71-5957

Department of Energy
Washington, DC 20585

APR 20 1999

Cass R. Chappell
Chief, Licensing Section
Spent Fuel Project Office, NMSS
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Chappell:

The U.S. Department of Energy requests revision of Nuclear Regulatory Commission Certificate of Compliance No. 5957 for the BMI-1 cask to reflect a change in one of the parameters for irradiated, low-enriched uranium MTR-type fuel assemblies, an authorized content per paragraph 5(b)(1)(xvii). Specifically, we request revision of paragraph 5(b)(2)(xvii) to increase the maximum allowable burnup from 12% to 14%.

Enclosed is a copy of a memorandum from the DOE Idaho Operations Office giving background information on the request, and six copies of the revised safety analysis. Please review this request in conjunction with our January 29, 1999 application for one-time shipment of irradiated low-enriched uranium fuel plates in the BMI-1.

If you have any questions, please contact me at 301-903-5078.

Sincerely,

Michael E. Wangler

Michael E. Wangler, Director
Package Certification and Safety Program
Office of Site Operations, EM-70

Attachments:
DOE-ID memorandum (one copy)
Safety analysis (six copies)

cc: see next page

NF01

cc w/o atts.:
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T. Bridges, LMITCO
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United States Government — Department of Energy

memorandum

Idaho Operations Office

Date: April 7, 1999

Subject: Request for Authorization to Ship Irradiated Materials Test Reactor (MTR) Type Fuel Assemblies with up to 14% Burnup in the BMI-1 Cask (OPE-TP-99-005)

To: Mr. Michael E. Wangler, EM-76
Packaging Certification and Safety Program

Reference: (a) Request for Authorization to Ship LEU, MTR-Type Fuel Assemblies in the BMI-1 Cask (OPE-OS-98-123)

(b) Revised Request for Authorization to Ship LEU, MTR-Type Fuel Assemblies in theBMI-1 Cask (OPE-OS-99-001)

Dear Mr. Wangler:

Reference (a) as supplemented by Reference (b), requested authorization to ship irradiated LEU, MTR-type fuel assemblies, with up to 282.7 grams of U-235 per assembly, from the University of Virginia reactor facility to the Savannah River Site. The request stated that the fuel assemblies have a maximum burnup of 12% and a minimum cool down period of 120 days. This request was approved by the NRC March 11,1999. Attached is a revision to the previously submitted request [References (a) and (b)], reflecting an increase in the maximum burnup from 12% to 14% for the University of Virginia LEU fuel.

The previous request for authorization to ship University of Virginia LEU fuel in the BMI-1 cask was based upon the best available information at the time. Subsequently, the University of Virginia has recalculated burnup for the LEU fuel. As a result, burnup for two of the fuel assemblies is now determined to exceed 12%. Fuel assembly V002, which had an initial U235 content of 275 grams, has a burnup of 12.4%. Its decay heat, as of April 15, 1999, is calculated to be 10.6 watts. A partial fuel assembly VP001, which had an initial U235 content of 138 grams, has a burnup of 13.4%. Its decay heat, as of April 15, 1999, is calculated to be 5.7 watts. As indicated by the calculated decay heat for these two elements, all the parameters important to safe transport (U235 content, source term, and decay heat) are enveloped by the safety evaluation previously submitted [References (a) and (b)].

Four copies of the revised BMI-1 cask amendment request are provided for submittal to the NRC. If there are any questions concerning this request, please feel free to contact Tom Bridges, Lockheed Martin Idaho Technologies Company, at (208) 526-8894.

for Miriam R. Taylor, Manager
Transportation Program

Attachment

cc: M. D. Ruska, LMITCO, MS 4105

BMI-1 Cask Amendment for University of Virginia LEU MTR-Type Fuel

1. INTRODUCTION

The DOE University Reactors Program requests authorization to transport the following fuel assemblies in the Battelle Memorial Institute (BMI)-1 Cask: University of Virginia, low enriched uranium (LEU), intact, irradiated, Materials Test Reactor (MTR)-type fuel assemblies with up to 282.7 g U-235. Universities with MTR-type fuel have or will be converting their reactors from high enriched uranium (HEU) fuel to LEU fuel. As a result of this fuel conversion, the U-235 content for these MTR-type fuel assemblies has increased significantly. The nominal U-235 content for the University of Virginia LEU fuel assemblies is 275 g per assembly.

The Certificate of Compliance (C of C) for the BMI-1 Cask (Reference 1) currently authorizes the following content and product container for MTR-type fuel assemblies with U-235 contents of 240 g:

> 12 intact, irradiated, MTR-type fuel assemblies, containing not more than 240 g U-235 per assembly prior to irradiation [C of C No. 5957, Condition 5(b)(1)(xv)], contained in a Texas A&M fuel basket configuration as defined by the BMI-1 Drawing No. BCL-000-500, Rev. A, as modified by BMI Drawing Nos. 00-000-236, Rev. C, and BCL-000-502, Rev. B [C of C No. 5957, Condition 5(a)(4)(v)].

HEU, intact, irradiated, MTR fuel assemblies from university reactors have been previously transported in the BMI-1 Cask, as authorized, using the Texas A&M basket.

This request is for authorization to transport up to eight University of Virginia LEU fuel assemblies in the BMI-1 packaging. The LEU fuel assemblies have (a) up to 282.7 g U-235 (b) maximum burnup of 14%, (c) maximum decay of 15 watts, and (d) minimum cool down period of 120 days. The fuel assemblies will be transported using the Texas A&M basket configuration. The eight fuel assemblies will be loaded in the peripheral compartments of the 12-compartment basket (see Figure 1-1). The four center compartments will contain aluminum inserts instead of fuel assemblies as shown in Figure 1-1.

As discussed in the subsequent sections of this amendment, all important parameters of the LEU MTR-type fuel assemblies, necessary to ensure containment, shielding, and criticality safety, are enveloped by to the HEU fuel assemblies previously transported in the BMI-1 Cask. The only exception is the quantity of U-235. The increased quantity of U-235 is evaluated extensively in the structural and criticality sections of this amendment. Based upon the findings of this evaluation, it is concluded that the BMI-1 Cask satisfies the requirements of 10 CFR 71 (Reference 2) for transport of up to eight LEU, intact, irradiated, MTR-type fuel assemblies, with U-235 content not exceeding 282.7 g per fuel assembly, loaded in the packaging as proposed.

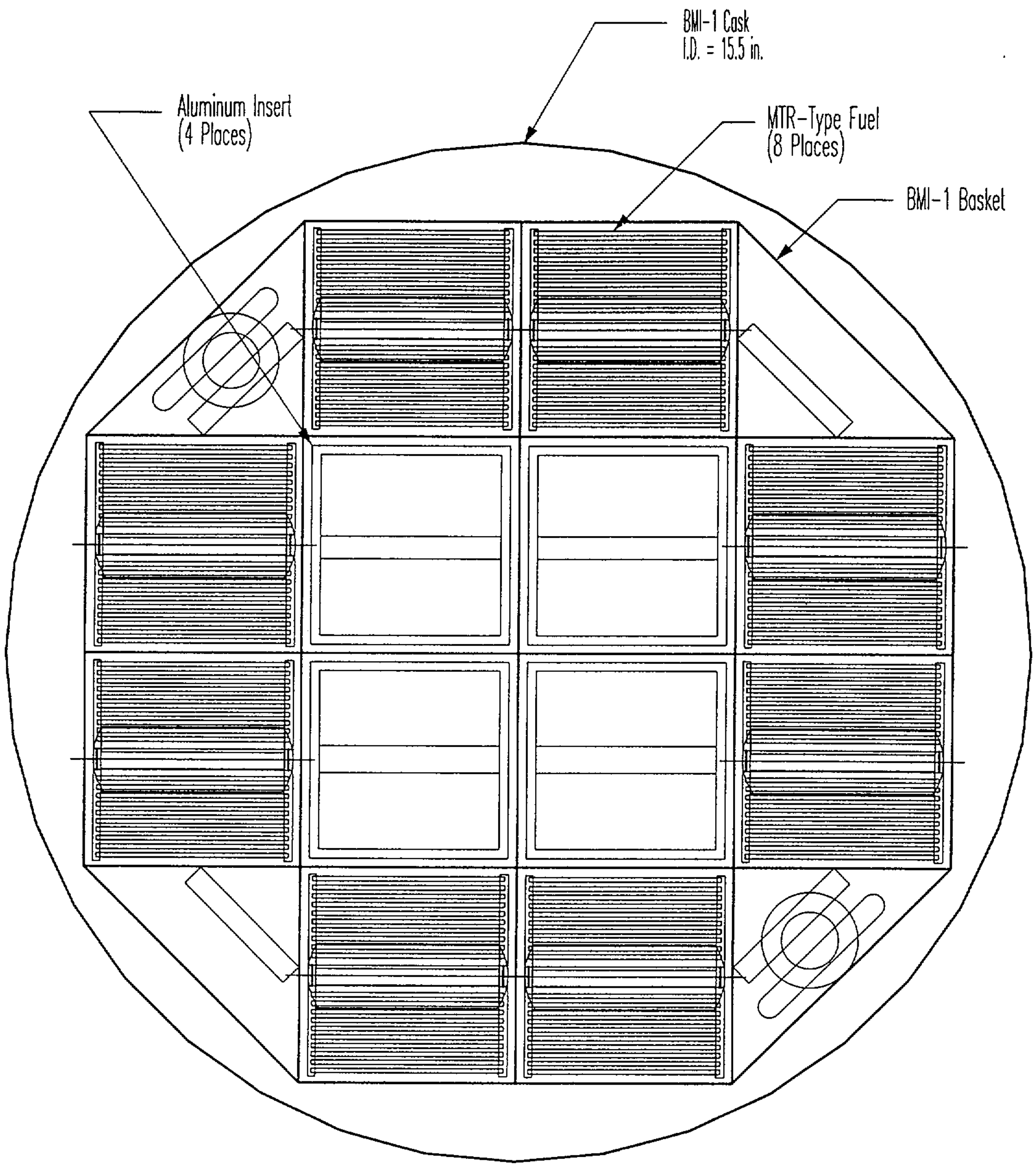

Figure 1-1. Loading configuration of LEU MTR-type fuel assemblies in the BMI-1 Cask. This diagram shows the location of the eight fuel assemblies loaded in the peripheral compartments of the BMI-1 basket and four aluminum inserts placed in the four center compartments of the basket.

2. STRUCTURAL

Loading of LEU MTR-type fuel assemblies in the Texas A&M basket configuration will be as shown in Figure 1-1. Eight LEU fuel assemblies will be loaded in the peripheral compartments of the basket. The four center compartments will be loaded with square aluminum inserts rather than fuel. These four aluminum inserts will ensure that criticality safety is provided during normal and hypothetical accident conditions of transport. The inserts prevent loading the cask with more than eight fuel assemblies. In the unlikely event of a hypothetical accident of a free drop on the side of the cask, the four aluminum inserts will provide assurance that the eight fuel assemblies will remain in a critically safe geometry in the peripheral compartments of the basket. In addition, the four aluminum inserts will provide structural protection to the center portion of the basket's dividing cruciform which contains the boral neutron poison material.

The four aluminum inserts required for the transport of University of Virginia fuel assemblies, which have a length of 37.67 in., are defined by Lockheed Martin Drawing No. 507584, Rev. 1. The 37.67-in. long inserts are 3-in. square, 6061-T6 aluminum alloy tubing with a 3/16-in. wall. Each insert has a 3/8-in. diameter aluminum pin welded in place at the top for handling purposes.

Component weights are:

Fuel assemblies: 13.8 lb each (Reference 3)
Aluminum inserts: 8.0 lb each

The mechanical properties of the aluminum materials evaluated include:

Material	Minimum Tensile Strength at Room Temperature (ksi)	Tensile Strength at 300°F (ksi)	Minimum Yield Strength at Room Temperature (ksi)	Yield Strength at 300°F (ksi)	Design Stress Intensity (S_m) (ksi)[a]
Al 6061-T6	38.0[b]	34.0[c]	35.0[b]	31.0[c]	11.3
Al 6061-0	18.0[c]	16.3[d]	8.0[c]	8.0[d]	5.3

a. The material design stress intensities were determined in accordance with the *ASME Boiler and Pressure Vessel Code,* Section II, Part D, Appendix 2.
b. ASTM Standard B 221.
c. The Aluminum Association, *Aluminum Construction Manual, Section 3, Engineering Data for Aluminum Structures*, Third edition, New York, NY, 1975.
d. Determined based on strength data obtained from Note c for aluminum alloy 5050-0, which has nearly identical room temperature properties as Al 6061-0.

Thirty-foot free drop impact accelerations (Reference 4, Page 2.218) used for this structural evaluation are:

Orientation	Impact Acceleration (G)
Top End	87.5
Bottom End	368
Side	400

A removable axial spacer will be placed in the bottom of the Texas A&M basket assembly under the University of Virginia fuel assemblies to limit axial movement of the fuel assemblies during transport. This spacer is an Al 6061-T6511 ring, measuring 1/2-in. thick and 3-in. high as defined by Lockheed Martin Drawing No. 507583, Rev 1. The narrow width of the spacer (1/2 in.) permits air flow through the fuel assemblies as a result of natural convection cooling.

The fuel plates of the University of Virginia fuel assemblies are not centered within the poison portion of the fuel baskets as a result of the removable axial spacers. The top of the active portion (meat) of the fuel plates are nominally 1-11/16 in. above the basket poison material. This is of insignificant consequence from the standpoint of criticality safety as discussed in Section 6. In the unlikely event of a 30-ft free drop on the packaging bottom, localized yielding of the bottom of the fuel assemblies and the top of the axial spacer will occur because of the limited bearing area between the two surfaces. This condition is of no safety consequence even if the entire height of the spacer were to collapse. The fuel assemblies would remain as centered within the basket as before the accident. In addition, the criticality safety analysis for hypothetical accident conditions is based the assumption that there is no poison material within the cask cavity.

The aluminum inserts have sufficient strength to maintain the fuel geometry, ensuring criticality safety for hypothetical accident conditions. The worst case loading for the four inserts results from a 30-ft free drop with the cask in a side drop orientation. The aluminum inserts must withstand the inertial loading from the weight above them during the impact. Therefore, the aluminum inserts on the impact side of the cask must resist the greatest inertial impact loading. The impact loading results from the weight of (a) one fuel assembly (13.8 lb), (b) two aluminum inserts ($2 \times 8 = 16$ lb) and the weight of the basket corresponding to two compartments ($2/12 \times 72 = 12$ lb). The total weight is 41.8 lb. The impact loading for a side impact is $400 \times 41.8 = 16,720$ lb. This loading must be resisted in compression by the two vertical walls of the tubing within the fuel basket length (25.12 in.). The aluminum insert compression area (a) for this loading is $2 \times 3/16 \times 25.12 = 9.42$ in.^{2} The resultant compressive stress (σ_c) for the aluminum tubing walls is given by $\sigma_c = p/a$.

$$\sigma_c = 16,720/9.42 = 1,775 \text{ psi.}$$

The critical buckling stress for aluminum is given by $P/A = \sigma_o - C_2(L/r)$ (Reference 5), for slenderness ratios (L/r) up to 90, where L is the effective column length. For plate components, $r = t/(\sqrt{12})$, where t is the plate thickness. The slenderness ratio for the aluminum insert walls is $L/r = 3/(0.1875/\sqrt{12}) = 55.4$, which is within the slenderness ratio range for the buckling equation. For aluminum, $\sigma_o = 19,200$ psi and $C_2 = 160$ (Reference 5).

Therefore, $P/A = 19,200 - (160 \times 55.4) = 10,336$ psi.

The recommended safety factor for determining an allowable compressive stress ($\sigma_{allowable}$) for aluminum is 2.5 (Reference 5).

$\sigma_{allowable} = 10{,}336/2.5 = 4{,}134$ psi.

The margin of safety is:

$MS = (\sigma_{allowable}/\sigma_c) - 1$

$MS = (4{,}134/1{,}775) - 1 = 1.3.$

Primary membrane stresses must also be evaluated to ensure that ductile rupture does not occur under accident conditions. The criteria of U. S. Nuclear Regulatory Commission, Regulatory Guide 7.6, Position 6 is: "Under accident conditions, the value of stress intensity (P_m) resulting from the primary membrane stresses should be less than the lesser of 2.4 S_m and 0.7 S_u (ultimate strength)." (Reference 6)

Since σ_c is a principal stress and the other principal stresses are zero, $P_m = \sigma_c = 1{,}775$ psi.

$2.4\ S_m = 2.4 \times 11{,}300\text{ psi} = 27{,}120\text{ psi}$

$0.7\ S_u = 0.7 \times 34{,}000\text{ psi} = 23{,}800\text{ psi}$

P_m is much less than the allowable of 23,800 psi, providing a very large margin of safety.

These margins of safety provide assurance that the aluminum inserts, located in the center four basket compartments, have sufficient strength for impact loading which could result from a hypothetical accident condition (30-ft free drop with the cask in a side drop orientation).

The structural integrity of MTR-type fuel assemblies is sufficient to ensure that they will remain intact in the unlikely event of a hypothetical accident condition. The fabrication specifications for these fuel assemblies require that swaging of the fuel plates in the side plates have sufficient mechanical integrity to resist a pull test of 150 lb per lineal in. (References 7 and 8). The University of Virginia fuel assembly plates weigh 176 g (0.39 lb) each (Reference 3). The inertial force acting on the fuel plates upon impact for the hypothetical accident condition of a 30-ft free drop on the cask bottom, is $0.39 \times 368 = 14.4$ lb. The mechanical strength resulting from the swaging of the fuel plates into the side plate grooves is 50 in. $\times$ 150 lb/in. = 7,500 lb. This is approximately 50 times that required to resist the impact loading. Thus, it is assured that (a) the fuel plates will not slide out of the side plates, and (b) the fuel assemblies will remain intact for this worst-case hypothetical accident condition.

The MTR-type fuel assembly side plate/fuel plate design provides sufficient structural integrity to ensure that the fuel assemblies will remain intact and not fracture as a result of a hypothetical accident 30-ft free drop condition. The University of Virginia fuel plates have a thickness of 0.050 in. and cladding thickness of 0.015 in. (Reference 8).

Maximum bending of the fuel plates occurs for the 30-ft free drop accident condition with the fuel plates in a horizontal position. The inertial loading for the packaging side drop orientation is 400 g. The fuel plate weight per area, based on their width of 2.81 in. and length of 24.63 in., is:

0.39 lb/(2.81 in. × 24.63 in.) = 0.0056 psi.

The resulting loading for the 400 g side drop impact is 400 × 0.0056 = 2.24 psi.

The fuel plate span between the side plates is 2.64 in. The fixed end moment (M) for a unit width of the fuel plate for the inertial impact loading is $M = wl^2/12$, where l is the beam span (in.) and w is the uniform loading (lb/in.); w = 2.24 lb/in. for a unit width of the fuel plate.

$M = (2.24 \times 2.64^2)/12 = 1.30$ in-lb/in.

The swaging of the fuel plates in the side plates provides a moment capacity (M_{cap}) that is equal to the friction force (150 lb/2) provided on each side of the fuel plate multiplied by the thickness of the fuel plate.

$M_{cap} =$ (75 lb/in.) × 0.05 in. = 3.75 in-lb/in.

The moment capacity based upon the mechanical strength of the swaged joint is nearly three times the fixed end moment calculated for the joint. Therefore, the fixed end boundary condition assumed for the fuel plate is justified.

The fuel plate bending stress for the maximum bending moment (fixed end moment) is determined by dividing the fixed end moment (M) by the plate unit width section modulus (s). The section modulus for the fuel plate, based upon the cladding thickness only for a unit width, is given by:

$s = (t^3 - t_f^3)/6t$

Where t is the fuel plate thickness and t_f is the thickness of the fuel plate meat (U_3Si_2-Al).

The thickness values are: t = 0.050 in. and t_f = 0.020 in.

$s = (0.050^3 - 0.020^3)/(6 \times 0.050) = 0.00039$ in.^{3}/in.

The fuel plate maximum bending stresses are: $\sigma_{bending} = 1.30/0.00039 = 3{,}333$ psi

The fuel plate cladding material is Al 6061-0 which has a yield strength of 8,000 psi. The calculated bending stresses have a safety factor of:

(8,000/3,333) = 4.3.

The criteria of U.S. Nuclear Regulatory Commission, Regulatory Guide 7.6, Position 6, requires that, "Under accident conditions, the stress intensity resulting from the sum of primary membrane stresses and primary bending stresses ($P_m + P_b$) should be the lesser value of 3.6 S_m and S_u." (Reference 6) The bending stress calculated for the fuel plates is a principal stress and the other principal stresses are zero. Therefore,

$P_m + P_b = \sigma_b = 3{,}333$ psi

$3.6\ S_m = 3.6 \times 5{,}300$ psi = 19,080 psi

S_u = 16,300 psi.

The margin of safety ensuring that ductile rupture does not occur under accident conditions is :

MS = (16,700/3,333) – 1 = 4.0.

Thus, it is assured that the fuel plates will not yield or fracture as a result of the worst-case hypothetical 30-ft free drop accident condition. The BMI-1 packaging satisfies the structural requirements of 10 CFR 71 for normal and hypothetical accident conditions for the transport of eight irradiated University of Virginia LEU MTR-type fuel assemblies.

3. THERMAL

The following thermal analysis was performed for the BMI-1 Cask, with University of Virginia LEU fuel assemblies, to determine the temperature of the fuel plates during normal conditions of transport. The analysis is based on the following conservative conditions:

1. The packaging decay heat is based on 15 watts per fuel assembly, which is significantly greater than the University of Virginia LEU fuel assembly average decay heat of 11.1 watts.
2. Heat transfer from the cask cavity to the cask inner wall was assumed to occur radially only for the length of the fuel plates (25 in.).
3. The cask inner wall temperature was assumed to be 186°F, which is the cask inner wall temperature determined from Page 3.12 in the BMI-1 Safety Analysis Report for Packaging (SARP) (Reference 4) for a package total decay heat of 1,020 watts.

Heat transfer by radiation from the fuel to the cask wall is assumed to be that of concentric cylinders with the same area (Reference 9):

$$Q_R = \frac{\sigma A\left(T_F^4 - T_W^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

Where:

Q = heat transfer rate (BTU/hr)
σ = Stefan-Boltzman Constant
A = heat transfer area (ft^2)
T_F = fuel plate temperature (°R)
T_W = cask wall temperature (°R)
ε_1 = surface emissivity
ε_2 = surface emissivity

$$\sigma = \frac{0.1712 * 10^{-8} BTU}{hr * ft^2 * {}^\circ R^4}$$

$\varepsilon_1 = \varepsilon_2 = 0.2 - 0.3$ (Reference 10)

$$A = \frac{\pi(15.5)(25)}{144} = 8.45 ft^2$$

$T_W = 186°F = 646°R$ [SARP, Page 3.12, (Reference 4)]

$Q = 15$ watts/fuel assembly
= 120 watts for 8 fuel assemblies
= 410 BTU/hr.

Heat transfer by natural convection within the cask is given by (Reference 11):

$$Q_C = h_C A(T_{air} - T_W)$$

Where:

h_c = convective heat transfer coefficient
A = heat transfer area (ft^2)
T_{air} = air temperature in cask (°F)
T_W = cask inner wall temperature (°F)

$h_C = 0.19(T_{air} - T_W)^{\frac{1}{3}}$ (Reference 11)
$A = 8.45 ft^2$

Convective heat transfer from fuel plates to air within the cask must balance the transfer of heat to the cask walls:

$$Q_C = h_C A_F (T_F - T_{air})$$

Where:

A_F = heat transfer area at fuel assemblies (ft^2)
T_F = fuel temperature (°F)

$h_C = 0.19(T_F - T_{air})^{\frac{1}{3}}$ (Reference 11)

$$A_F = \frac{2 * 2.6in. * 25in. * 22}{144} = \frac{19.8 ft^2}{FuelAssembly}$$

$A_F = 158.9 ft^2$ for 8 fuel assemblies

Equating heat transfer from fuel plates to cask wall permits solving for average air temperature in the cask in terms of the fuel plate temperature:

$$0.19(8.45)(T_{air} - T_W)^{\frac{4}{3}} = 0.19(158.9)(T_F - T_{air})^{\frac{4}{3}}$$

$$\frac{T_{air} - T_W}{T_F - T_{air}} = \left(\frac{158.9}{8.95}\right)^{\frac{3}{4}} = 9.03 \qquad (T_W = 186°F)$$

$$T_{air} - 186 = 9.03(T_F - T_{air})$$

$$10.03T_{air} = 9.03T_F + 186$$

$$T_{air} = \frac{(9.03T_F + 186)}{10.03}$$

$$Q = Q_R + Q_C = 410 \text{ BTU/hr}$$

$$410BTU/hr = \frac{\sigma A(T_F^4 - T_W^4)}{\frac{2}{\varepsilon} - 1} + h_C A(T_{air} - T_W)$$

$$410BTU/hr = \frac{\sigma A(T_F^4 - T_W^4)}{\frac{2}{\varepsilon} - 1} + .19(8.45)(T_{air} - T_W)^{\frac{4}{3}}$$

Substituting $T_{air} = \frac{(9.03T_F + 186)}{10.03}$

And solving for T_F, for $\varepsilon = 0.3$: $T_F = 238°F$ for $\varepsilon = 0.2$: $T_F = 243°F$

The fuel temperature determined by this analysis (243°F) is significantly below that assumed (300°F) for determining the aluminum insert and fuel plate cladding material properties.

The BMI-1 packaging satisfies the thermal requirements of 10 CFR 71 for normal and hypothetical accident conditions for the transport of eight irradiated LEU MTR-type fuel assemblies. The thermal parameters important for safe transport of LEU fuel assemblies are enveloped by the HEU MTR-type fuel assemblies currently authorized for transport in the BMI-1 Cask. Taking into account the U-235 fuel content, operating histories, and cooling periods of the University of Virginia LEU fuel assemblies, the decay heat per fuel assembly does not exceed 15 watts per fuel assembly. The BMI-1 Cask was originally evaluated and authorized to transport 24 fuel assemblies with a decay heat of 42.5 watts per fuel assembly using the standard basket configuration.

The axial power distribution of the LEU fuel assemblies is also consistent with that which was originally evaluated and authorized. The packaging total decay heat load, with eight LEU fuel assemblies, is approximately 12% of that which was used to demonstrate that the packaging satisfies the thermal requirements of the regulations. The differences in heat transfer characteristics, between the LEU fuel assemblies and currently authorized HEU fuel assemblies, are insignificant since the fuel assemblies have the same geometry, materials of construction, and amount of heat transfer surface area. Since the thermal parameters of the LEU fuel assemblies are enveloped by those of fuel already evaluated and authorized for transport in the BMI-1 packaging, the thermal requirements of 10 CFR 71 for normal and hypothetical accident conditions are met.

4. CONTAINMENT

The BMI-1 packaging satisfies the containment safety requirements of 10 CFR 71 for both normal and hypothetical accident conditions for the transport of eight irradiated LEU MTR-type fuel assemblies. The primary containment boundary of the BMI-1 Cask ensures containment of contents. The capability of the BMI-1 packaging to satisfy containment safety requirements is not affected for the transport of eight LEU fuel assemblies, since the content weight corresponding to this fuel is less than that already evaluated and authorized. The LEU fuel plate cladding material provides a secondary containment safety function during transport. University fuel assemblies are routinely tested as a part of normal reactor operations to verify no indication of fission product leakage. The package source term for eight LEU fuel assemblies, with a pre-irradiation fuel content of 275 g U-235, is less than half of that currently authorized for the cask (24 MTR-type assemblies with a pre-irradiation fuel content of 200 g U-235).

5. SHIELDING

The BMI-1 packaging satisfies the shielding requirements of 10 CFR 71 for both normal and hypothetical accident conditions for the transport of eight irradiated LEU MTR-type fuel assemblies. The radiation source term for eight LEU fuel assemblies (maximum 282.7 g U-235 prior to irradiation, maximum of 14% burnup, and a minimum of 120 days cool down) is enveloped by other contents previously evaluated and authorized [see packaging contents described in C of C No. 5957, Conditions 5(b)(1)(xiii) and (xv)]. The capability of the BMI-1 packaging to adequately provide its shielding function is unaffected for the eight LEU fuel assemblies. The combined weight of eight LEU fuel assemblies and the four aluminum inserts is less than the weight of the contents previously evaluated and authorized. Subsequent to loading of the packaging and prior to shipment of the LEU fuel, the package will be surveyed to verify that the package satisfies external radiation requirements.

6. CRITICALITY EVALUATION

The BMI-1 Cask will be used to transport nuclear fuel presently located at the University of Virginia. The fuel to be transferred is enriched U-235 (< 20%) MTR-type plate fuel, with a nominal 275g U-235 per assembly, and 22 plates per assembly. The contents of each BMI-1 Cask, using the Texas A&M fuel basket configuration, will be limited to no more than eight of these fuel assemblies (see Section 1).

Based on the results of the calculations described in this section, the BMI-1 Cask with the Texas A&M fuel basket complies with the requirements of Sections 71.55 and 71.59 of 10 CFR 71 for a fissile material package. The shipments will be limited to no more than eight fuel assemblies per cask in the eight peripheral compartments of the 12-compartment fuel basket. Aluminum inserts will be placed in the center four basket compartments to ensure that the fuel assemblies cannot migrate to the center positions during accident conditions.

6.1 Discussion and Results

The University of Virginia fuel assembly contains 22 flat fuel-loaded plates. The plates are composed of rolled uranium-silicide alloy powder (the fuel "meat") clad with aluminum. The fuel meat is 0.20-in. thick, with 0.15-in. thick aluminum cladding. Each plate contains 12.5g U-235, with 19.75 wt% enrichment. Thus, each assembly contains 275g U-235. The fueled portion of the plates is 23.5-in. long. Figure 6-1 shows a sketch of the University of Virginia fuel assembly.

The BMI-1 Cask is a 15.5-in. inside diameter, 54.0-in. inside height cylinder, with 0.25-in. thick stainless steel walls, surrounded by 8.0-in. thick lead, followed by 0.5-in. thick stainless steel. The base of the cylinder consists of 0.75-in. thick stainless steel, followed by 7.5-in. thick lead, and covered with 1.0-in. thick stainless steel. The lid bottom is 0.75-in. thick stainless steel, followed by 8.0-in. thick lead, and covered with 1.5-in. thick stainless steel. Figure 6-2 shows a sketch of the BMI-1 Cask.

The Texas A&M fuel basket is a 12-compartment carrier, with a 50.5-in. overall length. Each compartment is 3.31-in. x 3.31-in. square. Each arm of the poisoned center cruciform is 0.124-in. thick, 25.0-in. long, and 6.69-in. wide, thus extending the width of two compartments. The cruciform arms each contain two 2.97-in. wide, 0.062-in. thick, 24.5-in. long boral plates. The boral plates contain B_4C-Al, 35 wt% enriched in B_4C, and are clad with 0.011-in. thick aluminum. The boral plates are separated by a 0.25-in. stainless steel plate, with two 0.25-in. stainless steel plates on either side of the boral plates, two 0.25-in. stainless steel plates on top and bottom, and clad with 0.031-in. thick stainless steel. The other walls of the fuel basket are made of 0.125-in. thick stainless steel plate. The fuel assemblies are placed in the basket so that no more than two inches of the fuel plates extend past the boral plates. The Texas A&M basket, which permits longer fuel assemblies in the cask, is a modification of the BMI standard basket. Figure 6-3 shows a sketch of the Texas A&M basket.

Several thermal reactor critical benchmark experiments were evaluated using the KENO V.a code. A few experiments involved the SPERT-D fuel assemblies, which are 22 high-enriched (93 wt%) uranium alloy plates clad in aluminum contained in an aluminum box. In addition, benchmark experiments involving uranium-aluminum systems with lead reflection or discrete boron poisoning performed at the Pacific Northwest Laboratory were used to validate the results of this analysis. The details of these calculations are given in Section 6.5. Based on the results of these calculations, a 1% bias (0.01 Δk_{eff}) is added to the results involving boron poison, and no bias is added to the other results.

For normal conditions, calculations were performed with all degrees of moderation. Eight fuel assemblies, each with 282.7 g U-235 and 20 wt% enriched, were modeled in the cask in the eight peripheral compartments of the fuel basket. The poisoned center cruciform of the basket was modeled in the normal condition cases, with 75% density boron. For accident condition cases, the poisoned cruciform of the basket was conservatively ignored. Figures 6-4, 6-5, and 6-6 are sketches of the models used to represent the fuel, the cask, and the basket, respectively.

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure **6-1.** University of Virginia fuel assembly.

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 6-2. BMI-1 Cask.

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure **6-3.** Cross-section diagram of BMI-I fuel basket.

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 6-4. Sketch of fuel assembly model.

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 6-5. Sketch of fuel basket model.

FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 6-6. Sketch of cask model.

An effective multiplication factor (k_{eff}) of 0.153 ± 0.001 was calculated for an infinite array of casks in a triangular-pitch array with no water moderation inside or outside of the casks. This becomes 0.165 with the addition of the bias and two standard deviations (2σ) of the statistical uncertainty associated with the Monte Carlo calculations. It should be noted that KENO V.a has not been validated for extremely low k_{eff} values (<0.7), but the results are useful in determining the margin of safety.

A triangular-pitch array of three casks was modeled as described above, with full water density inside the fuel assemblies, 70% water density outside the fuel assemblies, no moderation between the casks, and full water reflection around the cask array. For this case, a k_{eff} value of 0.742 ± 0.001 was calculated. This becomes 0.754 with the addition of the bias and 2σ of the statistical uncertainty.

For the accident condition, a single cask was modeled without the center poisoned cruciform of the basket, and the fuel assemblies were modeled with optimal spacing between assemblies in the peripheral locations in the cask. The most reactive condition was full water moderation inside the fuel assemblies, 30% water volume fraction outside the fuel assemblies, and full water reflection outside the cask. For this condition a k_{eff} value of 0.926 ± 0.001 was calculated. This becomes 0.928 with the addition of 2σ of the statistical uncertainty. Thus, with the requirements of 10 CFR 71.59(b) for arrays of fissile material packages, a transport index based on nuclear criticality control for this package is 100.

6.2 Package Fuel Loading

The contents of the BMI-1 Cask will be limited to eight University of Virginia fuel assemblies loaded in the peripheral compartments of the fuel basket. The remaining four center locations of the 12-compartment basket will contain aluminum inserts. The maximum permissible U-235 content of the fuel assemblies is 282.7g U-235, with a maximum uranium enrichment of 19.95%. The maximum permissible gap between fuel plates in the assembly for normal or accident conditions is 0.14-in.

6.3 Model Specification

6.3.1 Description of Calculational Model

6.3.1.1 Fuel Assemblies. The University of Virginia fuel assemblies are described in their respective drawings and specifications (References 8 and 12). The fuel assembly contains 22 flat fuel-loaded plates. The plates are composed of a rolled uranium-silicide alloy powder clad with aluminum. The fuel meat is 0.20-in. thick, with 0.15-in. thick aluminum cladding. Each plate contains 12.5 g U-235 (12.85g maximum), with 19.75 wt% (19.95% maximum) enrichment. Thus, each fuel assembly contains 275g U-235 (282.7g maximum). The gaps between fuel plates are 0.093-in. thick. The fueled portion of the plates is 23.5-in. long, and the plates are 24.63-in. long.

For this analysis, a conservative fuel assembly was modeled. The fuel meat was modeled simply as 12.85g U-235 and 51.4g U-238, ignoring any silicide that may be present. This will have no effect on the reactivity in moderated conditions. The dimensions of the fuel meat were modeled as 2.47-in. wide, 0.02-in. thick, and 23.5-in. long. The overall dimensions of the fuel plate were modeled as 2.976-in. wide, 0.05-in. thick, 24.63-in. long, with the fuel meat centered in all directions, clad with 0.15-in. thick aluminum. The gaps between the fuel plates were conservatively modeled as 0.140-in. thick. This gap thickness is greater than the gap thickness of the University of Virginia fuel assemblies, and conservatively adds about 0.08 Δk_{eff} in reactivity. The overall dimensions of the fuel assemblies were thus 2.976-in. wide, 4.18-in. thick, and 24.63-in. long. The fuel assembly modeled will conservatively envelop the University of Virginia fuel assembly.

6.3.1.2 Basket and Cask. The Texas A&M Basket assembly is described in BMI Drawing BCL-000-500, as modified by BMI Drawing 00-000-236 (References 13 and 14). The Texas A&M Basket is a modification of the BMI standard basket that accommodates longer fuel assemblies. The only part of the basket that was included in the model was the poisoned center cruciform. The cruciform was modeled as described in Section 6.1, with 75% boron. The compartment walls of the basket were not modeled for conservatism. The fact that the compartment walls were not modeled allowed the fuel assemblies to be modeled closer together, and ignored the slight neutron absorption that the walls provide.

The BMI-1 Cask is described in BMI Drawing 43-6704-0001 (Reference 15). The cask was modeled as described in Section 6.1.

6.3.2 Package Regional Densities

Material densities in (atoms/barn-cm) and (g/cm^3) are presented in Table 6-1.

Table 6-1. Material compositions for BMI-1 Cask calculations.

Description	Material	Number Density (volume fraction)
Fissile Region ($\rho = 3.4$ g/cm^3)	U-235 U-238	1.73064×10^{-3} 6.83511×10^{-3}
Water Regions ($\rho = 1.0$ g/cm^3)	H_2O	Variable
Side Plates and Clad ($\rho = 2.7$ g/cm^3)	Al	6.02377×10^{-2}
Stainless Steel ($\rho = 7.9$ g/cm^3)	SS304	(1.0)
Boral Plates ($\rho = 2.5$ g/cm^3)	B-10 B-11 C Al	5.99720×10^{-3} 2.41395×10^{-2} 1.00456×10^{-2} 3.82052×10^{-2}
Lead ($\rho = 11.4$ g/cm^3)	Pb	3.29879×10^{-2}

6.4 Criticality Calculations

6.4.1 Calculational Method

Calculations were performed using the three-dimensional Monte Carlo code KENO V.a which is part of the SCALE-4 modular code system (Reference 16). All calculations documented in this evaluation were performed on an HP workstation operating under HP-UX with Version 10.2 of the Fortran compiler. Configuration Release 1.10 of the SCALE-4.0 code system and the associated 27-energy-group ENDF/B Version 4 cross sections were used to evaluate the KENO V.a models in this evaluation (Reference 17).

The KENO V.a Monte Carlo criticality code and the 27-energy-group ENDF/B Version 4 cross-section library were chosen because of their long successful use and easy availability. Validation of the code and cross sections is presented in Section 6.5.

6.4.2 Fuel Loading Optimization

Fuel was modeled as described in Section 6.3.1.1. Other parameters such as assembly placement, moderation, and fuel gap spacing were optimized as described below. The maximum U-235 loading (282.7g) and a just slightly more than the maximum enrichment (20%) of the actual fuel assembly was used in all calculations.

Under accident conditions, some of the fuel assemblies may compress a small amount. Compression of the fuel assemblies would be less reactive than the plate separation modeled. Section 2 shows that the plates will not separate further apart during an accident. The basket was not modeled for the accident conditions, but the geometry that the basket provides was used. Fuel assemblies were conservatively modeled within the peripheral locations. Adjacent fuel assemblies were placed side-by-side with no separation and displaced from their nominal basket position 0.6 in. towards the center of the cask. Aluminum inserts will be placed in the center four basket compartments to ensure that the fuel assemblies cannot migrate to the center positions during accident conditions.

Table 6-2 shows results that determine optimal fuel assembly placement, fuel gap moderation, moderation between fuel assemblies and cask, and interstitial moderation. Table 6-2 also shows that using a 0.14-in. spacing between fuel plates is conservative. The results of Table 6-2 also show that the reflection provided by the cask is more reactive than that from full water reflection.

The material of the basket walls was not modeled in either the normal or the accident conditions. The central poison cruciform of the basket was modeled in the normal conditions with 75% boron.

6.4.3 Criticality Calculation Results

The most reactive configurations of the shipping casks for both normal and accident conditions of transport are those in which the casks are as closely spaced as possible. Thus, when multiple casks were modeled, the casks were modeled touching in a triangular-pitch array. Conservatisms in the models include larger than normal fuel plate spacing, modeling the fuel as simply U-235 and U-238, modeling a slightly higher uranium enrichment than expected, 75% boron loading when modeled, optimum moderation, and ignoring basket material which allows closer spacing and disregards some neutron poisoning. Appendix A shows representative input files for the KENO V.a calculations.

6.4.3.1 Normal Conditions of Transport. For these calculations, normal conditions of transport include all cases for which the complete shipping casks remain in their original condition.

Table 6-3 shows the calculated multiplication factors (k_{eff}) and associated statistical uncertainties for normal transport conditions. Calculations for partial submersion of undamaged casks in water are included. It should be noted that KENO V.a has not been validated for extremely low k_{eff} values (< 0.7), but the results are useful in determining the margin of safety.

6.4.3.2 Accident Conditions of Transport. For these calculations, accident conditions of transport are the same as normal conditions of transport, except that the poisoned center

Table 6-2. Fuel loading optimization results.

Configuration		Results (including 2σ)
1.	One cask, 0.140-in. plate separation, fuel assemblies 0.6-in. toward center of cask from normal basket compartment position, no poison cruciform, full water density inside fuel assemblies, 30% density water outside fuel assemblies, full water reflection	0.928
2.	Same as case 1, fuel assemblies 0.5-in. toward center of cask	0.925
3.	Same as case 1, fuel assemblies 0.4-in. toward center of cask	0.919
4.	Same as case 1, fuel assemblies 0.3-in. toward center of cask	0.913
5.	Same as case 1, 50% density water outside fuel assemblies	0.926
6.	Same as case 1, 70% density water outside fuel assemblies	0.907
7.	Same as case 1, 20% density water outside fuel assemblies	0.912
8.	Same as case 1, 90% density water inside fuel assemblies	0.903
9.	Same as case 1, 80% density water inside fuel assemblies	0.869
10.	Same as case 1, 0.120-in. plate separation	0.899
11.	Same as case 1, 0.100-in. plate separation	0.857
12.	Same as case 1, 0.093-in. plate separation	0.846
13.	Same as case 1, cask replaced by water	0.853
14.	3 casks in triangular-pitch array, 75% boron loading, 70% density water outside fuel assemblies, full density water inside fuel assemblies, no flooding between casks, full water reflection	0.754[a]
15.	Same as case 14, 90% density water outside fuel assemblies	0.749[a]
16.	Same as case 14, 100% density water outside fuel assemblies	0.748[a]
17.	Same as case 14, 50% density water outside fuel assemblies	0.753[a]
18.	Same as case 14, 30% density water outside fuel assemblies	0.745[a]
19.	Same as case 14, 10% density water between casks	0.754[a]
20.	Same as case 14, 20% density water between casks	0.753[a]

a. Includes 1% bias.

Table 6-3. Calculated multiplication factors for normal conditions of transport.

Configuration		Results (including 2σ and 1% bias)
1.	Single cask, dry	0.041
2.	Infinite array of casks, dry	0.194
3.	Single cask, fully flooded	0.744
4.	Three casks, full density water inside fuel assemblies, 70% water moderation outside fuel assemblies, no moderation between casks, full water reflection	0.754

cruciform of the fuel basket was not modeled. For this condition with optimal moderation, a k_{eff} value of 0.926 ± 0.001 was calculated. The fuel cannot come under a more reactive condition since the basket cannot be damaged such that the fuel assemblies can migrate to the center of the cask (see Section 2).

6.5 Critical Benchmark Experiments

Several thermal-reactor critical benchmark experiments were evaluated using the KENO V.a codes. The cases selected were part of KENO V.a validations performed at the INEEL (References 18, 19, and 20).

6.5.1 Benchmark Experiment and Applicability

Three series of benchmark experiments were chosen to validate KENO V.a for use in this evaluation. The first is for SPERT-D fuel assemblies, the second is for low-enriched aluminum-clad rods with lead reflection, and the third is for low-enriched aluminum-clad rods with discrete boral poisoning.

SPERT-D fuel assemblies are high-enriched (93.2%) uranium-alloy plates clad in aluminum, contained in an aluminum box. One complete SPERT-D fuel assembly contains 22 plates with 0.065-in. water gaps and about 300 g U-235. Partial assemblies with fewer plates can be constructed. Non-integer numbers in the array dimensions in Table 6-4 reflects the use of partial assemblies. Reference 18 contains a complete description of each of the SPERT-D benchmark experiments.

The SPERT-D benchmark experiments provide validation of the methods and cross sections used to calculate k_{eff} for water moderated high enriched aluminum fuels for the following reasons:

1. Both the critical benchmark experiments and the university fuel assemblies are high enriched metal plates clad in aluminum.

2. Both the critical benchmark experiments and the university fuel assemblies are water moderated.

3. The H/X ratio for the critical experiments is 159. The H/X ratio for the representative fuel assembly is 298.

Benchmark experiments performed at Pacific Northwest Laboratories involving flooded arrays of low-enriched aluminum-clad rods with lead reflection were also used to validate the codes for lead reflection. The fuel rods consisted of 4.31 wt% enriched UO_2. The use of low enriched fuel does not reflect University of Virginia fuel, but the validation tests the cross sections for water moderated, lead reflected systems. The rods were placed in square-pitched arrays to form a cluster; the clusters were separated by various amounts of water and reflected on two sides by a 4.02-in. thick lead wall. The 1.0-in. pitch arrays (H/X = 256) were in the form of 13 x 8 rod clusters, and the 0.74-in. pitch arrays (H/X = 106) were in the form of 12 x 16 rod clusters. Table 6-5 shows the KENO V.a results for these experiments. Reference 19 contains a more complete description of these experiments.

Table 6-4. High enriched, water moderated, uranium-aluminum plate systems.

Benchmark Number	Dimensions (No. of assemblies)[a]	Spacing (cm)		Results
		Assemblies	Rows	
1	4 x 3.77 x 1	0.000	0.000	0.996 ± 0.001
2	4 x 3.16 x 1	0.635	0.635	1.003 ± 0.001
3	4 x 3.09 x 1	1.270	1.270	1.005 ± 0.001
4	4 x 3.16 x 1	1.905	1.905	0.993 ± 0.001
5	4 x 3.70 x 1	2.540	2.540	1.000 ± 0.001
6	5 x 4.03 x 1	3.175	3.175	1.000 ± 0.001
7	6 x 5.34 x 1	3.810	3.810	0.999 ± 0.001
8	7 x 6.68 x 1	4.064	4.064	0.995 ± 0.001
9	16 x 2.32 x 1	0.000	0.000	0.990 ± 0.001
10	16 x 3 x 1	1.270	5.5626	1.006 ± 0.001
11	16 x 4 x 1	1.270	6.5024	1.004 ± 0.001
12	16 x 4 x 1 16.18 cm between two 16 x 2 x 1 arrays	1.270	1.270	1.004 ± 0.001
			Average:	1.000 ± 0.001

a. Non-integer numbers indicate partial assemblies.

Table 6-5. Lead reflected, low enriched, water moderated, uranium-aluminum systems.

Case	Cluster Description	Spacing Between Clusters	Spacing Between Lead and Clusters	Results
1	13 x 8 1.0-in. square-pitch array	7.68 in.	0.0 in.	1.0041 ± 0.0012
2		7.74 in.	0.26 in.	1.0070 ± 0.0012
3		7.05 in.	0.52 in.	1.0059 ± 0.0012
4		3.61 in.	2.13 in.	0.9910 ± 0.0012
20	12 x 16 0.74-in. square-pitch array	6.80 in.	0.0 in.	0.9998 ± 0.0011
21		6.97 in.	0.26 in.	0.9975 ± 0.0012
22		6.67 in.	0.77 in.	0.9966 ± 0.0012
23		5.45 in.	1.97 in.	0.9951 ± 0.0012
			Average:	0.9996 ± 0.0012

Benchmark experiments performed at Pacific Northwest Laboratories involving flooded arrays of low-enriched aluminum-clad rods with boral plate poisoning were also used to validate the codes. The fuel rods consisted of 2.35 wt% enriched UO_2. Again, the use of low enriched fuel does not reflect University of Virginia fuel, but the validation tests the cross sections for water moderated, discrete boron poisoned systems. The rods were placed in 0.8-in. pitch square arrays (H/X = 196) to form a cluster, the clusters were separated by various amounts of water and reflected by water. A 0.28-in. thick boral plate was placed between the clusters. Table 6-6 shows the KENO V.a results for these experiments. Reference 20 contains a more complete description of these experiments.

Table 6-6. Low enriched, water moderated, uranium-aluminum systems with boral poison.

Case	Cluster Description	Spacing Between Clusters	Spacing Between Boral Plate and Center Cluster	Results
12	20 x 17	2.49 in.	0.25 in.	0.9918 ± 0.0018
13	20 x 17	3.56 in.	1.75 in.	0.9894 ± 0.0016
14	20 x 16 (center) 22 x 16 (two outer)	1.99 in.	0.25 in.	0.9932 ± 0.0016
			Average:	0.9915 ± 0.0017

6.5.2 Summary of Benchmark Calculations

For the SPERT-D and low-enriched lead reflection benchmark experiments, deviations from unity are much less than 1%, and less than 0.1% for the average k_{eff} results.

For the boral poison benchmark experiments, the calculated results of one experiment deviated from unity by 1%. Deviations from unity are about 0.8% for the average k_{eff} results. Thus, a 1% bias was conservatively added to the results involving boral poison.

The results of the code validation show that no bias needs to be added to the results where no boral poison is involved.

7. OPERATING PROCEDURES

Shipment of the University of Virginia LEU irradiated fuel assemblies in the BMI-1 Cask, using the Texas A&M basket configuration, requires the following operating procedures in addition to those currently in place:

1. The University of Virginia fuel assembly axial spacer (Lockheed Martin Dwg. No. 507583, Rev. 1) must be placed in Texas A&M basket removable lower section (Dwg. No. BCL-000-502). To accomplish this, the Texas A&M basket removable lower section must be temporarily unbolted from the BMI-1 basket. The axial spacer must be placed in the Texas A&M basket removable lower section with the ring drain slots and chamfers of the radial gussets facing down. After the axial spacer is properly placed in the removable lower section, the lower section must be reattached (bolted) to the BMI-1 basket.

2. Prior to loading the University of Virginia fuel assemblies in the Texas A&M basket, the four aluminum inserts (Lockheed Martin Dwg. No. 507584, Rev. 1) must be placed, with the lifting bails located at the top of the basket, in the center four compartments of the BMI-1 basket as shown in Figure 1-1.

3. The University of Virginia fuel assemblies must be placed in the eight peripheral compartments of the BMI-1 basket as shown in Figure 1-1. The fuel assemblies must be loaded upright with the fuel assemblies lifting bail at the top of the basket to ensure proper positioning of the fuel relative to the basket poison material.

8. CONCLUSION

This evaluation demonstrates that the BMI-1 Cask with up to eight LEU MTR-type fuel assemblies (each containing a maximum of 282.7 g of U-235), loaded as proposed, has adequate margin of safety to ensure that the general public and the environment are protected from undue risks. The package complies with the requirements of 10 CFR 71 for exclusive use shipments as a Type B quantity, fissile material container, with a criticality control Transport Index of 100.

Based upon the results of this evaluation, permission is respectively requested, in the form of a letter of agreement, to use the BMI-1 packaging as proposed to transport up to eight LEU, intact, irradiated, MTR-type fuel assemblies, each containing a maximum of 282.7 g U-235.

8. REFERENCES

1. U.S. Nuclear Regulatory Commission, Certificate of Compliance No. 5957 for the Model BMI-1 Cask, Revision 24, 3/26/96.

2. *Code of Federal Regulations,* 10 CFR 71, "Packaging and Transportation of Radioactive Material," Office of the Federal Register, January 1, 1998.

3. U.S. Department of Energy, DOESRAAD-98-002, Rev. 0, Appendix A, "Spent Nuclear Fuel Acceptance Criteria, No. 1STD, Rev. 0 under Contract No. DEAC05-76ER02426 with The University of Virginia."

4. U.S. Department of Energy, Isotope Production and Distribution Division NE-70, *Safety Analysis Report for the Model BMI-1 Shipping Cask*, Revision J, October 6, 1995.

5. A. Higdon, E. H. Ohlsen, and W. B. Stiles, *Mechanics of Materials,* New York: John Wiley & Sons, Inc., 1962, Pages 350 and 353.

6. U.S. Nuclear Regulatory Commission, Regulatory Guide 7.6, "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," Revision 1, USNRC, Washington, D.C., March 1978.

7. W. D. Richins and G. K. Miller, "An Assessment of Swaged Connections in a Nuclear Fuel Element Using Nonlinear Finite Analysis," ASME/JSME Pressure Vessel and Piping Conference, July 1995.

8. EG&G Idaho, Inc., *Specification For University of Virginia Standard, Partial, and Control Fuel Elements and Removable Plate Element Assembled for The University of Virginia Reactor*, TRTR-2, Rev. 2, March 18, 1993.

9. R. Siegel and J.R. Howell, *Thermal Radiation Heat Transfer*, McGraw Hill Book Co. (1972).

10. E. C. Guyer, Editor, *Handbook of Applied Thermal Design*, McGraw Hill Book Co. (1989).

11. W. H. McAdams, *Heat Transmission*, McGraw Hill Book Co., 3rd Ed.

12. EG&G Idaho, Inc., Drawing 428500, "University of Virginia Test Research & Training Reactor 2 Standard & Partial Fuel Element Assembly."

13. Battelle Memorial Institute, Drawing BCL-000-500, "Basket Assembly, BMI-1 Cask."

14. Battelle Memorial Institute, Drawing 00-000-236, "BMI-1 Basket Modification to Ship Texas A&M Fuel Assembly."

15. Battelle Memorial Institute, Drawing 43-6704-0001, "Shipping Cask Assembly."

16. L. M. Petrie and N. F. Landers, *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, NUREG/CR-0200, Rev. 4 (ORNL/NUREG/CSD-2), Oak Ridge National Laboratory, April 1992.

17. L. M. Montierth, *Software Quality Assurance Plan for CSAS4 HP720*, A00064, August 1992.

18. K. B. Woods, *Critical Experiments of SPERT-D Fuel in Water*, International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03/II, HEU-MET-THERM-006, May 1995.

19. S. S. Kim and V. F. Dean, *Water-Moderated $U(4.31)O_2$ Fuel Rods Reflected by Two Lead, Uranium, or Steel Walls,* International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03/IV, LEU-COMP-THERM-010, May 1995.

20. S. S. Kim and V. F. Dean, *Water-Moderated Rectangular Clusters of $U(2.35)O_2$ Fuel Rods (2.032-cm Pitch) Separated by Steel, Boral, Copper, Cadmium, Aluminum, or Zircaloy-4 Plates,* International Handbook of Evaluated Criticality Safety Benchmark Experiments, NEA/NSC/DOC(95)03/IV, LEU-COMP-THERM-016. May 1995.

Appendix A

Criticality Evaluation Input Listings

Listing 1. Infinite array of dry BMI-1 casks.

```
=CSAS25
ACC154 inf BMI Casks, 282.7g U-235, 20%, hex, 75% B,
0.1406 gap, 8 rods, dry
27GROUPNDF4     INFHOMMEDIUM
U-235          1  0  1.73064-3    END
U-238          1  0  6.83511-3    END
H2O            2  1.0             END
PB             3  0  3.29879-2    END
B-10           4  0  5.97613-3    END
B-11           4  0  2.40540-2    END
C              4  0  1.00456-2    END
AL             4  0  3.82052-2    END
AL             5  0  6.02377-2    END
SS304          6  1.0             END
H2O            7  0.1             END
END COMP
ACC154 inf BMI Casks, 282.7g U-235, 20%, hex, 75% B,
0.1406 gap, 8 rods, dry
READ PARA
  TME=150.0  GEN=203    NPG=1000
  FLX=NO     FDN=NO     AMX=NO     FAR=NO
  RUN=YES    PLT=YES    NUB=YES
END PARA
READ GEOM
  UNIT 1
   COM=* Horizontal SS *
   CUBOID  6  1  2P0.31750  0.15748  0.0  2P31.75
  UNIT 2
   COM=* upper Horizontal Poison *
   CUBOID  4  1  2P3.74396  0.0508    0.0  2P31.08706
   CUBOID  5  1  2P3.77190  0.07874   0.0  2P31.115
   CUBOID  6  1  2P3.77190  0.15748   0.0  2P31.75
  UNIT 22
   COM=* lower Horizontal Poison *
   CUBOID  4  1  2P3.74396  0.0  -0.0508    2P31.08706
   CUBOID  5  1  2P3.77190  0.0  -0.07874   2P31.115
   CUBOID  6  1  2P3.77190  0.0  -0.15748   2P31.75
  UNIT 3
   COM=* upper Hz Poison Array *
   ARRAY 3       0.0          0.0         -31.75
  UNIT 23
   COM=* lower Hz Poison Array *
   ARRAY 23      0.0          0.0         -31.75
  UNIT 4
   COM=* Vertical SS *
   CUBOID  6  1  0.15748  0.0   2P0.31750  2P31.75
  UNIT 5
   COM=* right Vertical Poison *
   CUBOID  4  1  0.0508   0.0  2P3.74396  2P31.08706
   CUBOID  5  1  0.07874  0.0  2P3.77190  2P31.115
   CUBOID  6  1  0.15748  0.0  2P3.77190  2P31.75
  UNIT 25
   COM=* left Vertical Poison *
   CUBOID  4  1  0.0    -0.0508    2P3.74396
2P31.08706
   CUBOID  5  1  0.0    -0.07874   2P3.77190  2P31.115
   CUBOID  6  1  0.0    -0.15748   2P3.77190  2P31.75
  UNIT 6
   COM=* right Vt Poison Array *
   ARRAY 6       0.0          0.0         -31.75
  UNIT 26
   COM=* left Vt Poison Array *
   ARRAY 26      0.0          0.0         -31.75
  UNIT 7
   COM=* Fuel Plate *
   CUBOID  1  1  2P3.13690  2P0.02540  2P29.845
   CUBOID  5  1  2P3.77952  2P0.06350  2P31.2801
  UNIT 8
   COM=* Gap *
   CUBOID  0  1  2P3.30200  2P0.17780  2P31.2801
   CUBOID  5  1  2P3.77952  2P0.17780  2P31.2801
  UNIT 9
   COM=* End Gap *
   CUBOID  0  1  2P3.30200  2P0.08890  2P31.2801
   CUBOID  5  1  2P3.77952  2P0.08890  2P31.2801
  UNIT 10
   COM=* UVA Fuel Element *
   ARRAY 10     -3.77952  -5.3086   -31.28010
  UNIT 11
   COM=* left side *
   ZHEMICYL+X  0  1  19.685     2P68.58
   HOLE      3      0.19686     0.0          31.75
   HOLE     23      0.19686    -0.15748      31.75
   HOLE      6      0.0         0.19686      31.75
   HOLE      6      0.0       -17.18946      31.75
   HOLE     10      3.93701    12.80090      32.22
   HOLE     10      3.93701   -12.80090      32.22
   HOLE     10     11.49606     7.10734      32.22
   HOLE     10     11.49606    -7.10734      32.22
   ZHEMICYL+X  6  1  20.32      2P70.485
   ZHEMICYL+X  3  1  40.64      90.805     -89.535
   ZHEMICYL+X  6  1  41.91      94.615     -92.075
  UNIT 12
   COM=* right side *
   ZHEMICYL-X  0  1  19.685     2P68.58
   HOLE      3    -17.18946     0.0          31.75
   HOLE     23    -17.18946    -0.15748      31.75
   HOLE     26     -0.15748     0.19686      31.75
   HOLE     26     -0.15748   -17.18946      31.75
   HOLE     10     -3.93701    12.80090      32.22
   HOLE     10     -3.93701   -12.80090      32.22
   HOLE     10    -11.49606     7.10734      32.22
   HOLE     10    -11.49606    -7.10734      32.22
   ZHEMICYL-X  6  1  20.32      2P70.485
   ZHEMICYL-X  3  1  40.64      90.805     -89.535
   ZHEMICYL-X  6  1  41.91      94.615     -92.075
  UNIT 13
   COM=* lower side *
   ZHEMICYL+Y  0  1  19.685     2P68.58
   HOLE      3    -17.18946     0.0          31.75
   HOLE      3      0.19686     0.0          31.75
   HOLE      6      0.0         0.19686      31.75
   HOLE     26     -0.15748     0.19686      31.75
   HOLE     10     -3.93701    12.80090      32.22
   HOLE     10      3.93701    12.80090      32.22
   HOLE     10    -11.49606     7.10734      32.22
   HOLE     10     11.49606     7.10734      32.22
   ZHEMICYL+Y  6  1  20.32      2P70.485
   ZHEMICYL+Y  3  1  40.64      90.805     -89.535
   ZHEMICYL+Y  6  1  41.91      94.615     -92.075
  UNIT 14
   COM=* upper side *
   ZHEMICYL-Y  0  1  19.685     2P68.58
   HOLE     23    -17.18946    -0.15748      31.75
   HOLE     23      0.19686    -0.15748      31.75
   HOLE      6      0.0       -17.18956      31.75
   HOLE     26     -0.15748   -17.18956      31.75
   HOLE     10     -3.93701   -12.80090      32.22
   HOLE     10      3.93701   -12.80090      32.22
   HOLE     10    -11.49606    -7.10734      32.22
   HOLE     10     11.49606    -7.10734      32.22
   ZHEMICYL-Y  6  1  20.32      2P70.485
   ZHEMICYL-Y  3  1  40.64      90.805     -89.535
   ZHEMICYL-Y  6  1  41.91      94.615     -92.075
 GLOBAL
  UNIT 15
   CUBOID     0  1  2P41.9101  2P72.5903   186.6901  -
0.0001
   HOLE     11     -41.91      0.0        92.075
   HOLE     12      41.91      0.0        92.075
   HOLE     13       0.0     -72.59025    92.075
   HOLE     14       0.0      72.59025    92.075
END GEOM
READ ARRAY
 ARA=3  NUX=5  NUY=1   NUZ=1
 FILL  1 2 1 2 1 END FILL
 ARA=6  NUX=1  NUY=5   NUZ=1
 FILL  4 5 4 5 4 END FILL
 ARA=10 NUX=1  NUY=45  NUZ=1
 FILL  9 7 8 20Q2 7 9  END FILL
 ARA=12 NUX=3  NUY=3   NUZ=3
 FILL  F11  END FILL
 ARA=23 NUX=5  NUY=1   NUZ=1
 FILL  1 22 1 22 1 END FILL
 ARA=26 NUX=1  NUY=5   NUZ=1
 FILL  4 25 4 25 4 END FILL
END ARRAY
READ BOUNDS  ALL=MIRROR  END BOUNDS
READ START  NST=6 TFX=-37.9 TFY=4.1 TFZ=123.0 LNU=203
END START
READ PLOT
 NCH=Ô .@!\+^=`Ô  PIC=MIX  PLT=YES
 TTL=* X-Y SLICE *
 XUL=-42.0  YUL=72.6   ZUL=123.0
 XLR=42.0   YLR=-72.6  ZLR=123.0
 UAX=1.0    VDN=-1.0   NAX=130  END
END PLOT
END PLOT
END DATA
END
```

Listing 2. One BMI-1 cask, accident condition, optimal moderation.

```
=CSAS25
ACC130 1 BMI Cask, 8 elements, 0.140ó gap, no poison,
cask water vf=0.3
27GROUPNDF4     INFHOMMEDIUM
U-235          1  0  1.73064-3    END
U-238          1  0  6.83511-3    END
H2O            2  1.0             END
PB             3  0  3.29879-2    END
B-10           4  0  5.97613-3    END
B-11           4  0  2.40540-2    END
C              4  0  1.00456-2    END
AL             4  0  3.82052-2    END
AL             5  0  6.02377-2    END
SS304          6  1.0             END
H2O            7  0.3             END
END COMP
ACC130 1 BMI Cask, 8 elements, 0.140ó gap, no poison,
cask water vf=0.3
READ PARA
  TME=150.0  GEN=203    NPG=1000
  FLX=NO     FDN=NO     AMX=NO     FAR=NO
  RUN=YES    PLT=YES    NUB=YES
END PARA
READ GEOM
  UNIT 1
   COM=* Horizontal SS *
   CUBOID  6  1  2P0.31750  2P0.15748  2P31.75
  UNIT 2
   COM=* Horizontal Poison *
   CUBOID  4  1  2P3.74396  2P0.0508   2P31.08706
   CUBOID  5  1  2P3.77190  2P0.07874  2P31.115
   CUBOID  6  1  2P3.77190  2P0.15748  2P31.75
  UNIT 3
   COM=* Hz Poison Array *
   ARRAY 3       -8.49630    -0.15748   -31.75
  UNIT 4
   COM=* Vertical SS *
   CUBOID  6  1  2P0.15748  2P0.31750  2P31.75
  UNIT 5
   COM=* Vertical Poison *
   CUBOID  4  1  2P0.0508   2P3.74396  2P31.08706
   CUBOID  5  1  2P0.07874  2P3.77190  2P31.115
   CUBOID  6  1  2P0.15748  2P3.77190  2P31.75
  UNIT 6
   COM=* Vt Poison Array *
   ARRAY 6       -0.15748    -8.49630   -31.75
  UNIT 7
   COM=* Fuel Plate *
   CUBOID  1  1  2P3.13690  2P0.02540  2P29.845
   CUBOID  5  1  2P3.77952  2P0.06350  2P31.2801
  UNIT 8
   COM=* Gap *
   CUBOID  2  1  2P3.30200  2P0.17780  2P31.2801
   CUBOID  5  1  2P3.77952  2P0.17780  2P31.2801
  UNIT 9
   COM=* End Gap *
   CUBOID  2  1  2P3.30200  2P0.08890  2P31.2801
   CUBOID  5  1  2P3.77952  2P0.08890  2P31.2801
  UNIT 10
   COM=* UVA Fuel Element *
   ARRAY 10      -3.77952  -5.3086   -31.28010
 GLOBAL
  UNIT 11
   CYLINDER  7  1  19.685     2P68.58
   HOLE      10      3.77953     11.87236    32.22
   HOLE      10     -3.77953     11.87236    32.22
   HOLE      10     -3.77953    -11.87236    32.22
   HOLE      10      3.77953    -11.87236    32.22
   HOLE      10     11.33858      6.30376    32.22
   HOLE      10    -11.33858      6.30376    32.22
   HOLE      10    -11.33858     -6.30376    32.22
   HOLE      10     11.33858     -6.30376    32.22
   CYLINDER  6  1  20.32      2P70.485
   CYLINDER  3  1  40.64      90.805     -89.535
   CYLINDER  6  1  41.91      94.615     -92.075
   CUBOID    2  1  4P71.91   124.615    -122.075
END GEOM
READ ARRAY
 ARA=3  NUX=5  NUY=1   NUZ=1
 FILL  1 2 1 2 1 END FILL
 ARA=6  NUX=1  NUY=5   NUZ=1
 FILL  4 5 4 5 4 END FILL
 ARA=10 NUX=1  NUY=45  NUZ=1
 FILL  9 7 8 20Q2 7 9  END FILL
END ARRAY
READ PLOT
 NCH=Ő .@!\+^=`Ő  PIC=MIX  PLT=YES
 TTL=* X-Y SLICE *
 XUL=-20.0   YUL=20.0    ZUL=34.0
 XLR=20.0    YLR=-20.0   ZLR=34.0
 UAX=1.0     VDN=-1.0    NAX=130  END
 NCH=Ő .@!\+^=`Ő  PIC=MIX  PLT=YES
 TTL=* X-Y SLICE *
 XUL=0.0     YUL=8.87    ZUL=34.0
 XLR=8.87    YLR=0.0     ZLR=34.0
 UAX=1.0     VDN=-1.0    NAX=130  END
END PLOT
END DATA
END
```

Listing 3. Three BMI-1 casks, normal condition, optimal moderation.

```
=CSAS25
ACC160 3 BMI Casks, 8 elements, 0.140ó gap, 75%
poison, cask vf=0.7
27GROUPNDF4     INFHOMMEDIUM
U-235          1  0  1.73064-3    END
U-238          1  0  6.83511-3    END
H2O            2  1.0             END
PB             3  0  3.29879-2    END
B-10           4  0  5.97613-3    END
B-11           4  0  2.40540-2    END
C              4  0  1.00456-2    END
AL             4  0  3.82052-2    END
AL             5  0  6.02377-2    END
SS304          6  1.0             END
H2O            7  0.7             END
END COMP
ACC160 3 BMI Casks, 8 elements, 0.140ó gap, 75%
poison, cask vf=0.7
READ PARA
  TME=150.0  GEN=203    NPG=1000
  FLX=NO     FDN=NO     AMX=NO     FAR=NO
  RUN=YES    PLT=YES    NUB=YES
END PARA
READ GEOM
  UNIT 1
   COM=* Horizontal SS *
   CUBOID  6  1  2P0.31750  2P0.15748  2P31.75
  UNIT 2
   COM=* Horizontal Poison *
   CUBOID  4  1  2P3.74396  2P0.0508   2P31.08706
   CUBOID  5  1  2P3.77190  2P0.07874  2P31.115
   CUBOID  6  1  2P3.77190  2P0.15748  2P31.75
  UNIT 3
   COM=* Hz Poison Array *
   ARRAY 3       -8.49630    -0.15748   -31.75
  UNIT 4
   COM=* Vertical SS *
   CUBOID  6  1  2P0.15748  2P0.31750  2P31.75
  UNIT 5
   COM=* Vertical Poison *
   CUBOID  4  1  2P0.0508   2P3.74396  2P31.08706
   CUBOID  5  1  2P0.07874  2P3.77190  2P31.115
   CUBOID  6  1  2P0.15748  2P3.77190  2P31.75
  UNIT 6
   COM=* Vt Poison Array *
   ARRAY 6       -0.15748    -8.49630   -31.75
  UNIT 7
   COM=* Fuel Plate *
   CUBOID  1  1  2P3.13690  2P0.02540  2P29.845
   CUBOID  5  1  2P3.77952  2P0.06350  2P31.2801
  UNIT 8
   COM=* Gap *
   CUBOID  2  1  2P3.30200  2P0.17780  2P31.2801
   CUBOID  5  1  2P3.77952  2P0.17780  2P31.2801
  UNIT 9
   COM=* End Gap *
   CUBOID  2  1  2P3.30200  2P0.08890  2P31.2801
   CUBOID  5  1  2P3.77952  2P0.08890  2P31.2801
  UNIT 10
   COM=* UVA Fuel Element *
   ARRAY 10      -3.77952  -5.3086   -31.28010
  UNIT 11
   CYLINDER  7  1  19.685     2P68.58
   HOLE      3      8.69316      0.0        31.75
   HOLE      3     -8.69316      0.0        31.75
   HOLE      6      0.0          8.69316    31.75
HOLE      6      0.0         -8.69316    31.75
   HOLE      10     3.93701     12.80090    32.22
   HOLE      10    -3.93701     12.80090    32.22
   HOLE      10    -3.93701    -12.80090    32.22
   HOLE      10     3.93701    -12.80090    32.22
   HOLE      10    11.49606      7.10734    32.22
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   HOLE       10   -11.49606     7.10734   32.22
   HOLE       10   -11.49606    -7.10734   32.22
   HOLE       10    11.49606    -7.10734   32.22
   CYLINDER .6  1  20.32       2P70.485
   CYLINDER  3  1  40.64       90.805     -89.535
   CYLINDER  6  1  41.91       94.615     -92.075
 GLOBAL
  UNIT 12
   CUBOID    0  1  2P83.8201   114.5003   -41.9101
186.6901  -0.0001
   HOLE       11      -41.91     0.0         92.075
   HOLE       11       41.91     0.0         92.075
   HOLE       11        0.0     72.59025     92.075
   REPLICATE 2 1  6R30.0 1
END GEOM
READ ARRAY
 ARA=3  NUX=5  NUY=1   NUZ=1
 FILL  1 2 1 2 1 END FILL
 ARA=6  NUX=1  NUY=5   NUZ=1
 FILL  4 5 4 5 4 END FILL
 ARA=10 NUX=1  NUY=45  NUZ=1
 FILL  9 7 8 20Q2 7 9  END FILL
END ARRAY
READ PLOT
 NCH=Ŏ .@!\+^=`Ŏ  PIC=MIX  PLT=YES
 TTL=* X-Y SLICE *
 XUL=-20.0  YUL=20.0   ZUL=34.0
 XLR=20.0   YLR=-20.0  ZLR=34.0
 UAX=1.0    VDN=-1.0   NAX=130  END
 NCH=Ŏ .@!\+^=`Ŏ  PIC=MIX  PLT=YES
 TTL=* X-Y SLICE *
 XUL=0.0    YUL=8.87   ZUL=34.0
 XLR=8.87   YLR=0.0    ZLR=34.0
 UAX=1.0    VDN=-1.0   NAX=130  END
END PLOT
END DATA
END
```

FIGURE WITHHELD UNDER 10 CFR 2.390

9904260232-01

=2 QTY	=1 REQD	QUAL LEVEL	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.
	AR	2		WELD FILLER METAL	ER4043 AWS A5.10	6
						5
	1	2	-4	BAIL	BAR, ø.375 AL 6061-T6 ASTM B221	4
	1	1	-3	SPACER	TUBING, □3 3/16 WALL AL 6061-T6 ASTM B221	3
						2
		1	-1	ASSEMBLY		1

PARTS LIST

DIMENSIONING AND SYMBOLOGY ARE AMERICAN NATIONAL STANDARD
UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS 125
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: .X = ±.1
DECIMALS: .XX = ±.01
.XXX = ±.010
FRACTIONS ±1/8
ANGULAR ±2°
DO NOT SCALE DRAWING

SUBCONTRACT NO.
REQUESTER: T. BRIDGES
DESIGN: D. MORRELL
DRAWN: Eric E. Thomas
PROJECT NO.
SPEC CODE
FOR REVIEW/APPROVAL SIGNATURES SEE DAR NO. 15033
EFFECTIVE DATE: 8/13/98

LOCKHEED MARTIN

BMI-1 CASK
UNIVERSITY OF VIRGINIA FUEL
BASKET INSERT

SIZE: D | CAGE CODE: 01MF3 | INDEX CODE NUMBER: AREA 544, TYPE 9999, OL 43, ORG 530 | DWG- 507584 | REV 1

SCALE: 1/1 | SHEET 1 OF 1

FIGURE WITHHELD UNDER 10 CFR 2.390

9904260232-02

QTY REQD	QUAL LEVEL	PART OR IDENTIFYING NO.	NOMENCLATURE OR DESCRIPTION	MATERIAL/SPECIFICATION OR VENDOR NAME	ITEM NO.
AR	2		WELD FILLER METAL	ER4043 AWS A5.10	6
					5
8	2	-4	FLANGE	BAR 3/8 THK, 3" WIDE AL 6061-T6511 ASTM B221	4
1	2	-3	RING	TUBING, 12" OD X .5" WALL X 3"LG AL 6061-T6511 ASTM B241	3
					2
	2	-1	ASSEMBLY		1
-1					

PARTS LIST

DIMENSIONING AND SYMBOLOGY ARE AMERICAN NATIONAL STANDARD UNLESS OTHERWISE SPECIFIED
SURFACE ROUGHNESS 125/
DIMENSIONS AND TOLERANCES ARE IN INCHES
TOLERANCES: .X = ±.1
DECIMALS: .XX = ±.03
.XXX = ±.010
FRACTIONS ±1/8
ANGULAR ±2°
DO NOT SCALE DRAWING

SUBCONTRACT NO.
REQUESTER: T. BRIDGES
DESIGN: D. MORRELL
DRAWN: Eric E Thomas
PROJECT NO.
SPEC CODE
FOR REVIEW/APPROVAL SIGNATURES SEE DWR NO. 15033
EFFECTIVE DATE: 8/13/98

LOCKHEED MARTIN

BMI-1 CASK
UNIVERSITY OF VIRGINIA FUEL
AXIAL SPACER

SIZE	CAGE CODE	INDEX CODE NUMBER AREA	TYPE	SL	ORG	DWG-	REV
D	01MF3	544	9999	43	530	507583	1

SCALE: NOTED
SHEET 1 OF 1

2 1