174	169	527	351	396
10.0	4	AL	U	H2O	1.26	3.47	150.8	52.1	68.5	190.7	0.0	0.0	417	234	182	176	544	373	412
10.0	5	AL	U	H2O	1.26	3.47	183.7	58.1	74.6	190.7	0.0	0.0	427	246	180	182	554	386	423
10.0	6	AL	U	H2O	1.26	3.47	214.5	64.4	80.9	190.7	0.0	0.0	435	255	193	187	560	395	432
10.0	7	AL	U	H2O	1.26	3.47	225.5	64.4	80.9	190.7	0.0	0.0	450	273	202	194	590	429	450
10.0	8	AL	U	H2O	1.26	3.47	250.1	70.8	87.3	190.7	0.0	0.0	454	279	205	197	589	430	456
10.0	9	AL	U	H2O	1.26	3.47	292.3	77.3	93.0	190.7	0.0	0.0	458	283	200	200	580	430	459
10.0	10	AL	U	H2O	1.26	3.47	310.1	81.2	97.7	190.7	0.0	0.0	465	291	212	203	596	439	467
10.0	11	AL	U	H2O	1.26	3.47	330.0	83.0	100.2	190.7	0.0	0.0	473	301	216	207	607	453	476

Table A.11. Basalt Reference Design; Canister Only, with 1 PWR Assembly/Package

FUEL NO. AGE		MATERIALS		THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES					STEADY STATE TEMPERATURES IN DEG. F				MAX FIRE-TEST TEMPERATURES IN DEG. F			
							ID	OD	LENGTH	FIN WT.	FIN THK.	FUEL FIN	INERT MATH	CANNA SILD	CASE SUPT.	FUEL FIN	INERT MATH	CANNA SILD	
10.0	32	AL	PS	H2O	4.02	4.25	198.1	54.6	79.6	103.5	0.0	0.0	491	371	241	226	641	539	499
10.0	33	AL	PS	H2O	4.02	4.25	195.4	55.0	80.0	103.5	0.0	0.0	493	373	243	227	642	540	501
10.0	34	AL	PS	H2O	4.02	4.25	198.2	56.3	81.3	103.5	0.0	0.0	496	377	245	229	647	546	505
10.0	35	AL	PS	H2O	4.02	4.25	202.2	57.1	82.1	103.5	0.0	0.0	499	381	247	231	650	550	508
10.0	36	AL	PS	H2O	4.02	4.25	207.3	58.2	83.3	103.5	0.0	0.0	501	383	248	232	651	552	510
10.0	37	AL	PS	H2O	4.02	4.25	208.4	58.2	83.3	103.5	0.0	0.0	506	388	251	234	650	559	515
10.0	38	AL	PS	H2O	4.02	4.25	211.4	58.9	83.9	103.5	0.0	0.0	509	392	252	236	662	564	518
10.0	39	AL	PS	H2O	4.02	4.25	215.8	59.7	84.7	103.5	0.0	0.0	511	394	254	237	664	567	520
10.0	40	AL	PS	H2O	4.02	4.25	220.7	60.4	85.0	103.5	0.0	0.0	512	396	255	238	666	568	522
10.0	55	AL	PS	H2O	4.02	4.25	269.8	68.1	97.1	103.5	2.0	0.25	532	419	245	224	716	625	503
10.0	56	AL	PS	H2O	4.02	4.25	292.0	73.0	102.0	103.5	2.0	0.25	522	408	242	221	690	605	575
10.0	57	AL	PS	H2O	4.02	4.25	296.2	74.0	103.0	103.5	2.0	0.25	523	409	242	222	690	606	576
10.0	58	AL	PS	H2O	4.02	4.25	297.2	74.0	103.0	103.5	2.0	0.25	527	413	244	223	703	611	579
10.0	59	AL	PS	H2O	4.02	4.25	298.3	74.0	103.0	103.5	2.0	0.25	530	417	245	224	708	617	583
10.0	60	AL	PS	H2O	4.02	4.25	299.3	74.0	103.0	103.5	2.0	0.25	533	421	247	226	713	622	586
10.0	61	AL	PS	H2O	4.02	4.25	302.5	74.5	103.5	103.5	2.0	0.25	535	423	248	226	715	625	588
10.0	62	AL	PS	H2O	4.02	4.25	306.4	75.2	104.2	103.5	2.0	0.25	537	425	249	227	717	627	589
10.0	63	AL	PS	H2O	4.02	4.25	307.5	75.2	104.2	103.5	2.0	0.25	540	429	250	228	722	633	592
10.0	64	AL	PS	H2O	4.02	4.25	312.0	76.0	105.1	103.5	2.0	0.25	541	431	251	229	723	634	594
10.0	65	AL	PS	H2O	4.02	4.25	315.3	76.5	105.6	103.5	2.0	0.25	543	433	252	230	725	636	596
10.0	66	AL	PS	H2O	4.02	4.25	319.1	77.2	106.2	103.5	2.0	0.25	545	435	253	230	727	639	597
10.0	67	AL	PS	H2O	4.02	4.25	320.1	77.2	106.2	103.5	2.0	0.25	549	439	255	232	731	643	600
10.0	27	AL	PS	H2O	9.39	3.75	106.2	58.4	79.6	107.0	0.0	0.0	470	346	226	213	587	489	444
10.0	28	AL	PS	H2O	9.39	3.75	109.9	51.1	80.4	107.0	0.0	0.0	473	350	228	214	601	494	448
10.0	29	AL	PS	H2O	9.39	3.75	194.2	52.0	81.3	107.0	0.0	0.0	476	354	230	216	605	499	451
10.0	30	AL	PS	H2O	9.39	3.75	196.9	52.5	81.7	107.0	0.0	0.0	480	358	232	218	610	505	456
10.0	31	AL	PS	H2O	9.39	3.75	197.9	52.5	81.7	107.0	0.0	0.0	486	365	235	220	617	514	461
10.0	32	AL	PS	H2O	9.39	3.75	206.7	54.6	83.8	107.0	0.0	0.0	485	364	235	221	616	512	461
10.0	33	AL	PS	H2O	9.39	3.75	212.3	55.0	85.1	107.0	0.0	0.0	487	366	237	222	618	514	464
10.0	34	AL	PS	H2O	9.39	3.75	215.1	56.3	85.6	107.0	0.0	0.0	490	370	239	224	622	519	468
10.0	35	AL	PS	H2O	9.39	3.75	219.2	57.1	86.4	107.0	0.0	0.0	493	373	240	225	626	523	471
10.0	50	AL	PS	H2O	9.39	3.75	275.9	67.4	96.7	107.0	0.0	0.0	530	417	243	245	671	577	511
10.0	51	AL	PS	H2O	9.39	3.75	279.6	68.1	97.4	107.0	0.0	0.0	532	420	245	246	674	580	513
10.0	52	AL	PS	H2O	9.39	3.75	280.7	68.1	97.4	107.0	0.0	0.0	536	425	247	248	679	586	517
10.0	53	AL	PS	H2O	9.39	3.75	281.7	68.1	97.4	107.0	0.0	0.0	540	429	249	250	684	592	521
10.0	54	AL	PS	H2O	9.39	3.75	280.0	68.1	101.4	107.0	2.0	0.25	522	400	230	210	604	591	530
10.0	55	AL	PS	H2O	9.39	3.75	289.1	68.1	101.4	107.0	2.0	0.25	526	412	239	219	609	596	541
10.0	56	AL	PS	H2O	9.39	3.75	285.6	73.0	102.2	107.0	0.0	0.0	539	427	249	250	680	580	521
10.0	57	AL	PS	H2O	9.39	3.75	316.7	74.0	107.3	107.0	2.0	0.25	510	403	237	217	676	581	535
10.0	58	AL	PS	H2O	9.39	3.75	317.7	74.0	107.3	107.0	2.0	0.25	521	407	238	219	680	587	538
10.0	59	AL	PS	H2O	9.39	3.75	318.8	74.0	107.3	107.0	2.0	0.25	525	410	240	220	685	592	542
10.0	60	AL	PS	H2O	9.39	3.75	319.0	74.0	107.3	107.0	2.0	0.25	528	414	242	221	689	597	545
10.0	61	AL	PS	H2O	9.39	3.75	323.1	74.5	107.0	107.0	2.0	0.25	530	417	243	222	692	600	547
10.0	62	AL	PS	H2O	9.39	3.75	327.2	75.3	108.5	107.0	2.0	0.25	531	419	244	223	694	602	549
10.0	35	AL	U	H2O	2.52	3.47	187.3	57.1	76.1	177.5	0.0	0.0	504	386	255	240	661	562	534
10.0	36	AL	U	H2O	2.52	3.47	192.2	58.2	77.2	177.5	0.0	0.0	505	388	256	241	662	564	535
10.0	37	AL	U	H2O	2.52	3.47	193.2	58.2	77.2	177.5	0.0	0.0	510	394	259	243	660	572	540
10.0	38	AL	U	H2O	2.52	3.47	196.5	58.9	77.9	177.5	0.0	0.0	513	397	261	245	673	576	543
10.0	39	AL	U	H2O	2.52	3.47	200.4	59.7	78.7	177.5	0.0	0.0	516	400	263	246	675	579	546
10.0	40	AL	U	H2O	2.52	3.47	205.2	60.0	79.7	177.5	0.0	0.0	517	402	264	247	677	581	548
10.0	41	AL	U	H2O	2.52	3.47	208.5	61.4	80.4	177.5	0.0	0.0	520	405	265	249	680	584	550
10.0	42	AL	U	H2O	2.52	3.47	214.7	61.7	84.7	177.5	2.0	0.25	501	383	234	216	603	586	576
10.0	43	AL	U	H2O	2.52	3.47	221.1	63.2	86.2	177.5	2.0	0.25	501	383	234	217	602	585	577
10.0	63	AL	U	H2O	2.52	3.47	207.3	75.2	98.2	177.5	2.0	0.25	540	420	255	234	726	637	615
10.0	63	AL	U	H2O	2.52	3.47	208.3	75.2	98.2	177.5	2.0	0.25	543	422	257	236	731	642	618
10.0	64	AL	U	H2O	2.52	3.47	202.7	76.0	99.0	177.5	2.0	0.25	544	423	257	236	731	643	619
10.0	65	AL	U	H2O	2.52	3.47	205.9	76.5	99.5	177.5	2.0	0.25	546	426	258	237	733	646	621
10.0	66	AL	U	H2O	2.52	3.47	209.5	77.2	100.1	177.5	2.0	0.25	547	428	259	238	735	648	623
10.0	67	AL	U	H2O	2.52	3.47	200.6	77.2	100.1	177.5	2.0	0.25	551	441	261	239	740	653	625
10.0	68	AL	U	H2O	2.52	3.47	201.6	77.2	100.1	177.5	2.0	0.25	554	445	262	240	744	658	628
10.0	69	AL	U	H2O	2.52	3.47	202.7	77.2	100.1	177.5	2.0	0.25	557	448	264	241	749	661	631
10.0	70	AL	U	H2O	2.52	3.47	213.3	79.5	102.5	177.5	2.0	0.25	554	445	263	241	743	656	629
10.0	71	AL	U	H2O	2.52	3.47	210.1	80.4	103.3	177.5	2.0	0.25	555	446	263	241	743	657	630
10.0	72	AL	U	H2O	2.52	3.47	219.1	80.4	103.3	177.5	2.0	0.25	558	450	265	242	747	662	633
10.0	73	AL	U	H2O	2.52	3.47	220.2	80.4	103.3	177.5	2.0	0.25	561	454	267	244	752	667	635

Table A.12. Basalt Reference Design: Canister Only, with 2 SWB Assemblies/Package

FUEL NO. AGE	CAN.	MATERIALS			THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES				STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
		INSERT	GAM. SHLD	HEWT SHLD	GAM. SHLD	HEWT SHLD		ID	OD	LENGTH	PIN ST.	PIN THK.	FUEL PIN	INSERT MATL	GAMMA SHLD	CASE SURF.	FUEL PIN	INSERT MATL	GAMMA SHLD
10.0	28	AL	PS	H2O	4.02	4.25	185.9	51.1	76.2	197.3	0.0	0.0	362	278	198	189	494	421	417
10.0	29	AL	PS	H2O	4.02	4.25	190.3	52.0	77.1	197.3	0.0	0.0	364	280	200	191	497	424	420
10.0	30	AL	PS	H2O	4.02	4.25	193.0	52.5	77.5	197.3	0.0	0.0	367	284	201	192	501	429	423
10.0	31	AL	PS	H2O	4.02	4.25	194.1	52.5	77.5	197.3	0.0	0.0	371	288	203	194	507	436	427
10.0	32	AL	PS	H2O	4.02	4.25	203.0	54.6	79.6	197.3	0.0	0.0	370	288	204	194	504	433	427
10.0	33	AL	PS	H2O	4.02	4.25	200.7	55.0	80.8	197.3	0.0	0.0	372	289	204	195	505	434	428
10.0	34	AL	PS	H2O	4.02	4.25	211.6	56.3	81.3	197.3	0.0	0.0	374	292	206	196	509	438	431
10.0	35	AL	PS	H2O	4.02	4.25	215.8	57.1	82.1	197.3	0.0	0.0	376	295	207	197	511	441	433
10.0	36	AL	PS	H2O	4.02	4.25	221.3	58.2	83.3	197.3	0.0	0.0	378	296	208	198	512	442	435
10.0	54	AL	PS	H2O	4.02	4.25	280.0	68.1	93.1	197.3	0.0	0.0	414	337	228	216	559	496	473
10.0	55	AL	PS	H2O	4.02	4.25	281.9	68.1	93.1	197.3	0.0	0.0	417	341	230	217	564	501	476
10.0	56	AL	PS	H2O	4.02	4.25	284.1	73.0	98.0	197.3	0.0	0.0	410	333	227	215	549	485	470
10.0	57	AL	PS	H2O	4.02	4.25	289.7	74.0	99.0	197.3	0.0	0.0	410	334	228	215	550	486	471
10.0	58	AL	PS	H2O	4.02	4.25	310.0	74.0	99.0	197.3	0.0	0.0	413	337	229	216	554	490	473
10.0	59	AL	PS	H2O	4.02	4.25	311.9	74.0	99.0	197.3	0.0	0.0	416	339	231	217	558	494	476
10.0	60	AL	PS	H2O	4.02	4.25	313.0	74.0	99.0	197.3	0.0	0.0	418	342	232	219	561	499	479
10.0	61	AL	PS	H2O	4.02	4.25	316.3	74.5	99.5	197.3	0.0	0.0	420	344	233	219	563	501	480
10.0	62	AL	PS	H2O	4.02	4.25	320.5	75.2	100.2	197.3	0.0	0.0	421	346	234	220	565	502	482
10.0	63	AL	PS	H2O	4.02	4.25	321.5	75.2	100.2	197.3	0.0	0.0	424	348	235	221	568	507	484
10.0	64	AL	PS	H2O	4.02	4.25	326.4	76.6	101.1	197.3	0.0	0.0	424	350	235	222	569	508	485
10.0	24	AL	PS	H2O	9.39	3.75	185.9	47.0	77.1	201.5	0.0	0.0	348	262	189	181	456	380	368
10.0	25	AL	PS	H2O	9.39	3.75	189.7	48.5	77.8	201.5	0.0	0.0	350	265	190	182	460	385	371
10.0	26	AL	PS	H2O	9.39	3.75	194.2	49.4	78.7	201.5	0.0	0.0	353	268	192	184	463	389	374
10.0	27	AL	PS	H2O	9.39	3.75	190.7	50.4	79.6	201.5	0.0	0.0	355	270	193	185	466	392	377
10.0	28	AL	PS	H2O	9.39	3.75	202.7	51.1	80.4	201.5	0.0	0.0	358	273	194	186	470	396	380
10.0	29	AL	PS	H2O	9.39	3.75	207.3	52.0	81.3	201.5	0.0	0.0	360	276	196	187	473	399	383
10.0	30	AL	PS	H2O	9.39	3.75	210.1	52.5	81.7	201.5	0.0	0.0	363	279	197	188	477	404	386
10.0	31	AL	PS	H2O	9.39	3.75	211.2	52.5	81.7	201.5	0.0	0.0	366	283	199	190	482	410	390
10.0	32	AL	PS	H2O	9.39	3.75	220.5	54.6	83.8	201.5	0.0	0.0	366	283	200	190	481	409	390
10.0	46	AL	PS	H2O	9.39	3.75	278.2	64.8	94.1	201.5	0.0	0.0	392	313	215	203	515	447	421
10.0	47	AL	PS	H2O	9.39	3.75	283.2	65.7	95.0	201.5	0.0	0.0	393	314	215	204	516	449	422
10.0	48	AL	PS	H2O	9.39	3.75	287.1	66.4	95.6	201.5	0.0	0.0	395	316	216	205	518	451	424
10.0	49	AL	PS	H2O	9.39	3.75	289.3	66.6	95.9	201.5	0.0	0.0	398	319	218	206	522	455	427
10.0	50	AL	PS	H2O	9.39	3.75	294.0	67.4	96.7	201.5	0.0	0.0	399	320	219	207	523	457	428
10.0	51	AL	PS	H2O	9.39	3.75	298.0	68.1	97.4	201.5	0.0	0.0	400	322	219	208	525	459	430
10.0	52	AL	PS	H2O	9.39	3.75	299.0	68.1	97.4	201.5	0.0	0.0	403	325	221	209	529	464	433
10.0	53	AL	PS	H2O	9.39	3.75	300.1	68.1	97.4	201.5	0.0	0.0	406	328	222	210	533	468	436
10.0	54	AL	PS	H2O	9.39	3.75	301.2	68.1	97.4	201.5	0.0	0.0	409	332	224	211	537	473	439
10.0	55	AL	PS	H2O	9.39	3.75	302.3	68.1	97.4	201.5	0.0	0.0	411	335	225	212	541	477	441
10.0	56	AL	PS	H2O	9.39	3.75	325.5	73.0	102.2	201.5	0.0	0.0	405	327	223	210	529	464	436
10.0	32	AL	U	H2O	2.52	3.47	187.7	54.6	73.5	191.2	0.0	0.0	378	292	209	200	514	444	450
10.0	33	AL	U	H2O	2.52	3.47	193.2	55.0	74.8	191.2	0.0	0.0	375	293	210	201	515	445	451
10.0	34	AL	U	H2O	2.52	3.47	196.0	56.3	75.3	191.2	0.0	0.0	378	296	212	202	519	449	454
10.0	35	AL	U	H2O	2.52	3.47	200.1	57.1	76.1	191.2	0.0	0.0	380	299	213	203	521	452	456
10.0	36	AL	U	H2O	2.52	3.47	205.4	58.2	77.2	191.2	0.0	0.0	381	300	214	204	521	453	458
10.0	37	AL	U	H2O	2.52	3.47	206.5	58.2	77.2	191.2	0.0	0.0	384	304	216	205	527	459	461
10.0	38	AL	U	H2O	2.52	3.47	210.0	59.9	77.9	191.2	0.0	0.0	387	306	217	207	530	462	464
10.0	39	AL	U	H2O	2.52	3.47	214.1	59.7	78.7	191.2	0.0	0.0	388	308	218	207	532	464	466
10.0	40	AL	U	H2O	2.52	3.47	219.2	60.0	79.7	191.2	0.0	0.0	390	310	219	208	533	465	467
10.0	41	AL	U	H2O	2.52	3.47	222.7	61.4	80.4	191.2	0.0	0.0	391	312	220	209	535	468	469
10.0	55	AL	U	H2O	2.52	3.47	264.2	68.1	87.1	191.2	0.0	0.0	420	345	237	224	573	511	500
10.0	56	AL	U	H2O	2.52	3.47	265.4	73.0	91.9	191.2	0.0	0.0	413	337	233	221	558	495	492
10.0	57	AL	U	H2O	2.52	3.47	298.9	78.0	93.0	191.2	0.0	0.0	418	338	234	222	558	495	493
10.0	58	AL	U	H2O	2.52	3.47	292.0	74.0	93.0	191.2	0.0	0.0	417	341	235	223	562	500	496
10.0	59	AL	U	H2O	2.52	3.47	293.1	71.0	93.0	191.2	0.0	0.0	419	344	237	224	566	504	499
10.0	60	AL	U	H2O	2.52	3.47	294.2	74.0	93.0	191.2	0.0	0.0	422	347	238	225	570	508	501
10.0	61	AL	U	H2O	2.52	3.47	297.4	74.5	93.5	191.2	0.0	0.0	424	349	239	226	572	511	503
10.0	62	AL	U	H2O	2.52	3.47	301.4	75.2	94.2	191.2	0.0	0.0	425	350	240	227	574	512	504
10.0	63	AL	U	H2O	2.52	3.47	302.5	75.2	94.2	191.2	0.0	0.0	427	353	241	228	577	516	507
10.0	64	AL	U	H2O	2.52	3.47	307.2	76.0	95.0	191.2	0.0	0.0	428	354	242	229	578	517	508
10.0	65	AL	U	H2O	2.52	3.47	310.5	76.5	95.5	191.2	0.0	0.0	430	355	243	229	580	519	509
10.0	66	AL	U	H2O	2.52	3.47	314.3	77.2	96.1	191.2	0.0	0.0	431	357	244	230	581	521	511
10.0	67	AL	U	H2O	2.52	3.47	315.4	77.2	96.1	191.2	0.0	0.0	433	360	245	231	585	525	513
10.0	68	AL	U	H2O	2.52	3.47	316.5	77.2	96.1	191.2	0.0	0.0	436	363	246	232	589	529	516
10.0	69	AL	U	H2O	2.52	3.47	317.6	77.2	96.1	191.2	0.0	0.0	438	365	248	234	592	533	518
10.0	70</																		

Table A.13. Basalt Reference Design: Canister Only, with 2 PWR Assemblies/Package

FUEL NO. AGE		MATERIALS			THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES				STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
		INSERT	CAN.	HEUT	GAM.	HEUT		ID	OD	LENGTH	FIN HT.	FIN THK.	FUEL FIN	INSERT MATL	CAN. GILD	CASE SUPT.	FUEL FIN	INSERT MATL	CAN. GILD
10.0	17	AL	PB	H2O	4.02	4.25	103.5	51.9	77.0	103.5	0.0	0.0	565	391	250	234	716	565	517
10.0	18	AL	PB	H2O	4.02	4.25	190.5	53.3	70.4	103.5	0.0	0.0	570	390	254	237	723	574	523
10.0	19	AL	PB	H2O	4.02	4.25	192.6	53.3	70.4	103.5	0.0	0.0	580	410	259	241	736	590	532
10.0	20	AL	PB	H2O	4.02	4.25	201.2	55.2	60.3	103.5	0.0	0.0	584	415	262	244	739	594	537
10.0	21	AL	PB	H2O	4.02	4.25	207.9	56.5	61.6	103.5	0.0	0.0	589	421	265	247	745	601	542
10.0	22	AL	PB	H2O	4.02	4.25	217.1	58.5	63.5	103.5	0.0	0.0	592	424	268	249	747	604	546
10.0	32	AL	PB	H2O	4.02	4.25	285.6	69.5	90.5	103.5	2.0	0.25	612	450	250	234	795	661	609
10.0	33	AL	PB	H2O	4.02	4.25	294.1	71.1	100.1	103.5	2.0	0.25	614	452	259	235	797	663	611
10.0	34	AL	PB	H2O	4.02	4.25	298.8	71.7	100.7	103.5	2.0	0.25	619	450	262	237	803	670	616
10.0	35	AL	PB	H2O	4.02	4.25	305.2	72.7	101.8	103.5	2.0	0.25	622	462	264	239	806	675	619*
10.0	36	AL	PB	H2O	4.02	4.25	313.5	74.2	103.2	103.5	2.0	0.25	624	465	265	240	808	677	621*
10.0	37	AL	PB	H2O	4.02	4.25	315.6	74.2	103.2	103.5	2.0	0.25	631	472	268	242	816	687	627*
10.0	15	AL	PB	H2O	9.39	3.75	103.7	40.7	77.9	107.0	0.0	0.0	540	370	236	222	677	521	465
10.0	16	AL	PB	H2O	9.39	3.75	191.3	50.2	79.5	107.0	0.0	0.0	554	377	240	225	684	529	472
10.0	17	AL	PB	H2O	9.39	3.75	199.5	51.9	61.2	107.0	0.0	0.0	559	384	243	228	690	537	470
10.0	18	AL	PB	H2O	9.39	3.75	200.8	53.3	62.6	107.0	0.0	0.0	564	391	247	231	697	545	484
10.0	19	AL	PB	H2O	9.39	3.75	200.9	53.3	62.6	107.0	0.0	0.0	574	402	252	235	709	560	490
10.0	20	AL	PB	H2O	9.39	3.75	217.9	55.2	64.5	107.0	0.0	0.0	577	407	255	237	713	565	490
10.0	29	AL	PB	H2O	9.39	3.75	205.1	66.2	99.5	107.0	2.0	0.25	596	429	246	224	757	617	556
10.0	30	AL	PB	H2O	9.39	3.75	209.7	66.0	100.1	107.0	2.0	0.25	601	435	248	226	763	625	560
10.0	31	AL	PB	H2O	9.39	3.75	291.0	66.0	100.1	107.0	2.0	0.25	600	440	252	229	772	636	567
10.0	32	AL	PB	H2O	9.39	3.75	305.2	69.5	102.0	107.0	2.0	0.25	606	443	252	229	770	633	567
10.0	33	AL	PB	H2O	9.39	3.75	314.0	71.1	104.3	107.0	2.0	0.25	609	445	253	230	772	636	570
10.0	34	AL	PB	H2O	9.39	3.75	310.9	71.7	105.0	107.0	2.0	0.25	613	451	256	232	777	643	574
10.0	19	AL	U	H2O	2.52	3.47	101.0	53.3	76.3	177.5	2.0	0.25	563	309	235	217	749	602	502
10.0	20	AL	U	H2O	2.52	3.47	190.2	55.2	70.2	177.5	2.0	0.25	567	393	237	219	751	605	506
10.0	21	AL	U	H2O	2.52	3.47	196.0	56.5	79.5	177.5	2.0	0.25	571	399	240	221	757	612	591
10.0	22	AL	U	H2O	2.52	3.47	205.0	58.5	81.5	177.5	2.0	0.25	574	402	241	223	750	613	594
10.0	23	AL	U	H2O	2.52	3.47	212.3	59.7	82.7	177.5	2.0	0.25	578	400	244	225	763	620	590
10.0	24	AL	U	H2O	2.52	3.47	210.4	60.9	83.0	177.5	2.0	0.25	583	413	247	227	768	626	603
10.0	35	AL	U	H2O	2.52	3.47	206.6	72.7	95.7	177.5	2.0	0.25	625	465	271	247	815	685	645
10.0	36	AL	U	H2O	2.52	3.47	294.5	74.2	97.2	177.5	2.0	0.25	627	460	272	240	817	687	640
10.0	37	AL	U	H2O	2.52	3.47	296.6	74.2	97.2	177.5	2.0	0.25	633	475	275	250	826	697	653
10.0	38	AL	U	H2O	2.52	3.47	303.1	75.0	100.0	177.5	3.0	0.25	632	474	269	244	831	703	666
10.0	39	AL	U	H2O	2.52	3.47	309.5	76.1	101.0	177.5	3.0	0.25	635	478	271	245	834	707	669
10.0	40	AL	U	H2O	2.52	3.47	317.2	77.4	102.4	177.5	3.0	0.25	637	480	272	247	836	709	670

Table A.14. Basalt Reference Design; Canister Only, with 4 BWR Assemblies/Package

FUEL NO.	AGE	MATERIALS		THICKNESS		CASE	DIMENSIONS					STEADY STATE				MAX FIRE-TEST			
				IN INCHES			IN INCHES					TEMPERATURES				TEMPERATURES			
		INERT	CAN.	HEWT	CAN.	HEWT	WEIGHT	ID	OD	LENGTH	PIN	PIN	FUEL	INERT	CANISTER	CASE	FUEL	INERT	CANISTER
CAN.	CAN.	SHEATH	SHEATH	SHEATH	SHEATH	(KILOS)				HT.	THK.	PIN	MATL	SHEATH	SHEATH		PIN	MATL	SHEATH
10.0	16	AL	PS	H2O	4.02	4.25	107.6	50.2	75.3	197.3	0.0	0.0	418	297	207	197	555	443	436
10.0	17	AL	PS	H2O	4.02	4.25	195.9	51.9	77.0	197.3	0.0	0.0	422	302	209	199	559	454	440
10.0	18	AL	PS	H2O	4.02	4.25	203.3	53.3	70.4	197.3	0.0	0.0	426	307	212	201	564	460	445
10.0	19	AL	PS	H2O	4.02	4.25	205.5	53.3	70.4	197.3	0.0	0.0	433	315	216	204	575	473	452
10.0	20	AL	PS	H2O	4.02	4.25	214.7	55.2	80.3	197.3	0.0	0.0	436	318	217	206	577	475	455
10.0	21	AL	PS	H2O	4.02	4.25	221.9	56.5	81.6	197.3	0.0	0.0	440	323	220	208	582	481	460
10.0	30	AL	PS	H2O	4.02	4.25	202.9	66.0	91.9	197.3	0.0	0.0	470	359	238	224	610	524	493
10.0	31	AL	PS	H2O	4.02	4.25	205.1	66.0	91.9	197.3	0.0	0.0	476	365	241	226	626	533	490
10.0	32	AL	PS	H2O	4.02	4.25	208.7	69.5	94.5	197.3	0.0	0.0	475	364	241	227	622	529	490
10.0	33	AL	PS	H2O	4.02	4.25	307.6	71.1	96.1	197.3	0.0	0.0	476	366	243	228	624	531	500
10.0	34	AL	PS	H2O	4.02	4.25	312.5	71.7	96.7	197.3	0.0	0.0	480	370	245	230	628	536	504
10.0	35	AL	PS	H2O	4.02	4.25	319.3	72.7	97.7	197.3	0.0	0.0	483	373	246	231	632	540	506
10.0	14	AL	FE	H2O	9.39	3.75	100.4	47.2	76.5	201.5	0.0	0.0	405	282	197	188	510	400	387
10.0	15	AL	FE	H2O	9.39	3.75	196.0	48.7	77.9	201.5	0.0	0.0	410	287	200	191	525	416	393
10.0	16	AL	FE	H2O	9.39	3.75	204.2	50.2	79.5	201.5	0.0	0.0	414	292	203	193	530	422	390
10.0	17	AL	FE	H2O	9.39	3.75	212.9	51.9	81.2	201.5	0.0	0.0	418	296	205	195	534	428	403
10.0	18	AL	FE	H2O	9.39	3.75	220.6	53.3	82.6	201.5	0.0	0.0	422	301	208	197	540	434	400
10.0	27	AL	FE	H2O	9.39	3.75	204.6	64.1	93.4	201.5	0.0	0.0	454	340	227	214	582	484	446
10.0	28	AL	FE	H2O	9.39	3.75	291.0	65.1	94.4	201.5	0.0	0.0	450	344	229	216	586	489	450
10.0	29	AL	FE	H2O	9.39	3.75	298.2	66.2	95.5	201.5	0.0	0.0	461	348	231	217	590	493	453
10.0	30	AL	FE	H2O	9.39	3.75	303.0	66.0	96.1	201.5	0.0	0.0	465	352	233	219	595	500	450
10.0	31	AL	FE	H2O	9.39	3.75	305.2	66.0	96.1	201.5	0.0	0.0	470	350	236	222	603	508	463
10.0	32	AL	FE	H2O	9.39	3.75	319.3	69.5	98.0	201.5	0.0	0.0	469	350	236	222	600	506	463
10.0	10	AL	U	H2O	2.52	3.47	100.3	53.3	72.3	191.2	0.0	0.0	430	311	210	200	575	472	469
10.0	19	AL	U	H2O	2.52	3.47	190.5	53.3	72.3	191.2	0.0	0.0	437	320	222	211	586	485	477
10.0	20	AL	U	H2O	2.52	3.47	199.3	55.2	74.2	191.2	0.0	0.0	440	323	224	213	588	487	480
10.0	21	AL	U	H2O	2.52	3.47	206.2	56.5	75.5	191.2	0.0	0.0	444	327	226	215	592	492	484
10.0	22	AL	U	H2O	2.52	3.47	215.7	58.5	77.5	191.2	0.0	0.0	446	330	228	216	593	494	486
10.0	23	AL	U	H2O	2.52	3.47	222.5	59.7	78.7	191.2	0.0	0.0	449	334	230	218	597	499	490
10.0	33	AL	U	H2O	2.52	3.47	209.3	71.1	90.0	191.2	0.0	0.0	480	371	250	235	633	541	523
10.0	34	AL	U	H2O	2.52	3.47	294.1	71.7	90.7	191.2	0.0	0.0	484	375	252	237	638	546	527
10.0	35	AL	U	H2O	2.52	3.47	300.7	72.7	91.7	191.2	0.0	0.0	486	378	253	239	641	550	530
10.0	36	AL	U	H2O	2.52	3.47	309.1	74.2	93.2	191.2	0.0	0.0	488	380	255	240	642	552	532
10.0	37	AL	U	H2O	2.52	3.47	311.3	74.2	93.2	191.2	0.0	0.0	493	386	257	242	649	560	536
10.0	38	AL	U	H2O	2.52	3.47	317.0	75.0	94.0	191.2	0.0	0.0	496	389	259	244	653	564	539

Table A.15. Basalt Reference Design: Canister Only, with 3 PWR Assemblies/Package

														STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F		
		MATERIALS		THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES													
FUEL NO. AGE	NO. CASE	INSERT	CAN. SHELD	INSRT SHELD	GAS. SHELD		INSRT SHELD	ID	OD	LENGTH	FIN ST.	FIN THK.	FUEL PIN	INSERT MATL	GASMA SHELD	CASE SURF.	FUEL PIN	INSERT MATL	GASMA SHELD	
10.0	12	AL	PB	H2O	4.02	4.25	106.3	52.5	77.5	103.5	0.0	0.0	610	401	255	230	763	500	525	
10.0	13	AL	PB	H2O	4.02	4.25	197.3	54.0	79.8	103.5	0.0	0.0	610	411	260	242	771	590	533	
10.0	14	AL	PB	H2O	4.02	4.25	200.2	56.9	82.0	103.5	0.0	0.0	625	419	265	246	770	599	541	
10.0	15	AL	PB	H2O	4.02	4.25	217.6	58.7	83.7	103.5	0.0	0.0	632	429	270	250	787	611	549	
10.0	22	AL	PB	H2O	4.02	4.25	290.4	70.6	99.7	103.5	2.0	0.25	652	454	260	236	833	666	612	
10.0	23	AL	PB	H2O	4.02	4.25	299.7	72.1	101.2	103.5	2.0	0.25	657	461	263	230	839	674	610	
10.0	24	AL	PB	H2O	4.02	4.25	300.4	73.5	102.5	103.5	2.0	0.25	663	467	266	241	846	682	623*	
10.0	25	AL	PB	H2O	4.02	4.25	316.2	74.6	103.7	103.5	2.0	0.25	669	475	269	243	853	690	629*	
10.0	10	AL	FE	H2O	9.39	3.75	104.0	49.2	70.5	107.0	0.0	0.0	584	368	236	221	711	510	463	
10.0	11	AL	FE	H2O	9.39	3.75	193.3	50.0	80.0	107.0	0.0	0.0	595	382	242	226	724	535	475	
10.0	12	AL	FE	H2O	9.39	3.75	202.5	52.5	81.7	107.0	0.0	0.0	604	394	248	231	737	550	486	
10.0	13	AL	FE	H2O	9.39	3.75	213.9	54.0	84.0	107.0	0.0	0.0	612	403	253	236	745	561	495	
10.0	20	AL	FE	H2O	9.39	3.75	287.2	66.7	99.9	107.0	2.0	0.25	630	436	248	226	799	626	561	
10.0	21	AL	FE	H2O	9.39	3.75	296.9	68.2	101.5	107.0	2.0	0.25	644	443	252	229	805	634	567	
10.0	22	AL	FE	H2O	9.39	3.75	310.2	70.6	103.9	107.0	2.0	0.25	646	447	254	230	800	630	571	
10.0	23	AL	FE	H2O	9.39	3.75	319.8	72.1	105.4	107.0	2.0	0.25	652	453	257	233	814	646	576	
10.0	13	AL	U	H2O	2.52	3.47	106.4	54.0	77.7	177.5	2.0	0.25	601	390	235	217	784	601	583	
10.0	14	AL	U	H2O	2.52	3.47	197.0	56.9	79.9	177.5	2.0	0.25	600	398	239	221	790	610	590	
10.0	15	AL	U	H2O	2.52	3.47	206.2	58.7	81.7	177.5	2.0	0.25	615	407	243	224	798	620	597	
10.0	16	AL	U	H2O	2.52	3.47	216.1	60.6	83.6	177.5	2.0	0.25	621	415	247	227	805	629	604	
10.0	24	AL	U	H2O	2.52	3.47	289.5	73.5	96.5	177.5	2.0	0.25	666	471	273	240	855	673	649	
10.0	25	AL	U	H2O	2.52	3.47	290.2	74.6	99.6	177.5	2.0	0.25	667	472	260	243	864	702	664	
10.0	26	AL	U	H2O	2.52	3.47	306.9	76.0	101.0	177.5	2.0	0.25	672	478	271	245	869	709	669	
10.0	27	AL	U	H2O	2.52	3.47	315.9	77.0	102.0	177.5	2.0	0.25	676	484	274	248	874	715	673	

Table A.16. Basalt Reference Design; Canister Only, with 7 BWR Assemblies/Package

												STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
		MATERIALS			THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES											
FUEL NO.	AGE	INSERT	CAN. SHLD	HEUT SHLD	CAN. SHLD	HEUT SHLD		ID	OD	LENGTH	PIN HT.	PIN THK.	FUEL PIN	INSERT MATL	CANNA SHLD	CASK SURF.	FUEL PIN	INSERT MATL	CANNA SHLD
10.0	11	AL	PS	H2O	4.02	4.25	109.5	50.0	75.0	197.3	0.0	0.0	407	323	219	207	628	484	460
10.0	12	AL	PS	H2O	4.02	4.25	198.9	52.5	77.5	197.3	0.0	0.0	495	333	224	211	638	496	469
10.0	13	AL	PS	H2O	4.02	4.25	210.6	54.0	79.0	197.3	0.0	0.0	500	340	220	214	645	504	476
10.0	14	AL	PS	H2O	4.02	4.25	222.1	56.9	82.0	197.3	0.0	0.0	506	347	231	210	651	512	482
10.0	21	AL	PS	H2O	4.02	4.25	290.2	60.2	93.3	197.3	0.0	0.0	545	394	255	239	697	568	524
10.0	22	AL	PS	H2O	4.02	4.25	303.6	70.6	95.7	197.3	0.0	0.0	547	397	257	240	699	571	527
10.0	23	AL	PS	H2O	4.02	4.25	313.3	72.1	97.2	197.3	0.0	0.0	552	403	260	243	704	577	532
10.0	24	AL	PS	H2O	4.02	4.25	322.5	73.5	98.5	197.3	0.0	0.0	557	409	263	245	710	584	537
10.0	9	AL	PS	H2O	9.39	3.75	105.3	46.9	76.2	201.5	0.0	0.0	466	290	204	194	581	430	403
10.0	10	AL	PS	H2O	9.39	3.75	197.3	49.2	78.5	201.5	0.0	0.0	473	307	209	190	591	442	412
10.0	11	AL	PS	H2O	9.39	3.75	206.2	50.0	80.0	201.5	0.0	0.0	482	317	214	203	602	456	422
10.0	12	AL	PS	H2O	9.39	3.75	216.0	52.5	81.7	201.5	0.0	0.0	489	327	218	206	612	460	431
10.0	19	AL	PS	H2O	9.39	3.75	287.3	64.4	93.7	201.5	0.0	0.0	531	370	244	229	665	532	480
10.0	20	AL	PS	H2O	9.39	3.75	300.3	66.7	95.9	201.5	0.0	0.0	534	382	247	231	669	537	484
10.0	21	AL	PS	H2O	9.39	3.75	310.6	68.2	97.5	201.5	0.0	0.0	539	387	249	233	674	544	489
10.0	22	AL	PS	H2O	9.39	3.75	324.5	70.6	99.9	201.5	0.0	0.0	542	390	252	235	677	547	493
10.0	12	AL	U	H2O	2.52	3.47	104.0	52.5	71.4	191.2	0.0	0.0	499	330	231	219	649	509	494
10.0	13	AL	U	H2O	2.52	3.47	195.3	54.0	73.7	191.2	0.0	0.0	504	345	235	222	655	517	501
10.0	14	AL	U	H2O	2.52	3.47	206.4	56.9	75.9	191.2	0.0	0.0	510	352	239	225	661	524	507
10.0	15	AL	U	H2O	2.52	3.47	216.1	58.7	77.7	191.2	0.0	0.0	516	359	243	229	669	533	514
10.0	22	AL	U	H2O	2.52	3.47	285.4	70.6	89.6	191.2	0.0	0.0	551	402	265	249	700	582	551
10.0	23	AL	U	H2O	2.52	3.47	299.7	72.1	95.1	191.2	2.0	0.25	534	381	235	218	712	584	579
10.0	24	AL	U	H2O	2.52	3.47	308.7	73.5	96.5	191.2	2.0	0.25	538	386	237	220	717	591	583
10.0	25	AL	U	H2O	2.52	3.47	316.8	74.6	97.6	191.2	2.0	0.25	543	392	240	222	724	598	588

Table A.17. Basalt Reference Design; Canister Only, with 4 Fuel Assemblies/Package

		MATERIALS				THICKNESS IN INCHES		DIMENSIONS IN INCHES				STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F			
FUEL NO.	INSRT CAN.	HEPT	GAS.	HEPT	CASE	WEIGHT	I.D.	O.D.	LENGTH	FIN	FIN	FUEL	INSRT	GASMA	CASE	FUEL	INSRT	GASMA	
AGE	CASE	SELD	SELD	SELD	SELD	(LBS)				WT.	THK.	FIN	RATL	SELD	SURF.	FIN	RATL	SELD	
10.0	9	AL	PS	H2O	3.00	4.25	170.6	52.7	77.5	103.2	0.0	0.0	642	400	255	230	792	570	526
10.0	10	AL	PS	H2O	3.00	4.25	191.2	55.4	80.5	103.2	0.0	0.0	653	410	262	244	804	593	537
10.0	11	AL	PS	H2O	3.91	4.25	205.0	57.1	85.9	103.3	2.0	0.25	645	404	236	217	820	610	571
10.0	12	AL	PS	H2O	3.93	4.25	216.0	59.0	87.9	103.3	2.0	0.25	655	417	242	221	833	626	582
10.0	13	AL	PS	H2O	3.96	4.25	230.4	61.6	90.5	103.4	2.0	0.25	662	426	246	225	840	636	589
10.0	17	AL	PS	H2O	4.07	4.25	281.9	70.5	99.6	103.6	2.0	0.25	690	462	263	230	871	676	610
10.0	18	AL	PS	H2O	4.07	4.25	293.3	72.4	101.6	103.6	2.0	0.25	697	471	267	241	878	685	625*
10.0	19	AL	PS	H2O	4.07	4.25	296.0	72.4	101.6	103.6	2.0	0.25	709	486	273	246	895	706	637*
10.0	20	AL	PS	H2O	4.07	4.25	310.9	75.0	104.1	103.6	2.0	0.25	713	491	276	248	898	711	642*
10.0	21	AL	PS	H2O	4.07	4.25	323.2	76.0	107.9	103.6	3.0	0.25	715	493	272	244	907	721	655*
10.0	8	AL	FE	H2O	9.24	3.75	176.2	48.3	77.3	107.5	0.0	0.0	630	385	243	227	760	540	477
10.0	9	AL	FE	H2O	9.24	3.75	195.2	52.7	81.7	107.5	0.0	0.0	636	393	248	232	766	549	487
10.0	10	AL	FE	H2O	9.24	3.75	200.3	55.4	84.3	107.5	0.0	0.0	647	406	255	230	779	565	499
10.0	11	AL	FE	H2O	9.20	3.75	210.7	57.1	86.1	107.5	0.0	0.0	650	421	262	244	794	584	512
10.0	12	AL	FE	H2O	9.32	3.75	230.1	59.0	88.1	107.6	0.0	0.0	669	435	269	250	806	600	524
10.0	15	AL	FE	H2O	9.44	3.75	275.6	66.0	95.4	107.9	2.0	0.25	672	430	249	227	830	620	562
10.0	16	AL	FE	H2O	9.44	3.75	280.1	68.2	101.6	107.9	2.0	0.25	678	447	253	230	830	639	570
10.0	17	AL	FE	H2O	9.44	3.75	301.4	70.5	103.9	107.9	2.0	0.25	684	455	257	233	845	640	577
10.0	18	AL	FE	H2O	9.44	3.75	313.3	72.4	105.0	107.9	2.0	0.25	691	463	260	236	853	650	584
10.0	19	AL	FE	H2O	9.44	3.75	316.7	72.4	105.0	107.9	2.0	0.25	703	470	266	240	860	677	595
10.0	10	AL	U	H2O	2.41	3.47	179.0	55.4	78.1	177.2	2.0	0.25	636	393	237	219	816	604	500
10.0	11	AL	U	H2O	2.43	3.47	189.5	57.1	79.9	177.3	2.0	0.25	640	400	243	224	831	623	600
10.0	12	AL	U	H2O	2.44	3.47	200.1	59.0	81.8	177.3	2.0	0.25	650	420	249	229	843	639	610
10.0	13	AL	U	H2O	2.46	3.47	213.1	61.6	84.4	177.3	2.0	0.25	665	430	254	233	851	649	617
10.0	14	AL	U	H2O	2.48	3.47	226.1	64.0	86.9	177.4	2.0	0.25	672	439	258	236	858	650	624
10.0	19	AL	U	H2O	2.56	3.47	279.3	72.4	97.5	177.5	3.0	0.25	707	484	272	246	906	710	672
10.0	20	AL	U	H2O	2.56	3.47	293.1	75.0	100.1	177.5	3.0	0.25	711	489	275	249	909	723	676
10.0	21	AL	U	H2O	2.56	3.47	304.9	76.0	103.0	177.5	4.0	0.25	715	493	275	247	910	733	690
10.0	22	AL	U	H2O	2.56	3.47	319.7	79.5	106.5	177.5	4.0	0.25	718	497	277	249	920	735	693
10.0	23	AL	U	H2O	2.56	3.47	331.5	81.2	110.2	177.5	5.0	0.25	723	503	278	250	929	746	706

Table A.10. Basalt Reference Design; Canister Only, with 9 BWR Assemblies/Package

										STEADY STATE TEMPERATURES IN DEG.F				MAX FIRE-TEST TEMPERATURES IN DEG.F					
MATERIALS				THICKNESS IN INCHES		CASE WEIGHT (LBS)	DIMENSIONS IN INCHES												
FUEL NO.	INSERT	CAN.	HEUT	CAN.	HEUT		ID	OD	LENGTH	FIN HT.	FIN THK.	FUEL PIN	INSERT MATL	CANNA SHLD	CASE SURF.	FUEL PIN	INSERT MATL	CANNA SHLD	
AGE	CASE	SHLD	SHLD	SHLD	SHLD														
10.0	8	AL	PB	H2O	3.08	4.25	171.6	48.3	73.1	197.0	0.0	0.0	504	320	217	205	647	483	459
10.0	9	AL	PB	H2O	3.08	4.25	190.0	52.7	77.5	197.0	0.0	0.0	510	327	221	209	650	487	464
10.0	10	AL	PB	H2O	3.08	4.25	204.1	55.4	80.1	197.0	0.0	0.0	516	337	226	214	660	499	474
10.0	11	AL	PB	H2O	3.91	4.25	214.7	57.1	81.9	197.1	0.0	0.0	520	349	232	219	672	515	485
10.0	16	AL	PB	H2O	4.04	4.25	280.4	68.2	93.3	197.3	0.0	0.0	561	390	253	237	711	563	521
10.0	17	AL	PB	H2O	4.07	4.25	294.6	70.5	95.6	197.4	0.0	0.0	566	396	257	240	716	570	526
10.0	18	AL	PB	H2O	4.07	4.25	306.6	72.4	97.6	197.4	0.0	0.0	572	403	261	243	723	578	532
10.0	19	AL	PB	H2O	4.07	4.25	310.2	72.4	97.6	197.4	0.0	0.0	582	416	266	248	737	595	543
10.0	20	AL	PB	H2O	4.07	4.25	325.1	75.0	100.1	197.4	0.0	0.0	586	420	269	250	741	599	547
10.0	7	AL	PB	H2O	9.24	3.75	168.8	44.0	72.9	201.2	0.0	0.0	494	307	207	197	614	445	418
10.0	8	AL	PB	H2O	9.24	3.75	180.1	48.3	77.3	201.2	0.0	0.0	500	314	212	201	620	453	419
10.0	9	AL	PB	H2O	9.24	3.75	208.3	52.7	81.7	201.2	0.0	0.0	505	321	216	205	625	460	426
10.0	10	AL	PB	H2O	9.24	3.75	222.2	55.4	84.3	201.2	0.0	0.0	513	331	221	209	635	473	436
10.0	14	AL	PB	H2O	9.40	3.75	275.1	64.0	93.3	201.6	0.0	0.0	543	360	240	225	673	519	471
10.0	15	AL	PB	H2O	9.44	3.75	288.1	66.0	95.4	201.6	0.0	0.0	550	376	244	228	681	529	479
10.0	16	AL	PB	H2O	9.44	3.75	301.2	68.2	97.6	201.6	0.0	0.0	556	383	248	232	688	538	486
10.0	17	AL	PB	H2O	9.44	3.75	315.2	70.5	99.9	201.6	0.0	0.0	561	389	251	234	694	546	491
10.0	18	AL	PB	H2O	9.44	3.75	327.7	72.4	101.0	201.6	0.0	0.0	566	396	254	238	701	554	498
10.0	9	AL	U	H2O	2.41	3.47	175.4	52.7	71.5	191.0	0.0	0.0	514	331	228	216	660	499	489
10.0	10	AL	U	H2O	2.41	3.47	188.3	55.4	74.1	191.0	0.0	0.0	522	341	233	221	670	511	499
10.0	11	AL	U	H2O	2.43	3.47	198.4	57.1	75.9	191.1	0.0	0.0	531	354	239	226	683	527	510
10.0	12	AL	U	H2O	2.44	3.47	209.6	59.0	77.3	191.1	0.0	0.0	540	364	245	231	694	540	519
10.0	13	AL	U	H2O	2.46	3.47	223.3	61.6	80.4	191.1	0.0	0.0	546	372	249	235	700	548	526
10.0	17	AL	U	H2O	2.53	3.47	275.4	70.5	89.5	191.3	0.0	0.0	571	401	265	248	726	581	551
10.0	18	AL	U	H2O	2.54	3.47	292.5	72.4	95.5	191.3	2.0	0.25	555	382	235	218	731	585	579
10.0	19	AL	U	H2O	2.56	3.47	296.8	72.4	95.5	191.3	2.0	0.25	564	394	240	222	746	603	588
10.0	20	AL	U	H2O	2.56	3.47	311.3	75.0	98.1	191.3	2.0	0.25	567	397	242	223	748	606	592
10.0	21	AL	U	H2O	2.56	3.47	322.8	76.8	99.8	191.3	2.0	0.25	572	403	244	226	754	612	597

INTERNAL DISTRIBUTION

1. W. D. Box	21-25. L. B. Shappert
2-6. J. A. Bucholz	26. W. C. Stoddart
7. W. D. Burch	27. J. S. Tang
8. A. G. Croff	28. J. T. Thomas
9. H. R. Dyer	29. C. C. Webster
10. C. W. Forsberg	30. R. M. Westfall
11. A. R. Irvine	31. G. E. Whitesides/R. P. Leinius/
Central Research Library
12. W. C. Jordan	32. R. Q. Wright
13. D. S. Joy	33. Central Research Library
14. J. A. Klein	34. ORNL-Y-12 Technical Library,
Document Reference Section
15. J. V. Pace, III	35-36. Laboratory Records Department
16. C. V. Parks	37. Laboratory Records, ORNL, RC
17. R. T. Primm, III	38. ORNL Patent Office
18. R. R. Rawl	
19. J. P. Renier	
20. T. H. Row	

EXTERNAL DISTRIBUTION

39. George Allen, Jr., Sandia National Laboratories, Div. 5323, P. O. Box 5800, Albuquerque, NM 87185
40. R. Barner, U.S. Department of Energy, Nevada Operations Office, P.O. Box 14100, Las Vegas, NV 89114
41. L. Barrett, U.S. Department of Energy, 1000 Independence Ave., RW-33, Washington, DC 20585
42. W. P. Barthold, Barthold and Associates, P. O. Box 11730, Albuquerque, NM 87192
43. E. Benz, Weston Corporation, 2301 Research Blvd., Rockville, MD 20850
44. W. Bixby, U.S. Department of Energy, Rt. 441 South, Bldg. 400, Middletown, PA 17057
45. C. Boggs-Mayes, U.S. Department of Energy, Chicago Operations Office, 9800 S. Cass Ave., Argonne, IL 60439
- 46-50. P. Bolton, Weston Corporation, 2301 Research Blvd., Rockville, MD 20850
51. E. Burton, U.S. Department of Energy, 1000 Independence Ave., RW-25, Washington, DC 20585
52. D. Carrell, Rockwell Hanford (BWIP), 1100 Jadwin, P. O. Box 800, Richland, WA 99352
53. S. Chu, U.S. Department of Transportation, Resources, and Special Programs Adm., DMT-60, Washington, DC 20590
54. N. Dayem-Sheaks, Weston Corporation, 2301 Research Blvd., Rockville, MD 20850
55. S. Denny, U.S. Department of Energy, 1000 Independence Ave., RW-33, Washington, DC 20585
56. L. Friel, Western Interstate Energy Board, Stapleton Plaza, 3333 Quebec St., Denver, CO 80207
57. R. Gale, U.S. Department of Energy, 1000 Independence Ave., RW-40, Washington, DC 20585
58. K. Gollhofer, U.S. Department of Energy, Albuquerque Operations Office, P. O. Box 5400, Albuquerque, NM 87115
59. S. Gupta, Battelle Project Management Division, 505 King Ave., Columbus, OH 43201
60. R. Halstead, Radioactive Waste Review Board, 3 South Pinckney St., 921 Tenney Bldg., Madison, WI 53702
61. R. Hannon, U.S. Department of Transportation, Resources, and Special Programs Adm., DMT-60, Washington, DC 20590

- 62-64. M. Heiskell, U.S. Department of Energy, Oak Ridge Operations Office, G-24, P. O. Box E, Oak Ridge, TN 37831
- 65. K. Henry, Rockwell Hanford (BWIP), 1100 Jadwin, P. O. Box 800, Richland, WA 99352
- 66. R. Izatt, U.S. Department of Energy, Richland Operations Office, 825 Jadwin Ave., P. O. Box 550, Richland, WA 99352
- 67. Robert Jones, P. O. Box 1510, Los Gatos, CA 95031-1510
- 68. C. Kimm, Battelle Project Management Division, 505 King Ave., Columbus, OH 43201
- 69. D. Langstaff, U.S. Department of Energy, Richland Operations Office, 825 Jadwin Ave., P. O. Box 550, Richland, WA 99352
- 70. D. Larson, Western Interstate Energy Board, Stapleton Plaza, 3333 Quebec St., Denver, CO 80207
- 71. J. A. Lenhard, U. S. Department of Energy, Oak Ridge Operations, Oak Ridge, TN 37831
- 72. L. Marks, U.S. Department of Energy, 1000 Independence Ave., RW-33, Washington, DC 20585
- 73. Marilyn McNabb, Nebraska Energy Office, State Capitol, Ninth Floor, P. O. Box 95085, Lincoln, NE 68509
- 74. G. W. McNair, Battelle Pacific Northwest Laboratory, Battelle Blvd., P. O. Box 999, Richland, WA 99352
- 75. J. Neff, U.S. Department of Energy, Salt Repository Program Office, 505 King Ave., Columbus, OH 43201
- 76. Bim Oliver, High Level Nuclear Waste Office, 355 W. North Temple, 3 Triad Center, Suite 330, Salt Lake City, UT 84180-1203
- 77. W. Pardue, Battelle Project Management Division, Office of Crystalline Repository Development, 9800 S. Cass Ave., Bldg. 360, Argonne, IL 60439
- 78. G. Parker, U.S. Department of Energy, 1000 Independence Ave., RW-25, Washington, DC 20585
- 79. J. Parker, Office of High Level Nuclear Waste Management, 5826 Pacific Ave., Lacey, WA 98504
- 80. R. W. Peterson, Battelle Project Management Division, 505 King Ave., Columbus, OH 43201
- 81. R. Philpott, U.S. Department of Energy, 1000 Independence Ave., RW 33, Washington, DC 20585
- 82. R. B. Pope, IAEA, Wagramerstrasse 5, Rm. A-2744, P. O. Box 200, A-1400, Vienna, Austria
- 83. M. Rahimi, Weston Corporation, 2301 Research Blvd., Rockville, MD 20850
- 84. Marvin Resnikoff, P. O. Box 92, Blairstown, NJ 07825
- 85. J. N. Rogers, Sandia National Laboratories, Div. 8474, Livermore, CA 94550
- 86. Tom Sanders, Sandia National Laboratories, Div. 6323, P. O. Box 5800, Albuquerque, NM 87185
- 87. C. Scardino, Science Applications, Inc. (NNWSI), 2769 S. Highland Ave, Las Vegas, NV 89114
- 88. K. J. Schneider, Battelle Pacific Northwest Laboratory, Battelle Blvd., P. O. Box 999, Richland, WA 99352
- 89. C. Toussaint, Weston Corporation, 2301 Research Blvd., Rockville, MD 20850
- 90. D. Vieth, U.S. Department of Energy, Nevada Operations Office, P.O. Box 14100, Las Vegas, NV 89114
- 91. J. Williams, U.S. Department of Energy, Salt Repository Program Office, 505 King Ave., Columbus, OH 43201
- 92-96. E. Wilmot, U.S. Department of Energy, 1000 Independence Ave., Washington, DC 20585