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Preliminary Design Report
Babcock & Wilcox

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BR-100
100-Ton Rail/Barge Spent Fuel Shipping Cask

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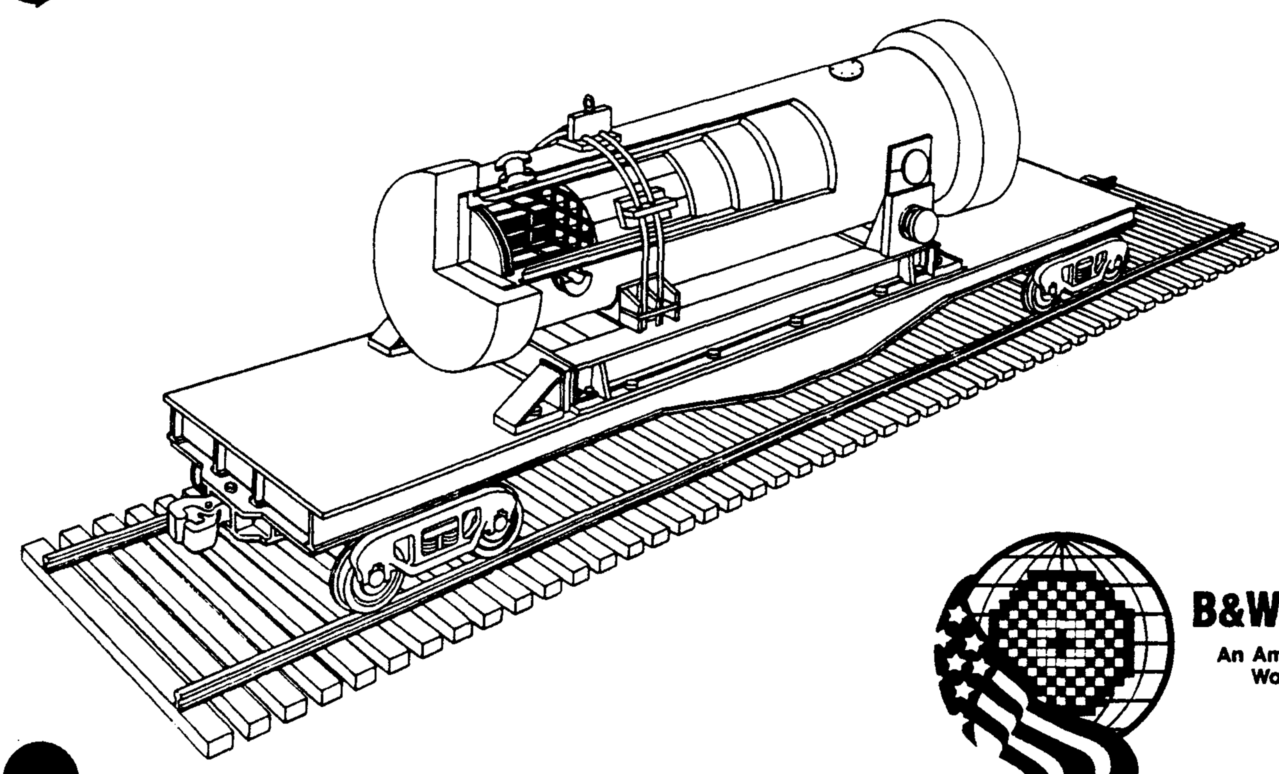

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1.0 OVERVIEW

Babcock & Wilcox (B&W) is one of five suppliers selected by the Department of Energy (DOE) to develop a from-reactor cask for their Cask System Development Program. B&W was selected to develop a 100-ton rail/barge cask and has designated their product the BR-100. The B&W Fuel Company (BWFC) is the lead organization within B&W for the BR-100 project and has assistance from other B&W divisions, from Robatel SA (a French cask designer and fabricator), and from Duke Power Company. The contract between B&W and DOE was signed on July 15, 1988, and B&W was given approval to start design activities on November 18, 1988.

The BR-100 cask is an efficient package that, with design-basis fuel per the contract Statement of Work (SOW), can transport 21 Pressurized Water Reactor (PWR) or 52 Boiling Water Reactor (BWR) fuel assemblies. All fuel described in the SOW--standard or nonstandard--can be accommodated with the BR-100, with the single exception of the extra-long fuel used at the South Texas Project. Exceptional flexibility in carrying nonstandard payloads--consolidated fuel, high-burnup fuel, short-cooled fuel, nonfuel-bearing components (NFBC), etc.--is also a characteristic of the BR-100. Through a combination of moderately high capacity, low fabrication cost, and efficient operations/maintenance, the lowest possible life-cycle cost was developed for the BR-100.

This Preliminary Design Report (PDR) is a summary of work performed by the BWFC in the preliminary design phase of the BR-100 project.

Section II of this report presents the preliminary design of the BR-100 cask and outlines its performance through display of several preliminary analyses. Section II follows the format of Regulatory Guide 7.9 and presents not only results of preliminary analyses but plans for further confirmatory analyses and testing. An exceptionally rigorous analytical and testing regime has been proposed to provide an optimal combination of payload efficiency and public/worker safety. All aspects of the BR-100 are shown to meet design objectives and to be acceptable from a regulatory perspective.

Section III compiles the noncertification items required by the contract Statement-of-Work and also presents subsections describing project operations. A checklist is supplied to cross-reference contract requirements to sections of this design package. The QA and project management roles within the BR-100 project are described and statused. Recommendations from an Advisory Review Board (ARB), established by BWFC to oversee BR-100 development, and a formal Design Review Board (DRB), as required by B&W procedures, are listed and corresponding responses by BWFC are described. A similar subsection on DOE Technical Review Group (TRG) comments is included and responses are listed. The estimated production cost of $1.5M per cask and its associated schedule are detailed. BR-100 certification and testing issues are defined and resolution strategies outlined. Railcar and ancillary equipment designs are shown and described. Repository, reactor, and rail/barge interfaces are described and salient issues identified. The role of Human Factors Engineering in the development of the BR-100 system is explained. Finally, the use of Life-Cycle Cost modeling in the design of the BR-100 is presented, and the rationale used for critical technical decisions is advanced.

Section IV contains the trade-off studies required by the SOW and gives comparative results of their effect on the BR-100. Burnup credit was incorporated to provide a cask capacity of 21 PWR fuel assemblies. Burnup credit was not needed for the 52 BWR assembly capacity. Reduction of the 2 m dose rate to 2 mr/hr using the baseline baskets was found to reduce the BR-100 payload to 12 PWR or 32 BWR assemblies; redesigned baskets had a 14 PWR or 40 BWR capacity. Transportation of five-year cooled fuel instead of ten-year cooled fuel (all at design baseline burnups and enrichments) reduced capacity in the baseline baskets to nine PWR assemblies, although all 52 BWR assemblies could still be accommodated. A redesign of the PWR basket would allow 16 five-year PWR assemblies to be shipped by themselves, but a more efficient solution of shipping 9 five-year assemblies in the inner portion of the basket and 12 ten-year assemblies on the basket outer row achieves a full payload and meets all shielding and thermal criteria. The BR-100 is shown to transport significant quantities of consolidated fuel and NFBC and full payloads of practically every fuel type in inventory. An attribute of the BR-100 is its ability to carry PWR control components or BWR channels with the fuel being transported. The BR-100's ability to carry large quantities of high-burnup fuel is demonstrated by the values in Table 1-1. All fuel is ten-year cooled, and enrichments were selected on the basis of reasonability and conservative source term/decay heat values (lower enrichments have higher source strengths and heat generation rates).

Shadow shielding, or selectively positioning lower burnup fuel in the basket periphery to shield higher burnup fuel in the center, can yield more efficient loading combinations (e.g., 9 60-GWd/mtU and 12 35-GWd/mtU assemblies for PWR, 44 50-GWd/mtU and 8 30-GWd/mtU assemblies for BWR). The BR-100 can dissipate over 15 kW of heat without exceeding design temperature limits. Section V contains the drawing list for the baseline BR-100 preliminary design and has foldout copies of those drawings in the order given on the list.

Table 1-1
BR-100 HIGH BURNUP CAPACITIES

Fuel Type	Burnup (GWd/mtU)	Enrichment (w/o)	Decay Heat (watts per ass'y)	Quantity/Cask Fuel Assemblies
PWR	35	3.0	574	21
PWR	40	3.5	661	21
PWR	45	4.0	748	19
PWR	50	4.5	837	16
PWR	55	4.5	956	16
PWR	60	4.5	1,088	14
BWR	30	3.0	178	52
BWR	35	3.0	215	52
BWR	40	3.5	248	52
BWR	45	4.0	282	52
BWR	50	4.5	316	48

Section VI contains various documents that illustrate the depth of B&W's commitment to the successful completion of the BR-100 project and contribute to an understanding of this report. ARB and DRB member resumes, human factors specialists resumes, and the Engineering Test Plan are among the documents included.

This Report presents much of the work performed by the BR-100 project team during the preliminary design phase. It shows that the BR-100 has evolved into an efficient package for the transportation of different payloads--even high-burnup, short-cooled, or nonstandard fuel.

1.0 GENERAL INFORMATION

1.1 INTRODUCTION

This Preliminary Design Report (PDR) provides a detailed description of the design, analyses, and testing programs for the BR-100 cask. The BR-100, shown in Figure 1-1, is a Type B(U) cask designed for transport by rail or barge. This report presents the preliminary analyses and tests which have been performed for the BR-100 and outlines the confirmatory analyses and tests which will be performed. The format and content of Section II (Design Description) follow the guidelines provided by Regulatory Guide 7.9.

The basic structure of the BR-100 includes a multiwall cask body and a stainless steel closure lid. The cask body is made of inner and outer stainless steel shells welded to a forged stainless steel bolting flange at the top and separate forged plates at the bottom. Layers of lead and borated concrete between the steel shells provide a gamma and neutron shields respectively. Impact limiters, consisting of balsa and redwood encased in a Kevlar^R/epoxy composite, are attached to each end of the cask. Separate Pressurized Water Reactor (PWR) or Boiling Water Reactor (BWR) fuel baskets are loaded into the cask cavity to provide compartments for the fuel to be transported. A shield plug of lead encased in stainless steel is located between the payload and the closure lid. The total empty weight of the BR-100 on its skid is 168,900 lb (PWR configuration) or 169,900 lb (BWR configuration). Its corresponding loaded weight can range up to 201,700 lb (heaviest PWR payload) or 203,700 lb (heaviest BWR payload). The overall dimensions of the BR-100, with impact limiters, are 252 in in length and 125 in in diameter. With impact limiters removed, the external dimensions are 202 in in length and 82 in in diameter.

The BR-100 is transported horizontally in an intermodal shipping skid compatible with rail or barge shipment. Cask loading and unloading operations are performed with the cask in a vertical orientation. The closure lid end is defined as the top, with the packaging vertical, and is defined as the forward end when it is horizontal. Trunnions bolted to the cask body are provided for lifting and handling operations, including rotation of the packaging between the vertical and horizontal positions.

The design basis maximum operating pressure of the BR-100 is assumed to be 100 psi, which includes all effects from temperature, residual water, and hypothetical release of fill gas/fission products from 100% of the fuel rods transported. The spent fuel is shipped dry in a helium atmosphere. The heat generated by the spent fuel is dissipated to the surrounding environment by convection and radiation. No forced air cooling or cooling fins are required. Acceptable performance of the containment boundary seal material (Viton^R GLT) is anticipated for the full range of predicted temperatures.

The BR-100 has a capacity of 21 intact PWR fuel assemblies or 52 intact BWR fuel assemblies. Alternative payloads could include other forms of High Level Waste (HLW), consolidated fuel, or NonFuel-Bearing Components (NFBC). The BR-100 can dissipate over 15 kW in decay heat while staying within temperature design limits.

1.2 PACKAGE DESCRIPTION

1.2.1 Packaging

The isometric view of the BR-100 shown in Figure 1-1 identifies the major components or subassemblies of the packaging. Cask materials of construction are summarized in Table 1-1. This section provides physical descriptions of each major component. Detailed drawings for the BR-100 preliminary design are provided in Section V of this design report and provide the basis for all analysis. Fabrication drawings are yet to be generated.

Table 1-1
CASK MATERIALS

	Materials	Specification
Containment		
Inner shell assembly	304L SS	ASME SA-240 or SA-358, Class 1
Closure lid	XM-19 SS	ASME SA-240, Sol. Ann./WQ
Closure bolts	Alloy 718	ASME SB-637
Seals	Viton[R]	Parker V835-75
Gamma shield	Lead	ASTM B29
Neutron shield	Borated concrete/Copper fins	
Cask Body		
Outer shell	304L SS	ASME SA-240 or SA-358, Class 1
Bottom head	304L SS forging	ASME SA-182, Sol. Ann./WQ
Reinforcement ring	XM-19 SS	ASME SA-182, Sol. Ann./WQ
Trunnion	XM-19 SS forging	ASME SA-182, Sol. Ann./WQ
Blank	304L SS	ASME SA-182, Sol. Ann./WQ
Trunnion bolts	Alloy 718	ASME SB-637
Fusible plug	60 Bi; 40 Cd alloy	
Shield plug casing	XM-19 SS	ASME SA-240, Sol. Ann./WQ
Impact limiter	Balsa/redwood/Kevlar[R]	
		Continued...

Table 1-1, Continued
CASK MATERIALS

	Materials	Specification
Basket		
Fuel cell	Al 6061	ASME SB-221,T6511
Formers	Al Alloy SG70A	ASME SB-26, T71
Upper grid	Al Alloy SG70A	ASME SB-26, T71
Bottom plate	Al 6061	ASME SB-209, T6
Neutron poison	Al, B_4C Cermet	

1.2.1.1 Containment Vessel

The containment vessel is comprised of the cask forged inner bottom, the inner steel shell, the forged bolting flange, and the closure lid, which is attached with 32 nickel-alloy bolts. The bolts are 9.0-inches long with a diameter of 2.5 in in the threaded portion and 2.375 in in the shank. Sealing of the lid to the cask is accomplished by a pair of concentrically arranged O-ring face seals mounted in grooves machined in the underside of the lid. Both O-rings are made of Viton GLT, but the inner seal serves as the primary containment boundary. The outer seal serves to facilitate the leak testing of the inner seal.

The only penetrations through the containment vessel are two ports in the closure lid which are used for cask operations. During transport, both ports are individually sealed and then covered by a bolted cover plate that also has two Viton O-ring face seals. The closure lid seals and penetration seals have provisions for helium leak checks.

The cask body portion of the containment vessel consists of the inner stainless steel cylindrical shell closed at one end by a bottom plate. The bottom plate is attached to the shell with a full penetration weld. The shell is attached to a forged bolting flange at the open end by a full penetration weld. The cask cavity is nominally 58.5 in in diameter with a usable length of 181 in. The material used does not require heat treatment after welding.

The closure lid is a stainless steel forged disk 80.5 in in diameter, with a maximum thickness of 5.5 in. The bolt circle has a diameter of 73.0 in with 32 holes 2.531 in in diameter. Alignment pins or offset bolts will be used to maintain a specific orientation with the cask body.

The cask shell, bolting flange and bottom plate material is ASME-grade 304L and the lid material is ASME-grade XM-19, both austenitic stainless steels with excellent toughness and ductility properties. No coating or cladding is required to supplement the natural corrosion resistance of the materials used.

1.2.1.2 Noncontainment Packaging Components

The containment bolting flange is attached with a full penetration weld to the steel outer shell. The outer shell is also attached with full penetration welds to eight trunnion reinforcement rings (four equally spaced at each end) and to a forged bottom plate. The outer shell and bottom plate are ASME-grade 304L stainless steel. The trunnion reinforcing rings are ASME-grade XM-19 stainless steel with an inner welded plate of ASME-grade 304L stainless steel. The outer shell has twelve tapped penetrations (four equally spaced per plane, three planes per length) that are each hermetically sealed with a low-melting-point fusible plug; the plugs will melt if exposed to the hypothetical thermal conditions listed in 10CFR71, allowing a portion of the water within the borated concrete to change to steam and vent to the atmosphere. This vented steam has no radioactive constituents and is small in volume but provides significant thermal enhancement to the BR-100's performance.

Sandwiched between the inner and outer steel shells is a 4.5-in-thick inner layer of lead and a 4.5-in-thick outer layer of borated concrete. The lead provides a gamma shield for the BR-100, and the borated concrete provides a combination neutron shield and thermal shield. Copper fins are positioned within the concrete to provide enhanced heat transfer during normal operation but let the concrete provide insulation for the lead and payload during thermal events. The thicknesses of the lead and concrete are changed slightly at the ends of the body to compensate for variation in gamma and neutron strength. Concrete is not required at the top and bottom of the cask.

Near the closure end, four trunnions are located spaced 90^{o} apart in the same plane. Near the bottom end, two trunnions and two blanks are located, each pair 180^{o} apart. Trunnions and blanks are bolted to the trunnion reinforcing ring. The trunnions are made of ASME grade XM-19 stainless steel. The blanks are made of 304L stainless steel, and the bolts are an ASME grade nickel-alloy.

1.2.1.3 Fuel Support Structure

Two different fuel support structures (i.e., baskets) were designed for the BR-100; one for PWR use and the other for BWR use. Each basket has the same components:

Fuel cells, support formers, top and bottom plates, tie rods, drain pipes, and banding straps. Components not part of the basket but used with it include aluminum stand-offs that vary from fuel type to fuel type and ensure the top of the fuel is within 2 in of the top of the fuel cavity.

Each basket has either PWR or BWR fuel cells that are made of extruded or drawn ASME-grade aluminum tubes with Cermet neutron absorber plates attached to the outside walls. The cells fit together to form gaps that provide neutron flux traps. The cast or extruded ASME-grade aluminum formers provide a transition between the square cells and the circular cask cavity and also provide structural support and an efficient heat transfer path. The Cermet plates are made of a ceramic-metallic powder metallurgical product that contains approximately 60% B_4C and 40% aluminum, all encased in a thin aluminum sheet. All remaining basket components except the banding straps are ASME-grade aluminum, and all aluminum components are hard anodized. The banding straps are made of 304L stainless steel.

The basket is assembled by positioning the fuel cells and formers on the lower plate, assembling the top plate and axial tie rods, and installing the banding straps. The tie rods and banding straps have no function during cask operations and are used only during basket changeout or inspection. No welds are used in the construction of the basket. Generous lead-ins in the top plates help guide the fuel assemblies into place. Fuel up to 180 in in length can be accommodated.

The PWR basket has fuel cavities that provide a minimum 8.72-in square and 12.306-in diagonal. This ensures at least a .090 in radial clearance for the largest fuel assemblies to be transported. The cells have a nominal .550-in gap between opposing Cermet plates.

The BWR cells have a minimum 5.72-in square cavity. They also have Cermet plates attached to their outer walls but do not need gaps that provide flux traps.

1.2.1.4 Impact Limiters

The two impact limiters used on the BR-100 are identical and interchangeable. Each one is attached to the cask body with eight fasteners. Balsa and redwood provide energy absorption and are hermetically sealed in a Kevlar/epoxy composite structure. The casing maintains proper moisture levels and confines the wood if it is crushed in an accident.

The impact limiters are 125 in in diameter and 36 in long. They overlap the cask body by 11 in. They each have fusible plugs that are used for periodic moisture inspection and also provide a steam relief vent during thermal accidents.

The attachment fasteners are designed to be easily checked to ensure security during transport. Each impact limiter has a lifting lug, but they are not used during normal operations due to a lifting/trolley mechanism designed into the railcar.

1.2.2 Operational Features

The BR-100 is compatible with both wet and dry loading/unloading operations. Preparation for those operations first requires that the impact limiters be removed. The cask is then rotated from horizontal to vertical using a crane and lifting equipment. Only the front two trunnions are used with the lifting equipment while the two rear trunnions pivot in the shipping skid saddles.

Access to the cask cavity and fuel basket is obtained by loosening the 32 closure lid bolts and removing the lid. The shield plug is then removed and the cask placed in a position to receive fuel. After the fuel is loaded, the shield plug is installed, the cavity is dewatered (if necessary), and the closure lid reinstalled. The cavity is inerted with a partial atmosphere of helium, all seals are checked, and the package is returned to the shipping skid. More detailed descriptions of these steps are provided in Section II-7.

1.2.3 Contents of Packaging

The BR-100 has a design payload of ten-year cooled fuel, with burnups of 35 GWd/mtU (PWR) and 30 GWd/mtU (BWR) and enrichments from 3.0 to 4.5 w/o. Within those constraints, separate baskets have been designed that accommodate 21 PWR assemblies or 52 BWR assemblies in any loading pattern. Trade-off studies have determined that significant quantities of short-cooled, high-burnup, or nonstandard fuel can be easily adapted for transport.

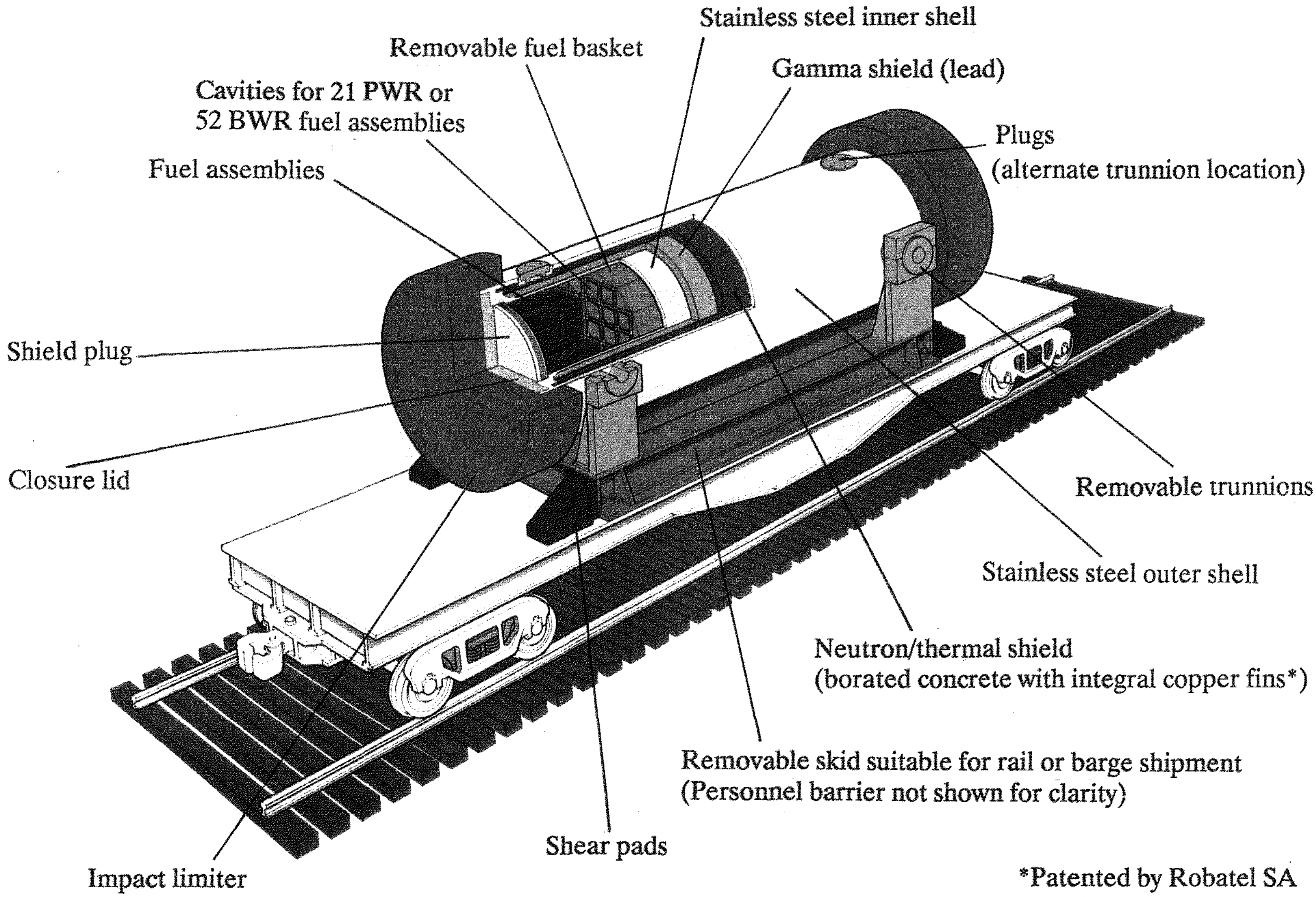
1.3 APPENDIX

The drawings for the BR-100 preliminary design are listed and contained in Section V of this Design Report.

Figure 1-1

Babcock & Wilcox BR-100

100-Ton Rail/Barge Cask



*Patented by Robatel SA

2.0 STRUCTURAL EVALUATION

This section presents BWFC strategy for ensuring that the BR-100 cask meets (or will be shown to meet) all applicable structural criteria required to maintain a subcritical array for the spent fuel and keep radiation exposure within federal limits. The cask body, closure lid, fuel basket, trunnions, and impact limiters are shown to provide acceptable protection for the spent fuel (cask payload). Normal and hypothetical accident evaluations are performed using analytical techniques per NRC Regulatory Guide 7.6. In the final design phase, experimental verification will be performed on a complete quarter-scale model and on scaled or full-size component tests.

Materials of construction analytical results in terms of margin of safety for normal and hypothetical accident conditions are summarized in Table 2-1 and Table 2-2.

The cask body inner and outer vessel walls are constructed from 304L stainless steel. For the preliminary design, most structural evaluations were performed using empirical equations or very conservative techniques. For some loading conditions, these preliminary analysis results may show very small margins for 304L, but in the final design, either 304L will be verified or XM-19, a stronger stainless steel material, will be used.

Table 2-1
MARGIN OF SAFETY-NORMAL CONDITIONS OF TRANSPORT
Preliminary

Component	Margin of Safety	
	Primary Membrane Tensile	Primary Membrane Plus Bending
Cask outer shell	>500	73
Cask inner shell	262	45
Cask bottom outer forging	>500	15
Closure lid	>500	32
Closure lid bolts	115	N/A
PWR cell	N/A	70
BWR cell	N/A	82
Trunnion	N/A	13

Notes

1. Margins are reported in % and derived by $\frac{\text{AllowableStress} - \text{ActualStress}}{\text{Actual Stress}} \text{ X } 100$
2. Fatigue and thermal stress analyses will be reported in the final design.
3. For details on loading, temperature, and stress, refer to Section 2.6, Normal Conditions of Transport, and tables 2-6 to 2-13.

Table 2-2

MARGIN OF SAFETY- HYPOTHETICAL ACCIDENT CONDITION

Preliminary

Component	Margin of Safety			
	Primary Membrane		Primary Plus Bending[4]	Puncture
	Tensile	Compressive Buckling[5]		
Cask outer shell	487	13	7 (304L) 86 (XM-19)	224
Cask inner shell	>500	393	1 (304L) 67 (XM-19)	31
Cask bottom outer forging	491	N/A	6 (304L) 75 (XM-19)	96
Closure lid	367	N/A	1	306
Closure lid bolts	106	N/A	N/A	Note 2
PWR Cell	N/A	61	2	N/A
BWR Cell	N/A	638	9	N/A

Notes

1. Margins are reported in % and derived by $\frac{\text{Allowable Stress} - \text{Actual Stress}}{\text{Actual Stress}} \times 100$
2. Stresses and margin due to puncture will be reported in the final design.
3. For details on loadings, temperature, and stresses, refer to Table 2-14 and Section 2.7, Accident Conditions.
4. Values for XM-19 shell material are shown in addition to the 304L baseline material. More discrete analyses should increase the 304L margins, but XM-19 is available as an economical, proven alternate material.
5. Buckling criteria per ASME Section III, except for cells. The PWR and BWR fuel cell uses ANSYS buckling criteria.

2.1 STRUCTURAL DESIGN

2.1.1 Discussion

The BR-100 cask structure is designed to maintain the subcritical condition of spent fuel and safe shipment of spent fuel by rail or barge. The main components of the cask system are:

- o Cask body
- o Closure lid
- o Shield plug
- o Fuel basket
- o Impact limiter
- o Trunnions

A schematic drawing of the cask is shown in Figure 2-1. The BR-100 cask is designed to transport 21 PWR or 52 BWR intact spent fuel assemblies by rail or barge. The loaded BR-100 cask weighs approximately 100 tons.

2.1.1.1 Cask Body

The cask body is made up of multiwalled cylinders. The cask consists of a 1-in-thick 304L stainless steel inner containment vessel, a 4.5-in-thick lead gamma shield, a 4.5-in-thick borated concrete thermal neutron shield and a 1.75-in-thick 304L stainless steel outer containment vessel. The thicknesses of lead and concrete are altered slightly in the upper and lower region to optimize radiation shielding. The outer vessel has an 82-in outside diameter and is 201.5 in long. The inner vessel has a 58.5-in inside diameter and provides a cavity of 181 in to accommodate various sizes of fuel designs. The borated concrete shell has a 78.5-in outside diameter and the lead shell has a 69.5-in outside diameter.

The bottom of the cask body is also of multiwall construction. The outer bottom is made of a 4.25-in-thick, 82-in diameter 304L stainless steel forging. The inner bottom, made of 304L stainless steel, has a thickness ranging from 2.75 in to 3 in thick and is 60.5 in in diameter. Between these two forgings is a 3-in-thick layer of lead for gamma radiation shielding. The inner and outer forgings are welded to the side walls by full penetration welds.

The inner shell comprises a containment pressure vessel when combined with a closure lid that bolts to the cask body. The outer shell provides a thermal barrier for hypothetical thermal accidents and resists puncture accident scenarios. The cask is able to survive a 30-ft drop and a 40-in drop onto a 6-in diameter, 8-in-long mild steel punch without releasing radioactive material, exceeding radiation shielding limits, or allowing a potentially critical geometry.

The outer shell has 12 tapped penetrations for installation of fusible plugs. The penetrations are hermetically sealed with low-melting-point fusible plugs (Figure 2-5). The plugs seal the cask outer shell during normal conditions in order to contain the water in the concrete. The plugs will melt if exposed to the hypothetical thermal condition allowing a portion of the water within the borated concrete to change to steam and vent to the atmosphere.

The 12 fusible plugs are located on three levels and are equally spaced four per level. The locations of the fusible plugs were selected to provide for uniform escape of the steam generated. Their number and size were defined to limit the pressure in the concrete, allowing reasonable steam flow rates through the fusible plugs.

The strength of borated concrete is not utilized in the structural analyses of the preliminary design. In the final design, the compressive strength of the concrete will be utilized in the puncture analyses. Copper fins, 0.08-in thick, are embedded in the concrete for thermal reasons. The arrangement of copper fins in the concrete (Figure 2-5) enhances the heat flow out of the cask during normal operation, while water (steam) ejection from the concrete during hypothetical thermal accidents restricts the heat absorption from external sources.

The closure interface for the cask body consists of a thick-walled ring flange made from a 304L stainless steel forging which is connected directly to the inner and outer shells with full penetration welds.

2.1.1.2 Closure Lid

A two-piece closure system is employed on the BR-100 (Figure 2-2). It is composed of a shield plug for radiation shielding and a separate closure lid for pressure containment. The closure lid is a 5-in-thick, 80.49-in-diameter, XM-19 stainless steel plate. The lid has a 0.5-in-thick, 60.5-in-diameter shear lip. The closure lid is secured to the cask body by 2.5-in-diameter 18UNF-3 bolts with a 4.0-in shank length made of Inconel 718 material. The closure lid, in conjunction with the cask body, functions as a pressure vessel. It also helps provide a thermal barrier for hypothetical thermal accidents. Two penetrations in the closure lid provide necessary operational access. These penetrations are discussed in Section II-4, Containment.

2.1.1.3 Shield Plug

The shield plug is 5 in thick and 60.5 in in diameter. It is made of a 3.5-in-thick layer of lead enclosed in a .75-in thick, 304L stainless steel casing. The structural strength of the shield plug is not considered in the structural analysis.

2.1.1.4 Fuel Basket

The fuel basket has the functions of laterally supporting the fuel assemblies, providing criticality control, and transmitting heat from the fuel to the cask body during transport and storage.

The fuel basket is made up of individual fuel cells, formers, tie rods, and straps. All of this hardware is assembled as a unitized design for handling during cask assembly. The BR-100 has separate PWR and BWR baskets that are designed to be removable and interchangeable.

The PWR fuel basket (Figure 2-3) consists of 21 individual fuel cells, 8 formers, 1 bottom plate, 1 upper grid, 8 tie rods and 4 straps. The BWR fuel basket (Figure 2-4) consists of 52 fuel cells, 12 formers, 1 bottom plate, 1 upper grid, 12 tie rods, and 4 straps. The fuel cells are individual pieces that provide partitioning between fuel assemblies. The fuel cells are made of alloy 6061 aluminum extrusions with T6511 temper. Aluminum was selected for its high alloy thermal conductivity and high strength-to-weight ratio. Spaces are provided between the PWR fuel cells for water to provide flux traps and for poison plates. Ceramic-metallic (Cermet) plates, made from B_4C and aluminum powder, provide criticality control (Figure 2-7). The Cermet plates are held in place by grooves machined in the fuel cell walls. The formers are aluminum castings made of SG70A material. The tie rods are made of aluminum. The eight tie rods (1.5-in in diameter) and straps are structural members only for normal handling of the empty fuel basket to allow insertion and removal from the cask body. Their stresses are expected to be very small and will be evaluated in the final design.

2.1.1.5 Impact Limiter

Impact limiters are installed on both ends of the cask during transport to protect the cask and fuel assemblies from excessive impact forces. The BR-100 impact limiters are made of redwood and balsa wood covered with a Kevlar/epoxy composite. The impact limiters are secured to the cask body with attachment bolts and are designed to remain attached to the cask body under accident loadings.

The impact limiters fully cover the closure lid and bottom end and extend partially along the cask body side walls. They provide impact protection for every drop orientation. As their name implies, they protect the cask and fuel assemblies by limiting the impact forces transmitted to them during a hypothetical accident.

Impact limiter performance will be verified by an extensive testing program. BWFC is developing a computer program, ILAN, to assist in limiter design and predict limiter performance. ILAN will calculate the force-deflection curve for the impact limiter for different angles of impact, cask-body forces, and acceleration for both primary and secondary (slap down) impact. ILAN will be used as a design tool and will also be used to calculate the worst angle of impact for testing.

Another function of the impact limiter is to provide insulation of the containment boundary seals from the adverse effects of high temperatures experienced during the hypothetical thermal accident. It also provides a thermal barrier to the top and bottom of the cask during hypothetical thermal accidents.

Design, analysis, and test results of the impact limiter are provided in appendices 2.10.1 and 2.10.2.

2.1.1.6 Trunnions

Trunnions are installed on the cask to lift, rotate, and secure the cask to a transport vehicle. The cask is handled vertically when it is lifted or placed for loading/unloading or for storage of the fuel assemblies. Four trunnions, 90^{o} apart, provide redundant lifting points for the cask. The cask is laid horizontally for transportation. There are four potential trunnion locations (at 90^{o} locations) on each end of the cask. Two trunnions at the bottom are also used for securing the cask to the transporter.

Two trunnions at the bottom of the cask are used as pivot points during rotation of the cask from horizontal to vertical. Their centerlines are offset 1 in from the top-end trunnion centerlines to provide a stable condition during rotation of the cask. The two other trunnion attachment locations at the bottom are not used during normal operations. The trunnions are removable and replaceable. Blind flanges cover unused trunnion locations. They provide attachment lifting points to retrieve the cask in any position after an accident.

The trunnions are made of forged XM-19 stainless steel and are bolted to the cask's outer vessel by 16 1-in-diameter Inconel 718 bolts (Figure 2-8). They are bolted to a forged XM-19 reinforcement ring. The reinforcement ring is full-penetration welded to the vessel body.

Figure 2-1
BR-100 Cask
Longitudinal Section

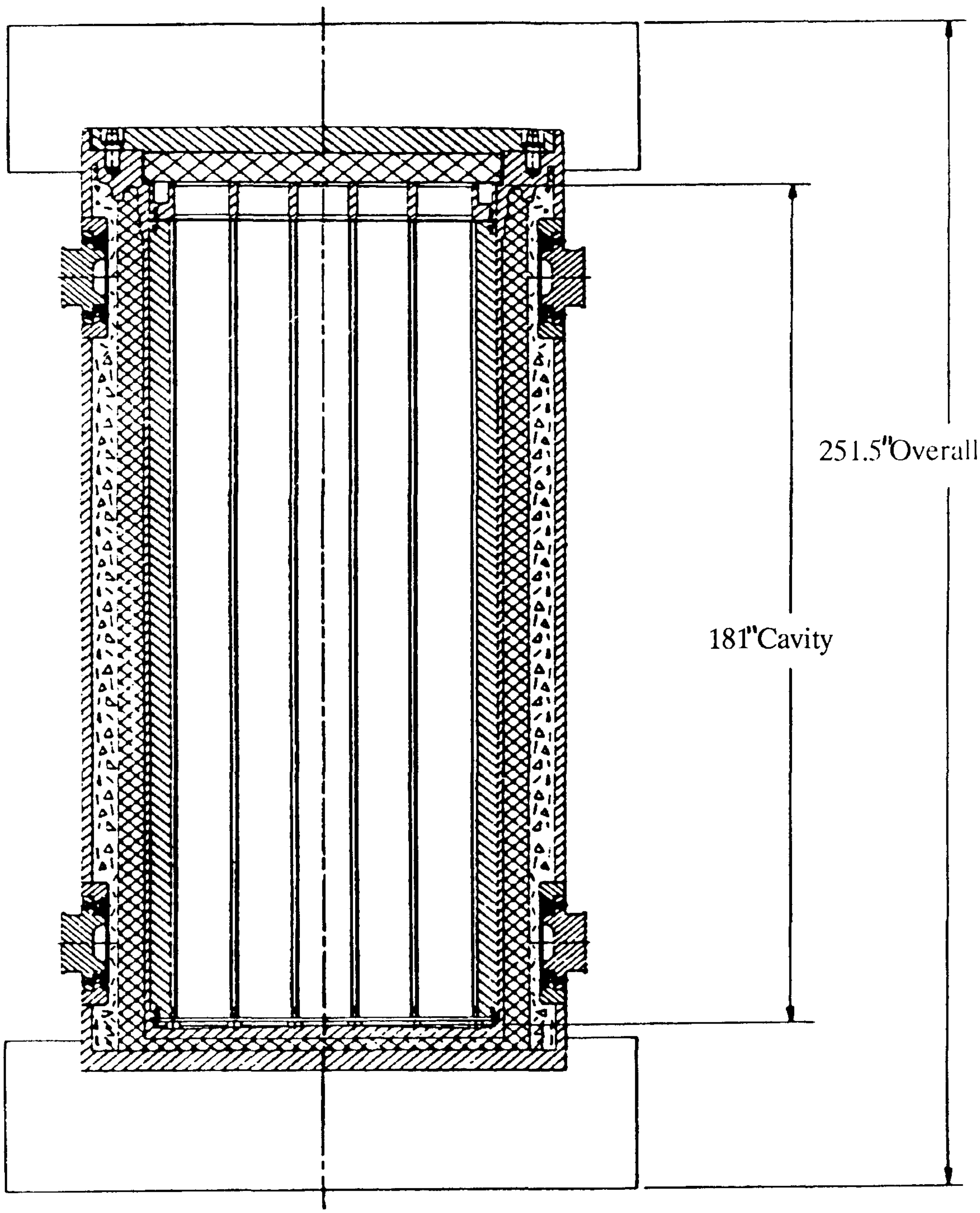


Figure 2-2
BR-100 Cask
Seal Region

Upper Flange Region

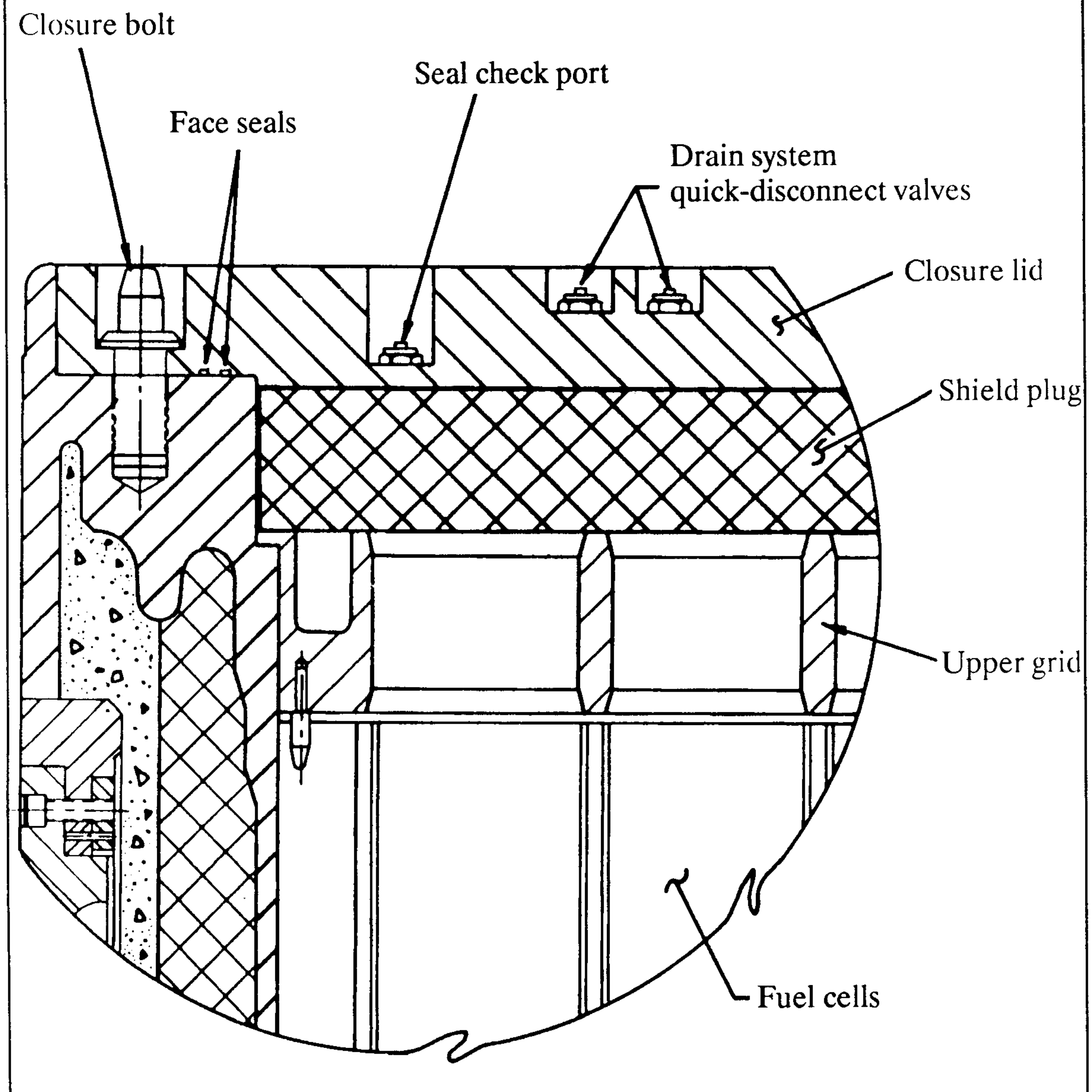


Figure 2-3

BR-100 Cask

21 PWR Configuration

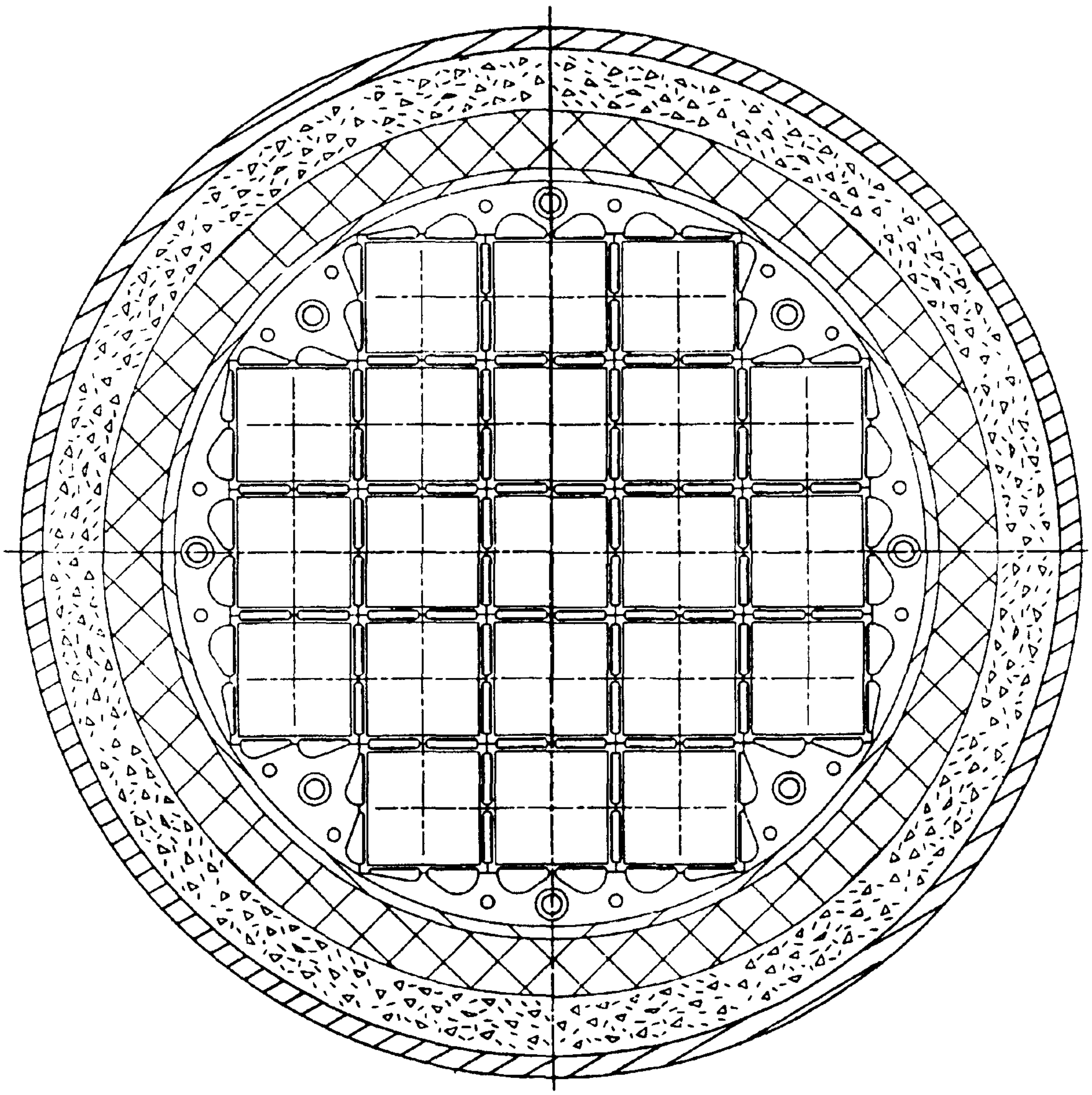


Figure 2-4

BR-100 Cask

52 BWR Configuration

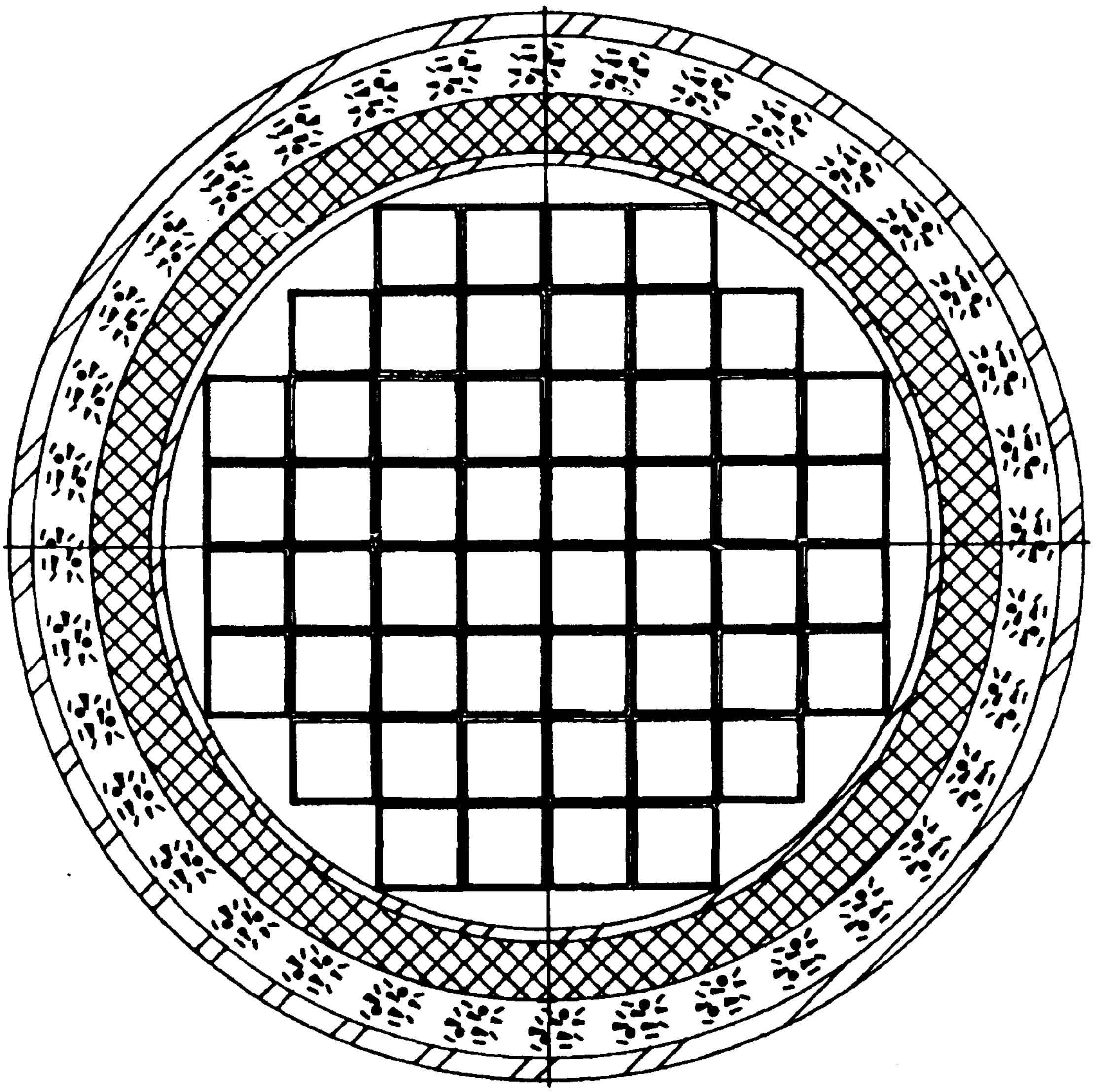


Figure 2-5
BR-100 Cask
Multilayer Cask Wall

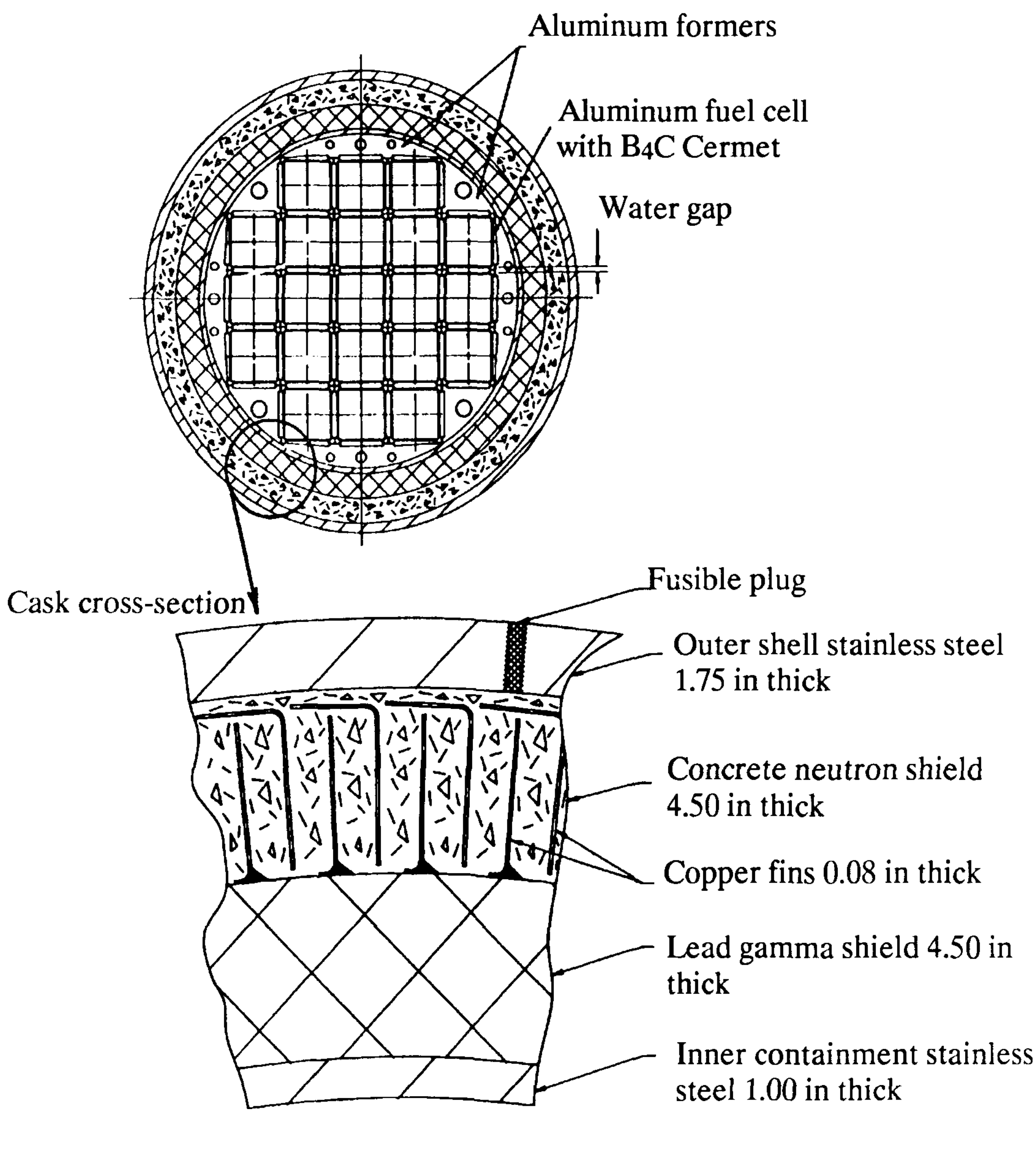


Figure 2-6
BR-100
PWR Basket Cross-Section

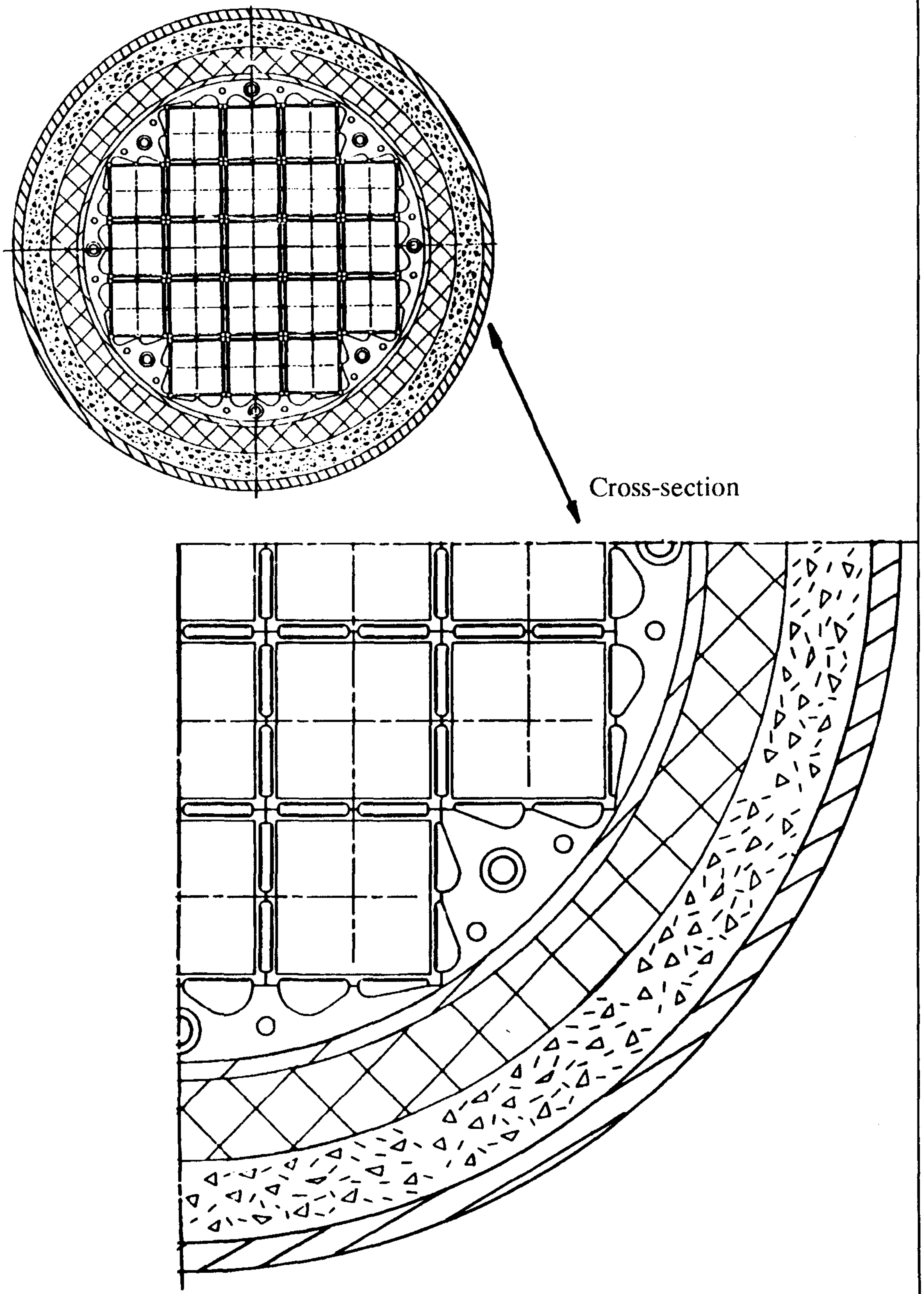
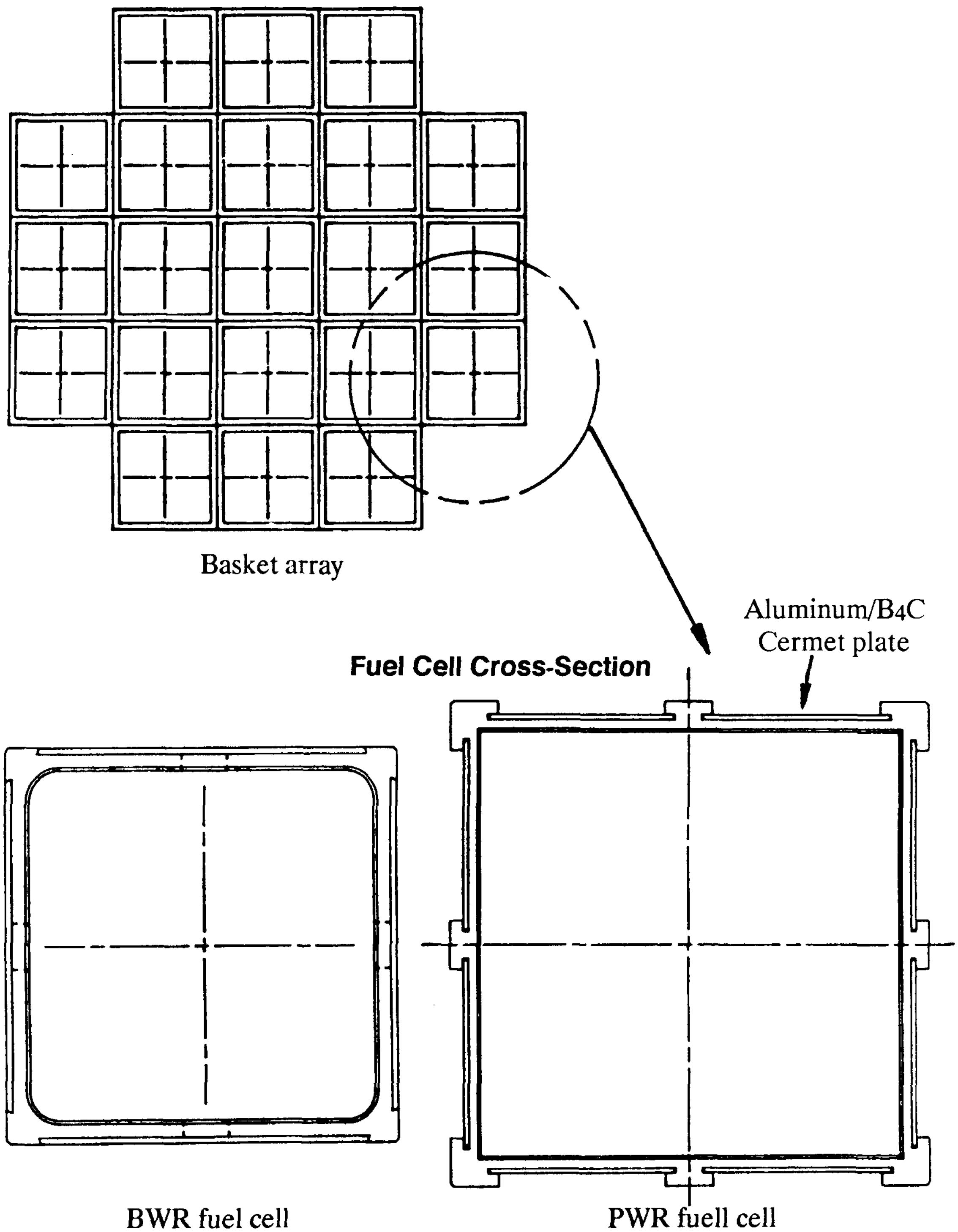


Figure 2-7
BR-100 Cask
Fuel Cell



2.1.2 Design Criteria

Section 71.71, Normal Conditions of Transport, and Section 71.73, Hypothetical Accident Conditions, of 10CFR71 (1986 Revision), Packaging and Transportation of Radioactive Material, describe normal conditions of transport and hypothetical accident conditions that produce thermal and mechanical loads.

NRC Regulatory Guide 7.6, Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels, Revision 1, dated March 1978 is used in conjunction with NRC Regulatory Guide 7.8, Load Combinations for the Structural Analysis of Shipping Casks for Radioactive Material, Revision 01, dated March 1989 to evaluate the structural integrity of the BR-100 cask.

Level A (normal) and Level D (accidental) service limit stress allowables for primary membrane, primary bending, secondary, peak-bearing, shear, and buckling stresses for containment structures and fasteners, and noncontainment structures and fasteners are taken from Section III of the American Society of Mechanical Engineers Boiler and Pressure Vessel (ASME BPV) Code of 1986. Material data used in the evaluation correspond to the design stress values S_m, yield strength S_y, and ultimate strengths S_u at specified temperatures given in the ASME BPV Code, Section III, Class 1. A summary of allowable stress limits used in the containment structure is presented in Table 2-3.

Table 2-3
CONTAINMENT STRUCTURE ALLOWABLE STRESS LIMITS

Stress Category	Normal Conditions	Accident Conditions
Primary membrane stress intensity	S_m	Lesser of 2.4 S_m or 0.7 S_u
Primary membrane + bending stress intensity	1.5 S_m For cask shell α S_m	Lesser of 3.6 S_m or S_u Lesser of α(2.4 S_m) or α0.7 S_u
Range of primary + bending stress intensity	3.0 S_m	N/A
Bearing stress	S_y	S_y for seal surfaces, S_u elsewhere
Pure shear stress	0.6 S_m	0.42 S_u
Peak	Per ASME Section III	Per ASME Section III
Buckling		ASME Section III or ASME Code Case N-284 or ANSYS with adequate safety margin

Notes

S_m = Material design stress integrity

Sy = Material yield strength.

S_u = Material ultimate strength

α = Shape factor, defined as the ratio of the load set producing a fully plastic section to the load set producing initial yielding in the extreme fibers of the section (NB-3221.3).

2.1.2.1 Containment Structure

The cask body internal vessel and closure lid are considered to be a containment structure. Table 2-3 presents the stress limits for these components.

2.1.2.2 Noncontainment Structure

The cask outer vessel, fuel basket, shield plug, and trunnions are noncontainment structures. For the preliminary design, as a conservatism, the stress limits specified in Table 2-3 for containment structure are also used for noncontainment structures.

The fuel cells are constructed of alloy 6061 aluminum extrusions (ASME Section II Material SB221). Aluminum 6061 is an ASME Section III, Class 3 component material. There are some differences in design methodology between Class 1 and Class 3 construction. Among them of importance are inspection requirements and consideration of fatigue. We intend to satisfy ASME Code Class 1 component design (NB-3000), fabrication (NB-4000), inspection (NB-5000), and testing (NB-6000) requirements. The design requirements will be satisfied using design stress intensity values determined based upon the requirements of Article III-2000. Since this hardware is not an ASME Code component, the ASME Code Committee's approval is not required. The ASME Code is used here as a design guide. The Class 1 component stress limits (Table 2-3) are used for the fuel cells.

2.1.2.3 Impact Limiter

The criteria for the impact limiters are established in two categories. The first criterion relates to the performance under normal loadings and accidental-drop-event impact loadings. The impact load, reaction forces, and inertia load should not exceed those values used in the structural analyses of the containment vessel and fuel basket. This evaluation will be accomplished by analysis, followed by a confirmatory scale model test program. The impact limiter is allowed to exceed yield for all conditions. The acceptance criterion for all impact-related loads within the impact limiter is that no cask "hard points" come directly in contact with the impact surface, and also impact limiters should not bottom out.

The second category relates to the impact-limiter attachments. The attachments are designed such that the impact limiter remains attached to the cask during and after hypothetical accident conditions. The stresses in the attachment should be limited so that the factor of safety against failure (ultimate stress, S_u) is at least 0.7. The impact limiter design and analysis are presented in appendices 2.10.1 and 2.10.2.

2.1.2.4 Trunnion

For lifting and handling loads, the noncontainment normal condition allowables are utilized. The details of evaluation are presented in sections 2.4.3 and 2.4.4. A minimum factor of safety of 3.0 against yield is used for lifting a fully loaded package per requirement of 10CFR71.45. The BR-100 cask tie-down system should be capable of withstanding without exceeding material yield strength a static force applied to the center of gravity of the cask having a vertical component of two times the weight, a horizontal component in the direction of travel of ten times the weight, and a horizontal component in the transverse direction of five times the weight.

Additional trunnion design criteria are imposed by NUREG 0612, Control of Heavy Loads at Nuclear Power Plants. NUREG 0612 requires lifting attachments to conform to a 5 G load factor for redundant lift systems and a 10 G load factor for nonredundant lift systems. Resulting stresses are compared to material ultimate strengths.

2.1.2.5 Other Structural Failure Modes

Brittle Fracture:

Primary materials used for the cask are 304L stainless steel, XM-19 stainless steel, and 6061 aluminum. All stainless steel materials meet the requirements of ASTM A20-77 (15 ft-lb Charpy) at -40°F. Therefore, they are considered to have adequate toughness and are safe from brittle fracture.

The fuel cells are made of aluminum 6061 extrusion with T6511 temper. A linear elastic fracture mechanics analysis was performed to obtain a critical flow size to the fuel cells. The analysis was based on proposed international brittle fracture acceptance criteria (Reference 2.11) and fracture toughness data from the 1988 edition of Battelle's Structural Alloys Handbook (Reference 2.12) The critical crack size for hypothetical accident loadings (worst loadings) is larger than the quarter thickness of the fuel cells. Based on this, the brittle fracture is not a concern for this design. The fracture mechanics results are presented in Section 2.7.

2.2 WEIGHTS AND CENTERS OF GRAVITY

2.2.1 Weights

Regulatory Guide 7.9 requires a listing of the weights of major individual subassemblies of the cask and the total weight of the packaging and contents. BWFC also has included in this section an evaluation of the crane hook load and the gross vehicle weight of the cask, which are limited by crane capacities and railroad regulations, respectively. Packaging and contents weight, crane hook load, and gross vehicle weight are defined and listed herein for both the PWR and BWR configurations.

This section identifies the subassemblies considered for the weight calculations and provides their weights. All weights will be rounded to the nearest 100 lb.

Weights for the major subassemblies of the cask system are listed in Table 2-3A. The major subassemblies include the package, payload, and ancillary equipment.

The package includes the cask body, shield plug, main lid, basket assembly and impact limiters. The cask body as considered here includes the six removable trunnions but does not include the shield plug and main lid. The weight of the lid includes its 32 bolts. The basket assembly comprises individual fuel cells, formers, the bottom plate, the upper grid, and miscellaneous parts for assembling the basket. The design goal of the impact limiters is a unit weight of 4,000 lb.

The payload weight includes the stand-offs and the payload. The stand-offs are the parts located in the bottom of the fuel cells, specific to the type of fuel loaded, that ensure the top end fittings of the fuel assemblies are all at approximately the same level at the top of the cask cavity. Payload weight is the maximum weight of the fuel assemblies to be transported in the cask. The PWR payload weight consists of 21 B&W 15x15 assemblies weighing 1,540 lb each, which does not include fuel control components. The BWR payload weight consists of 52 GE 8 x 8 assemblies weighing 645 lb each, which does not include fuel channels.

The ancillary equipment includes the dewatering tool, handling equipment, railcar, skid, and the personnel barrier. This equipment is in the design phase, so weights listed are design goals.

The weight of the water corresponds to the quantity in the cask cavity when the cask is fully loaded, in the pool, and before dewatering. This water weight is necessary for the calculation of the crane hook load as defined by the DOE, although the water is removed by standard operations before the crane lift.

Table 2-3A
WEIGHTS OF THE MAJOR COMPONENTS FOR THE PWR AND BWR BR-100 Configurations

Component	PWR lb	BWR lb
Cask body	139,000	139,000
Shield plug	5,200	5,200
Main lid	7,700	7,700
Basket assembly	9,000	10,000
Impact limiters	8,000	8,000
Stand-offs	500	300
Payload	32,300	33,500
Dewatering tool	1,000	1,000
Handling equipment	2,500	2,500
Railcar	45,000	45,000
Skid	11,500	11,500
Personnel barrier	500	500
Water	10,000	8,500

Packaging and Contents Weight

This weight considers the cask as transported, fully loaded with its maximum payload and with its impact limiters. All the subassemblies considered are listed below with their weights for both PWR and BWR configurations.

	PWR, lb	BWR, lb
Cask body	139,000	139,000
Shield plug	5,200	5,200
Main lid	7,700	7,700
Basket assembly	9,000	10,000
Impact limiters	8,000	8,000
Stand-offs	500	300
Payload	32,300	33,500
Packaging and Contents	201,700	203,700

Gross Vehicle Weight

The gross vehicle weight is the weight of the cask system during transportation. It includes the weight of packaging and contents and the weights of the railcar, skid, and personnel barrier. The weight is tabulated below for both PWR and BWR configurations.

	PWR, lb	BWR, lb
Packaging and contents	201,700	203,700
Railcar	45,000	45,000
Skid	11,500	11,500
Personnel barrier	500	500
Gross Vehicle Weight	258,700	260,700

The gross vehicle weight is currently limited to 263,000 lb by the cask contract Statement of Work. The margins shown for both PWR and BWR configurations may allow transportation of some additional equipment on the railcar or allow a margin for additional component weight.

Crane Hook Load

The crane hook load is defined as the gross weight of the cask when lifted out of the pool (with maximum payload and fully loaded with water) and the lifting equipment. The crane hook load includes, therefore, the weights of the cask body with its contents, the shield plug, the water inside the cask, the dewatering tool (which replaces the main lid during in-pool operations), and the handling equipment. The corresponding weights are tabulated below for both PWR and BWR configurations.

	PWR, lb	BWR, lb
Cask body	139,000	139,000
Shield plug	5,200	5,200
Basket assembly	9,000	10,000
Stand-offs	500	300
Payload	32,300	33,500
Dewatering tool	1,000	1,000
Handling equipment	2,500	2,500
Water*	10,000	8,500
Crane Hook Load	199,500	200,000

*Removed by standard operation before crane lift.

The crane hook load is limited to 200,000 lb by the cask contract Statement of Work. The BR-100 cask meets this limit for both PWR and BWR configurations, even in the most conservative scenario.

2.2.2 Centers of Gravity

This section defines the position of the center of gravity for the BR-100. The center of gravity of major subassemblies, the center of gravity of the cask during transportation in its empty and loaded conditions (only one PWR configuration considered), and the position of the center of gravity for the cask system (loaded with PWR fuel on the railcar) are defined.

Center of Gravity of the Major Subassemblies

In this section, we assume that all the centers of gravity of the major subassemblies are located on the longitudinal axis of the cask. The external face of the bottom of the cask is taken as the origin of the axis.

The weights and positions of the center of gravity of the major subassemblies are listed below:

	Weight, lb	Center of Gravity , in
Cask body	139,000	92.27
Lid	7,700	198.85
Shield plug	5,200	193.50
Impact limiters	8,000	100.75
PWR basket	9,000	99.53
PWR stand-offs payload	500	13.25
B&W 15x15	32,300	99.00

Center of Gravity of the Cask During Transportation

This section considers the center of gravity of the BR-100 during normal transportation both with its PWR basket empty and with its maximum PWR payload.

The first case considers the PWR basket to be empty and the cask in a horizontal shipping mode. This configuration is shown in Figure 2-7A, which also defines the reference point for further discussion as the bottom rear point of the cask. The center of gravity of the cask is located 101 in from the external surface of the bottom of the cask. If it is assumed that the center of gravity for the cask and impact limiters is located on the longitudinal axis of the cask and that the maximum deviation of the basket center of gravity is 0.25 in, the resulting deviation of the center of gravity of the system considered is less than 0.015 in. In conclusion, the center of gravity of the system considered here is very close to the geometric center of the cask on the longitudinal axis at 100.75 in from the reference point.

The second case considers the PWR basket and its maximum PWR payload during transportation. The center of gravity of this configuration is 100.5 in from the reference point shown in Figure 2-7A. If it is again assumed that the center of gravity for the cask and impact limiters is located on the longitudinal axis of the cask, that the maximum deviation of the center of gravity for the basket is 0.25 in and that the maximum deviation of the center of gravity for the fuel assemblies is 0.50 in, the resulting deviation of the center of gravity of the system is less than 0.15 in. In conclusion, the center of gravity of the system considered here is very close to the geometric center of the cask on the longitudinal axis at 100.75 in from the reference point.

Center of Gravity of the Cask System

This section considers the vertical position of the center of gravity of the system constituted during transportation by the railcar, the cask, and the ancillary equipment from the reference point shown in Figure 2-7B.

The following assumptions are made:

Position of the center of gravity*	
Railcar	35 in
Skid	50 in
Personnel Barrier	107 in
Packaging and Contents	107 in

*The reference being taken as the top of the rails

The resulting position of the center of gravity is 92 in above the top of the rail for both PWR and BWR envelope payloads, which is 6 in below the maximum limit specified by the railroad regulations.

Figure 2-7A

Center of Gravity

Longitudinal Axis

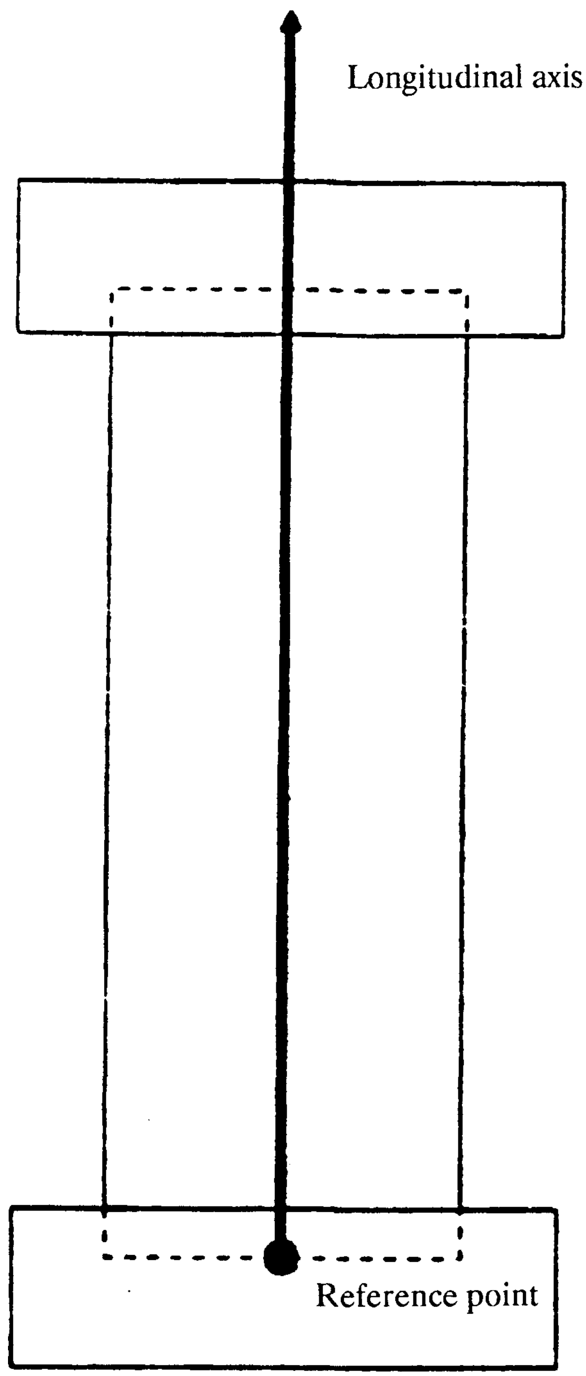
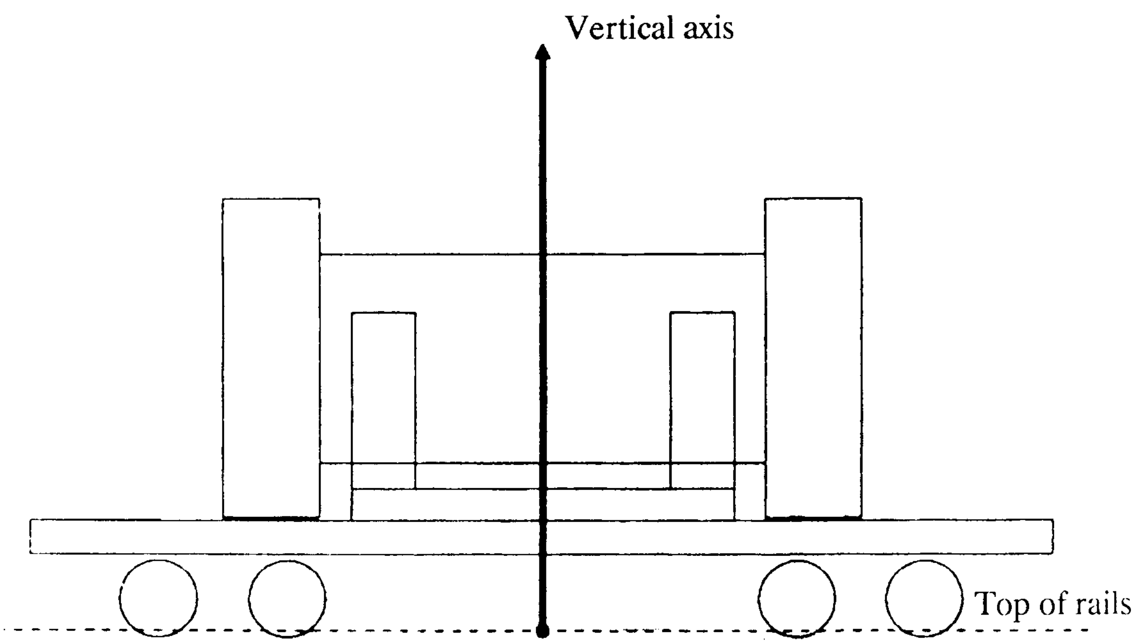


Figure 2-7B
Center of Gravity
Vertical Axis



2.3 MECHANICAL PROPERTIES OF MATERIALS

The structural evaluation of the BR-100 cask involves the analysis of several different components. These components and the materials used in their fabrication were described in the preceding sections of this document. The mechanical properties required to perform the structural analyses were compiled in a handbook, "Materials Handbook for BR-100 Rail/Barge Spent Fuel Cask," BWFC Document 51-1174181. The mechanical properties provided in the handbook were extracted primarily from the ASME Boiler and Pressure Vessel Code, Section III, Division 1 Appendices (Reference 2.4) and the Aerospace Structural Metals Handbook, Volume II (Reference 2.13).

Mechanical properties that are needed but that are not presently provided in the BR-100 Materials Handbook will be generated by engineering tests. Mechanical property engineering tests are currently planned on materials to be used in fabricating the following cask components:

1. Fuel cells
2. Neutron absorber
3. Thermal/neutron shield
4. Seal gasket
5. Impact limiters

The specific types of tests and parameters to be investigated are discussed in the following sections.

2.3.1 Fuel Cell Structural Testing

Tension and compression tests are planned to measure strength, ductility, modulus of elasticity, and Poisson's ratio of aluminum alloy 6061-T6511. Specimens will be fabricated from a full-size, aluminum fuel cell that has been extruded, machined and hard anodized in accordance with design specifications. The tests will be conducted over the anticipated ranges of service temperature and possible strain rates.

In addition to the tension and compression tests described above, full-scale, prototypic fuel cell sections will be tested under simulated drop-accident conditions. Loading of the fuel cell sections during the simulated accidents will include loads from fuel basket formers and other surrounding fuel cells as well as loads anticipated from the spent-fuel assemblies. The simulated accidents will be performed with the fuel cell sections oriented in various rotational positions to assure that a complete understanding of the fuel cell structural behavior is obtained.

2.3.2 Neutron Absorber Mechanical Testing

Flexural strength, bend deflection limits, and load/deflection information will be generated for the aluminum/B_4C absorber material. Bend tests will be used to generate these data over a range of anticipated service temperatures and deflection rates. These tests will be performed on as-fabricated plates as well as plates that have been subjected to thermal cycles (-40°F to 350°F) and vibratory conditions typical of rail transport.

2.3.3 Thermal/Neutron Shield Structural Testing

Compression and flexural tests will be conducted on the concrete to be used in the thermal/neutron shield. These tests will be performed on specimens that have been poured into a net-shape specimen mold as well as on specimens that have been cored from a full, cask-length column to simulate the actual cask fabrication pouring operation. The testing will generate compression and flexural strength and modulus values for the concrete in the as-cured, dried, and aged conditions as a function of service temperature, axial location in the concrete column, and batch-to-batch compositional variations. The effect of relative mechanical integrity after thermal cycling will be investigated by measuring the relative dynamic modulus.

Structural integrity of the thermal/neutron shield as a component of the cask will be investigated using thermal-cycle tests and impact tests. The thermal-cycle tests will be conducted on shield samples fabricated with actual materials and design thicknesses for the outer shell, concrete, fins, and gamma shield. The anticipated internal heat flux will be maintained on the inside surface of the shield as the outer shell surface temperature is cycled to simulate the thermal extremes the cask may experience. The concrete in the thermal cycle test samples will be in the as-cured condition for some samples and "aged" for other samples. Detailed examination of the concrete and material interfaces after each test will provide information on the ability of the thermal/neutron shield to withstand thermal cycling without diminishing its structural integrity.

The analysis of the mechanical response of the thermal/neutron shield to impact loadings will be supported by drop impact testing of layered combinations of stainless steel/concrete/lead/stainless steel. These impact tests will be conducted by dropping a steel rod with various weights from different heights onto the layered combinations and measuring the resulting deformations.

2.3.4 Seal Gasket Testing

The mechanical response, as indicated by the seal leak-tightness, of the Viton (Parker V835-75) seal material to normal operating and accident conditions will be measured as a function of temperature and design compression variations. The tests will be conducted with seal gaskets placed in design grooves machined in actual materials to be used in the cask construction. The gaskets will be tested in the as-received condition as well as after exposure to mechanical and thermal-cycle preconditioning.

2.3.5 Impact Limiter Testing

The impact limiters for the BR-100 cask will be designed using an iterative approach involving tests and analyses. Scoping compression tests conducted on both balsa and redwood in constraining cylinders of both stainless steel and Kevlar have demonstrated the energy-absorbing superiority of the wood/Kevlar combination. Based on these scoping tests, quarter-scale wood/Kevlar impact-limiter models of varying design will be constructed and tested to establish their crushing characteristics under both static and dynamic loading conditions. For the dynamic tests, scaled weights will be dropped onto the models to simulate cask drops. Qualitative crush characteristics will be evaluated and limited force-deflection data will be estimated. Static tests will employ the use of an instrumented load-testing machine. The force-deflection curves will be generated for various designs and various contact angles. Information obtained from this testing will be used to improve analysis techniques and to provide feedback for improved impact-limiter designs.

When the impact limiter design has been completed, the specific wood and Kevlar selected for use will be characterized to establish the mechanical property variability that can be expected for the anticipated environment. The wood will be compression tested using confined specimens with various wood-grain orientations, densities, and water content levels. Service temperature and deformation rate effects will be studied to provide data for use in analytic tool development. Tension testing of the Kevlar will be conducted to investigate the effects of temperature, stain rate, and Kevlar water absorption. These data will also be used to enhance analytic capabilities.

2.4 General Standards for All Packages

2.4.1 Chemical and Galvanic Reactions

The anticipated environmental conditions both internal and external to the cask were explicitly considered during materials selection for the various cask components. The relatively mild atmospheric conditions anticipated for the exterior of the cask and the predominantly inert atmosphere of the interior precludes the need for a highly corrosion-resistant superalloy for shell fabrication. Thus, the moderately corrosion-resistant 304L stainless steel offers the ideal combination of strength, ductility, toughness, weldability, moderate cost, availability, and ASME acceptability for both the outer and inner shells.

The Inconel 718 bolting material for the lid and trunnions was selected primarily for its relatively high ASME Code allowable design stress intensity values. The bolt operating temperatures are anticipated to remain well below 300^{o}F. Studies have been reported in the literature that indicate no susceptibility of Inconel 718 to stress corrosion cracking at temperatures of up to 310^{o}F even under severe chloride and H_2S environments (see references 2-14, 2-15, and 2-16).

The low-free-oxygen environment and hermetic seal of the thermal/neutron shield creates the unlikelihood of any significant oxidation or corrosion of the copper fins, lead, or stainless steel. The anticipated absence of any significant corrosion of these metals will be confirmed by examination of the concrete/metallic interfaces in the "aged" thermal-cycle test sample.

The aluminum selected for fabrication of the fuel basket will provide several favorable attributes for this application. Aluminum has good strength relative to its weight, excellent thermal conductivity, ease of fabrication, and very good corrosion resistance, wear resistance, and thermal emissivity when hard anodized. The corrosion- and wear-resistant behavior of the fuel cell aluminum alloy 6061-T6511 will be investigated to confirm the anticipated adequacy of these properties. Corrosion behavior will be studied for the hard anodized, scratched, and bare aluminum conditions. Simulated spent-fuel pool water (oxygenated) at 140^{o}F alternating with helium gas at 350^{o}F will be the environmental conditions of exposure. Both contact wear, to simulate transport vibrations, and abrasive wear, to simulate fuel assembly insertion and withdrawal loading of the fuel cells, will be investigated to confirm anodizing layer adherence and protection against wear.

The neutron-absorber material will be fabricated using B_4C particles surrounded by a matrix of aluminum. A thin layer of aluminum will surround this B_4C metal-matrix core. The aluminum will be hard anodized to enhance corrosion resistance and thermal emissivity. Corrosion tests will be conducted on this neutron-absorber material to assure that the anodized aluminum has sufficient corrosion resistance and that dissolution of the B_4C is not occurring during exposure to spent fuel pool water.

Galvanic effects are not expected with the BR-100 cask. No significant corrosion potential differentials will exist anywhere on or in the cask. Metallic components exposed on the exterior of the cask will be stainless steel and Inconel 718 only. These exhibit very similar corrosion potentials as evidenced by their proximity to each other in galvanic series. The lack of an oxidizing environment within the thermal/neutron shield and the minimal amount of free water will create a very poor electrolytic environment and, therefore, minimal galvanic effects between the copper and lead. This information will be confirmed by the thermal/neutron shield engineering tests described above.

The fusible plug material (60% Bi and 40% Cd) is an eutectic with a melting point of 291°F. It was selected for its melting characteristics at a temperature sufficiently above the concrete temperature limit of 250°F and yet at a low enough temperature to allow escape of steam and early dehydration of the concrete near the outer shell during a hypothetical fire accident. The fusible plug interface with the outer shell will be protected from contact with water by a silicone sealant placed in the plug hole. Regular inspection and replacement guidelines to assure maintenance of this seal will be developed during final design.

The oxide layer on the aluminum, formed by anodizing the fuel basket components, in combination with the oxide layer that forms naturally on stainless steel will minimize the possibility of electrical contact between these two materials at the cask interior wall. Even if contact is made between bare aluminum and stainless steel, minimal corrosion potential differences exist between these metals in all but the most severe marine or high chloride, aqueous environments.

2.4.2 Positive Closure

For safety reasons, the design of the closure system must incorporate provisions to ensure that the cask cannot be opened unintentionally or by unauthorized persons. More generally, the containment function must be protected against unauthorized operations. This function is what is called positive closure.

Our cask design is particularly well protected against unauthorized opening during transportation where impact limiters are in place and securely attached to the cask. However, positive closure is to be ensured during all the stages of cask utilization.

During final design, positive closure of the penetration cover plates and of the seal check ports will be addressed. During final design, we will address the positive closure of the main lid by developing the unique high-level-security closure concept of the BR-100 cask.

The high-level-security bolt and fastening system consists of the main closure lid, the closure bolt fasteners, and the bolt driver for installation or removal.

2.4.2.1 High-Security Bolt

The high-security bolt consists of conventional materials, thread form, body, and bearing surface under the head. All of these features are selected and specified to satisfy the system design requirements common to all fastener applications. The unique feature of this bolt is the driven surface of the head, which is a hardened, plain cylindrical surface sized to match a special installation and removal tool. Installation torque requirements, as determined by closure, assembly, and sealing, establish the bolt-head material, heat treatment, and size.

To achieve the highest level of security, the cylindrical position of the bolt head is recessed below the surface of the closure head to minimize the potential effective use of a conventional adjustable-jaw tool such as a pipe wrench, "vise grips," or strap wrench to grip and rotate the bolt head.

The thread lead for the bolt head can be either to the right or left. The use of a left-hand thread would provide additional security by confusing a vandal or terrorist.

Figure 2-8 illustrates the bolt (Item 1) with its cylindrical head (Item 2), attached part recess (Item 4), and bask body.

2.4.2.2 Installation and Removal Tool

The installation/removal tool consists of a housing with an internal cylinder that contains a commercially available Formsprag™ overrunning clutch unit (i.e., back-stop or indexing device) of the proper size and torque capacity to meet the functional and design requirements. The overrunning clutch unit will vary with the bolt size, material, and torque requirements. This overrunning clutch device is retained within the housing by a washer and commercially available internal retaining ring in a matching groove.

In operation, the installation/removal tool is placed in the recess on the bolt head and rotated clockwise for a right-hand thread until the specified torque has been attained, as shown in Figure 2-9. To remove the bolt, the tool is removed, inverted, replaced on the bolt head and rotated counterclockwise.

Figure 2-9 shows the installation/removal tool (Item 3) in place on the bolt head and in the recess. The overrunning clutch device (Item 7) is shown in both plan and elevation sections within the housing (Item 8).

2.4.2.3 Special Features

A variety of speciai features can be adapted to both the security bolt and installation/removal tool to satisfy special or unusual functions.

A conical lead-on and gripping recess (or detent) has been added to the bolt head to adapt the bolt to robotic use and for remote handling, installation, or removal in radioactive environments.

The exterior of the installation/removal tool (Item 8 in Figure 2-9) was designed for use with any type of commercially available wrench by producing the housing from the appropriately shaped and sized drawn bar stock. In addition, this outside could include any number of drive flats or points such as a spline or external gear with gripping pins, grooves, or detents. Thus, the installation/removal tool can be modified for use with a variety of drive methods or devices suitable for direct contact with conventional tools or adapted to robotics or long-handled drive tools for remote operation.

The housing can be designed to incorporate two identical clutch units, as shown in Figure 2-9, or with a single unit in either one tool or two different tools (i.e., one for installation and another for removal).

The use of an overrunning clutch in this tool design provides the additional features of a minimum of backlash with an infinite ratcheting action for restricted movement on bolt installation or removal.

For security purposes, the manufacture and use of the installation/removal tool(s) would be controlled by the cask or equipment owner or regulatory agency responsible for the bolt installation, assembly, and removal. Because special knowledge is required to design this fastening system, it cannot be duplicated easily. Thus, the owner or regulatory agency would lend the tool(s) separately for cask unloading and monitor its location and return. The tool(s) would be delivered separately from the cask by a courier, restricted delivery, or other means of bolt removal by authorized personnel at the proper location. Therefore, a breach of security by unauthorized individuals, vandals, terrorists, or others is minimized.

2.4.2.4 Closure Bolt Advantages

This security fastening system offers the following advantages:

1. Prevents unauthorized cask opening or disassembly.
2. Protects the integrity of the assembly and payload against theft.
3. Protects the public from hazardous contents through inadvertent opening.
4. Requires a special tool designed with special knowledge to remove the bolts.
5. Without special knowledge of this fastening system, common personnel cannot relate the use of the tool to the removal of the bolts.

2.4.2.5 Fastening System Development Status

Even with the knowledge gained in the foregoing paragraphs, the operation of this fastener system can be difficult to visualize and comprehend. Therefore, because a demonstration sample approximately half the size of a conventional overrunning clutch was available, a half-size demonstration mock-up of light and readily available material (Al 6061-T6 alloy) was produced for design feasibility and study.

The mock-up has been very useful to date. It has functioned as intended, and as a result of two inadvertent drops, we have modified the Formsprag device to withstand even greater impact loads without coming apart. A photograph of the mock-up components is provided as Figure 2-10.

Initial testing of bolt and tool function has been partially assessed with the mock-up. Bolt and tool installation and removal functions, including backlash and ratcheting, are satisfactory. Even with the relatively soft Al 6061-T6, no Brinnelling of the bolt head has been observed.

After the bolt, Formsprag, and tool have been designed and fabricated from the selected materials, torquing, retorquing, overtorquing (Brinnel effects), locking, unlocking, coating, and related tests are planned and will be undertaken to determine total feasibility.

Figure 2-8
High-Security Closure Bolt

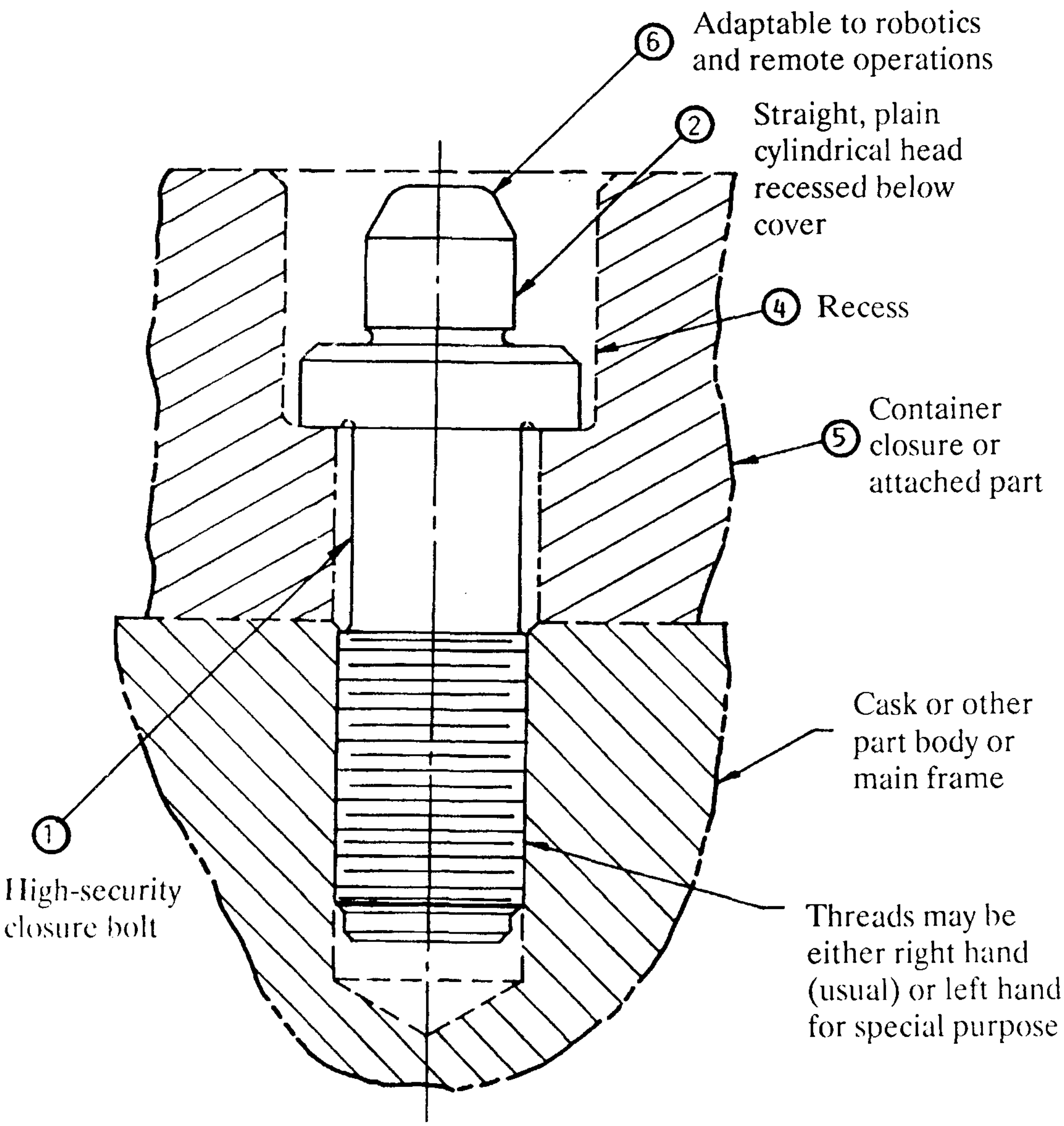


Figure 2-9

High-Security Closure Bolt Installation and Removal Tool

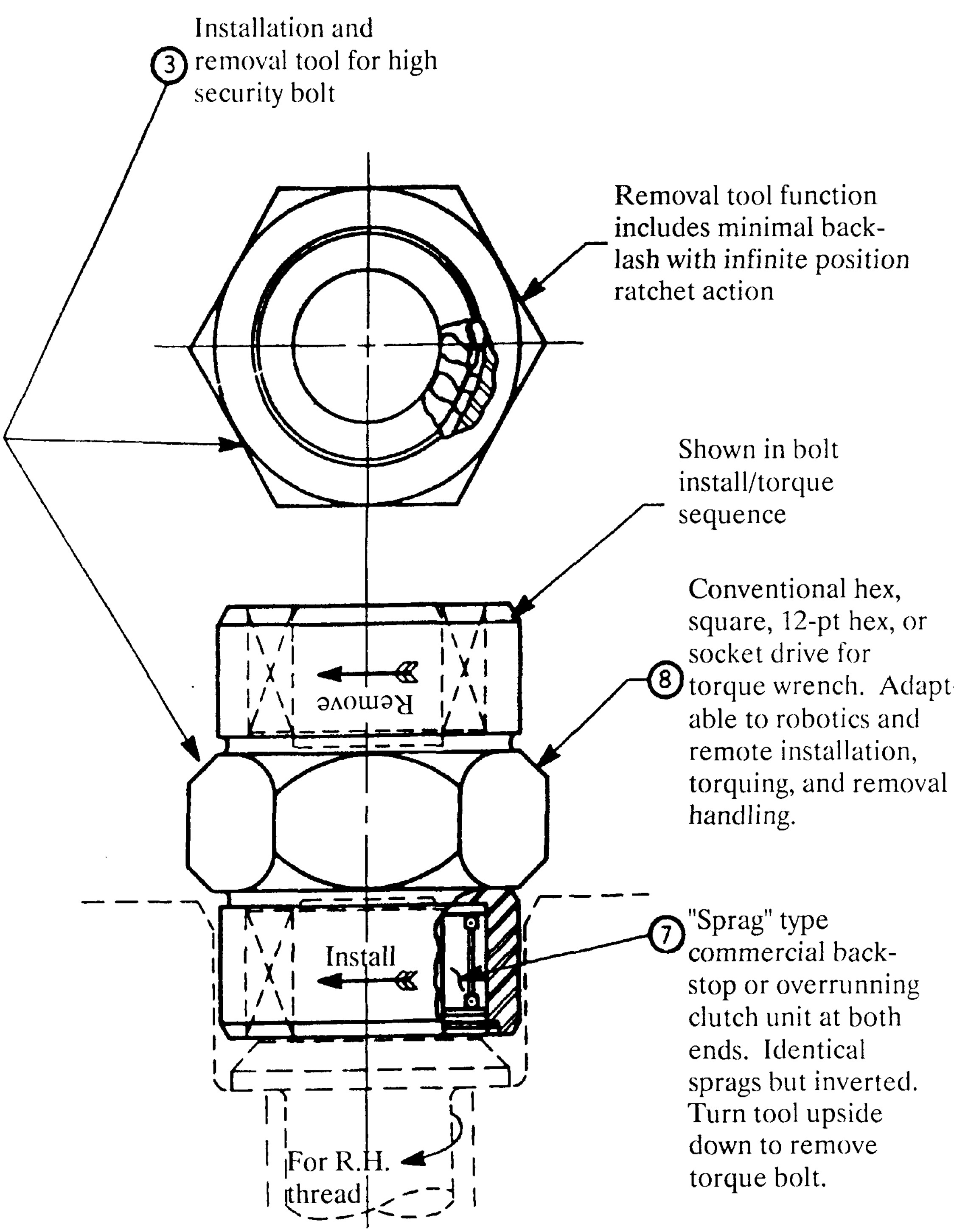
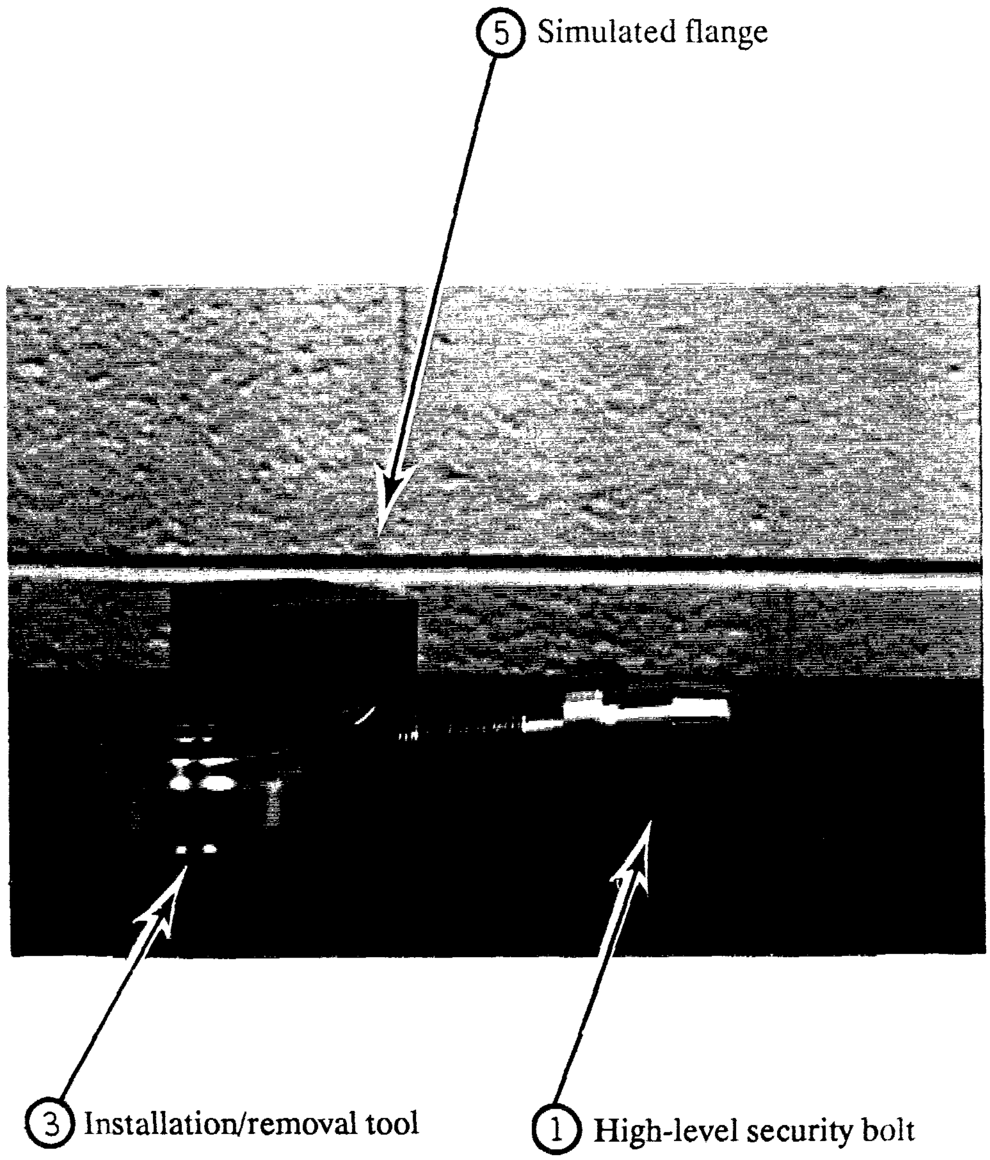


Figure 2-10

High-Security Closure Bolt Specimen



2.4.3 Lifting Devices

The BR-100 cask is lifted by two trunnion attachments in the upper region of the cask. Each trunnion attachment is composed of the following components:

- o trunnion (XM-19 stainless steel)
- o cap screw fasteners (Inconel 718)
- o reinforcement ring (XM-19 stainless steel)
- o cask outer shell (304L)

The trunnion attachment is shown in Figure 2-11.

Each trunnion attachment component is stress analyzed for conformance to 10CFR71, Paragraph 71.45, and NUREG 0612, Section 5 (references 2.1 and 2.7, respectively). Safety factors and stress limits for each standard are given below.

Standard	Safety Factor	Design Stress Limit
10CFR71 (lifting)	3	Yield strength
NUREG 0612 (redundant lift system)	5	Ultimate strength
NUREG 0612 (nonredundant lift system)	10	Ultimate strength

The BR-100 cask is designed for compatibility with a redundant lifting system. However, the cask can also be used with a nonredundant lift system. Therefore, a safety factor of ten corresponding to the nonredundant lifting system condition is used for NUREG 0612 analysis.

The maximum lifting load is considered to act in the cask axial direction. The trunnion, fasteners, and reinforcement ring are analyzed for principal stresses and stress intensity. Resulting stress intensities are compared to material stress-limit values (at 200°F for conservatism). The trunnion lifting load at 1 G is 100 kips (20 kips for 2 trunnions). The margin of safety (M.S.) is determined by:

$$M.S. = \frac{(\text{Allowable stress} - \text{Actual stress})}{\text{Actual stress}} X\ 100$$

A description of each attachment component follows with analytical results shown in Table 2-4.

<u>Trunnion</u>

The trunnion is analyzed as a cantilever beam with a point load acting at midspan of the loaded face. Maximum normal stress (bending) is considered to occur at the outermost fiber (outside diameter) of the trunnion cross-section. Maximum shear stress is considered to occur at the innermost fiber (trunnion centerline). Stress intensity is calculated at each location. The maximum stress intensity value is used for comparison to design allowables.

Fasteners

The trunnion-to-reinforcement ring fasteners are 1-in 8UNC-2B Inconel 718 cap screws. The fasteners are analyzed for thread and shank stresses. Results have shown that thread stress is always greater than shank stress; therefore, thread stresses are presented in this report. Deflection equations are used to determine applied load distribution in the 16 fasteners. The maximum applied bolt load of 10 kips is used for stress calculations. The female thread stress in the reinforcement ring is compared to design allowables.

Reinforcement Ring

The reinforcement ring is analyzed for female thread stress and weld stress. Thread stress is considered the same as fastener thread stress but compared to XM-19 material allowables. Weld stress is analyzed using linear elastic analytical techniques. The full penetration groove weld is continuous; therefore, full credit is taken for outer shell weld thickness and strength (per Reference 2.4, Article NB).

Outer Shell

A Bijlaard analysis (Reference 2.6) is used to determine outer shell stress at the reinforcement ring-weld interface. The Bijlaard method was developed to determine stresses in two intersecting cylinders. The Bijlaard stress intensities are compared to outer shell strength.

Table 2-4
LIFTING ANALYSIS
Trunnion Load = 100 kips at 1 G

Requirements	Stress Intensity, ksi	Material Type	Allowable Stress, ksi	% Margin of Safety
10CFR71 Limit = Yield Safety factor = 3 Load = 300 kips				
Trunnion	7.1	XM-19	47.0	562
Fasteners	40.0	Inconel 718	150.0	275
Reinforcing ring				
Threads	40.0	XM-19	47.0	18
Weld	7.7	304L	21.3	177
Outer shell	12.2	304L	21.3	75
NUREG 0612 Limit = Ultimate Safety Factor = 10 Load = 1,000 kips				
Trunnion	23.6	XM-19	99.5	322
Fasteners	81.1	Inconel 718	185.0	128
Reinforcing ring				
Threads	81.1	XM-19	99.5	23
Weld	25.7	304L	66.2	158
Outer shell	20.3	304L	66.2	226

2.4.4 Tiedown Devices

The BR-100 cask is mounted to the shipping skid for transportation. The tiedown system is required to meet 10CFR71 loads as follows:

Vertical	2 G load
Transverse	5 G load
Longitudinal direction of travel	10 G load

The cask outer shell and weld will be analyzed using finite-element techniques. Finite-element results will be presented in the final design report. The trunnion and fasteners are analyzed for tiedown in a similar manner to lifting in Section 2.4.3.

The vertical load case is the same as lifting (with a 3 G load factor). Since the lifting load is the worst case (and acceptable with adequate margin), vertical tiedown loads are not considered bounding for the trunnion attachment.

The transverse load is analyzed as a distributed load acting on the reinforcement ring through two side trunnions. The cap screw fasteners are considered to carry no load since the load application is compressive.

The longitudinal load will be reacted by a cask/skid mechanical system. The longitudinal tiedown system will be developed integrally with the cask shipping skid. Stress values for the trunnion attachment will be determined as the skid system is developed. Calculated stress values for each component are shown in Table 2-5.

Table 2-5
TIEDOWN ANALYSIS
Trunnion Load = 100 kips at 1 G

Requirement	Stress Intensity, ksi	Material Type	Allowable Stress, ksi	% Margin of Safety
10CFR71 Transverse load				
Limit = Yield				
Safety factor = 5				
Load = 550 kips				
Trunnions	2.7	XM-19	47.0	1,641
Fasteners	Note 1	Inconel 718		
Reinforcing ring				
Threads	Note 1	XM-19		
Weld	Note 1			
Outer shell	Note 1			
			Continued	

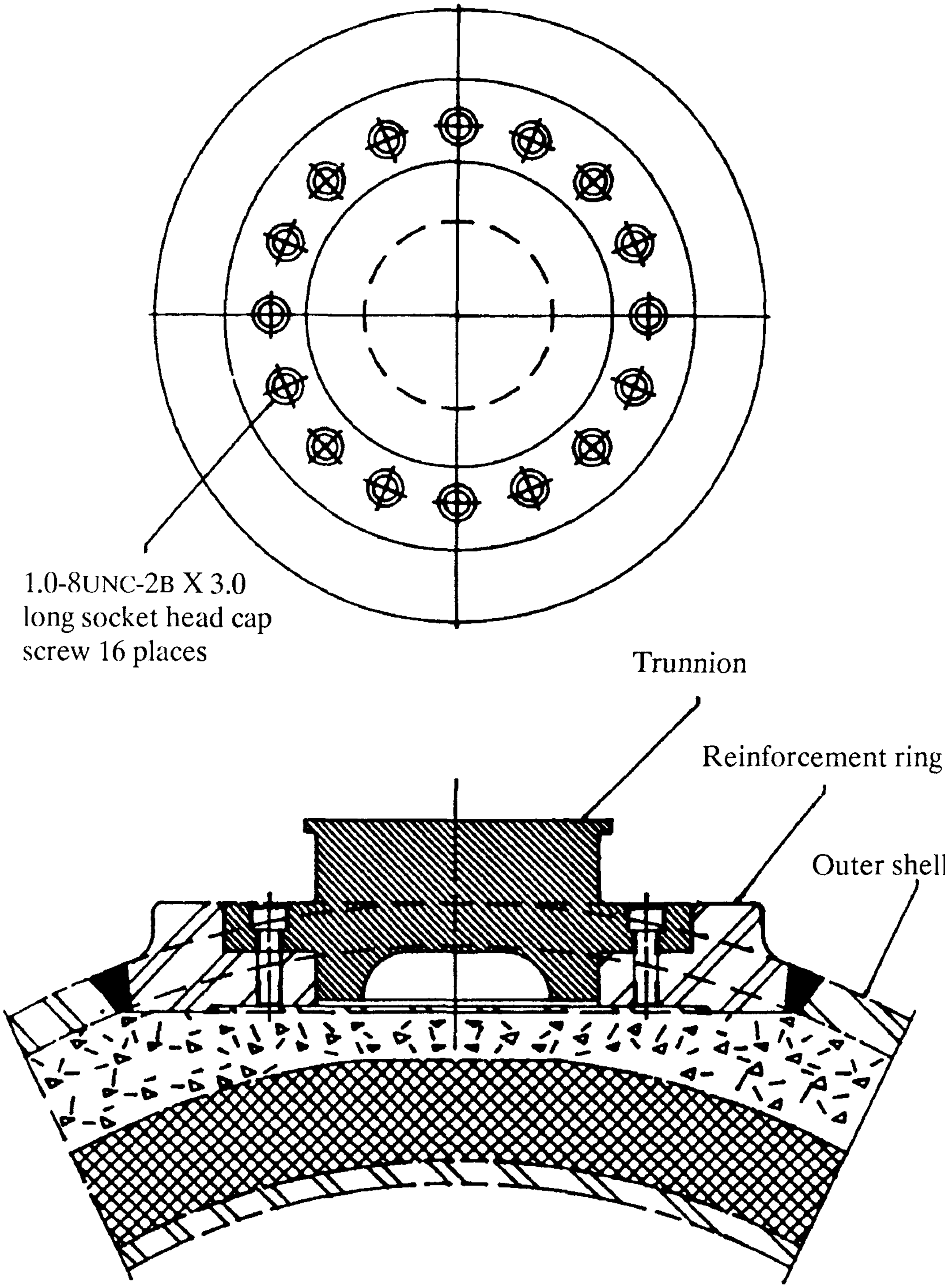
Table 2-5, Continued
TIEDOWN ANALYSIS
Trunnion Load = 100 kips at 1 G

Requirement	Stress Intensity, ksi	Material Type	Allowable Stress, ksi	% Margin of Safety
10CFR71 Longitudinal				
Load = Yield				
Safety factor = 10				
Load = 1,000 kips				
Trunnions	1.30	XM-19	47.0	262
Fasteners	41.7	Inconel 718	150.0	260
Reinforcing ring				
Threads	41.7	XM-19	47.0	13
Weld	Note 2			
Outer shell	Note 2			

Notes

1. Fastener and reinforcing ring threads carry no transverse load.
2. Weld and outer shell to be analyzed by the finite-element method for the final design report.

Figure 2-11
BR-100 Cask
Trunnion Attachment



2.5 STANDARDS FOR TYPE B AND LARGE QUANTITY PACKAGING

2.5.1 Load Resistance

This section is not applicable to the BR-100 cask. This section addresses the compression requirement which is now classified in the 1986 revision of 10CFR71 under Normal Conditions of Transport. The compression requirement is only applicable to packages weighing up to 5,000 kg.

2.5.2 External Pressure

This section addresses the Immersion - All Packages requirement classified in the 1986 revision of 10CFR71 under Hypothetical Accident Conditions.

The Immersion - All Packages condition considers immersion under a head of water of at least 15 m (50 ft), an external gauge pressure of water of 0.147 MPa (21 psi) being considered to meet these conditions. In addition to this regulatory condition, we are required to consider for the BR-100 design immersion under a head of water of at least 200 m, an external gauge pressure of 2 MPa (285 psi) being considered to meet these conditions. Therefore, the 200-m immersion condition will replace the regulatory 15-m immersion condition.

The 200-m immersion condition will be addressed in section 2.7, Hypothetical Accident Conditions, under section 2.7.4, Water Immersion.

2.6 NORMAL CONDITIONS OF TRANSPORT

The BR-100 shipping cask meets the performance requirements specified in Section 71.71 of 10CFR71. The following subsections detail the status of the preliminary structural analysis. The normal operating conditions addressed here are based on design criteria discussed in Section 2.1.2. The normal condition of transport includes:

1. Heat - An ambient temperature of 100°F,
2. Cold - An ambient temperature of -40°F,
3. Reduced external pressure to 3.5 psia,
4. Increased external pressure to 20 psia,
5. Vibration normally incidental to transportation,
6. Water spray that simulates rain of 2 in/hr for at least 1 hr,
7. Free drop - 1-ft drop on unyielding, horizontal surface, and
8. Penetration - Impact of the hemispherical end of a vertical steel cylinder of 1.25-in diameter and 13-lb weight dropped from a height of 40 in.

2.6.1 Heat

The thermal evaluation of the heat test is reported in Section 3.4.

2.6.1.1 Summary of Pressures and Temperatures

The following temperatures and pressures were used in the cask component stress analyses.

The maximum temperatures used to evaluate each component are dependent on location. The following table lists by component what bounding temperatures were used to evaluate the cask

Table 2-6
CASK TEMPERATURES USED TO EVALUATE COMPONENT STRESSES

Component	Temperature, °F
Basket assembly	250 to 275
Inner shell	300
Closure lid	200
Bottom plate - outer	200
Outer shell	200
Closure bolts	200

Brittle fracture is not expected to be a concern for proposed BR-100 cask materials; therefore, minimum temperatures are not used to evaluate any stress conditions.

The maximum pressures have been established either from various licensing requirements or from various test requirements. The hypothetical event that sets the maximum internal pressure to be investigated occurs when all the fuel rods in the cask rupture releasing previously contained fission and fill gases. The maximum external pressure for normal operation is specified as 20 psi atmospheric pressure test per 10CFR71. These pressures were combined to present worst case conditions in the cask regardless of the reality of the analyzed situation. The following table lists the pressures used in this analysis.

Table 2-7
MAXIMUM PRESSURES USED TO EVALUATE CASK STRESSES

Location	Pressure, psia
Internal	Pi = 150* Po = 0
External	Pi = 0 Po = 20

The lid and bottom plate were evaluated at 100 psi which is the maximum allowable pressure for international licensing. The outer shell was evaluated with an internal pressure of 30 psig to simulate water vapor retention (see sections 3.4.4 and 3.5.4) within the concrete.

2.6.1.2 Differential Thermal Expansion

The thermally-induced stresses in the cask and its various components will be calculated during the final design. The necessary temperatures and pressures will be taken from the applicable thermal calculations.

The BR-100 cask is designed to allow the structures to have free thermal expansion wherever possible. For this reason, the thermal expansion stresses are expected to be very small. During the design phase, the basket components were configured to allow for minimum differential thermal expansion between the cells, grid, formers, and inner shell. The basket components are all aluminum and the inner shell is stainless steel. The basket was sized to allow for its greater expansion without interference with the shell.

The other major components that will be investigated during the final design are listed below.

1. Differential expansion between the inner and outer shells in the ring flange area of the cask.
2. Differential expansion between the steel/lead/concrete/steel layers of the cask.
3. Differential expansion between the stainless steel closure lid and the Inconel 718 closure lid bolts.
4. Differential expansion between the trunnion/bolt/reinforcement ring assembly.

The thermal stresses are not considered significant at this point because they are typically deformation limited and are considered as secondary stresses.

2.6.1.3 Stress Calculations

The thermal stresses are expected to be small. Structural behavior under thermal conditions will be addressed in the final design.

2.6.1.4 Comparison with Allowable Stresses

Not applicable at this point in the preliminary design.

2.6.2 Cold

Cold temperatures have no adverse effect on the cask. At -40^{o}F, brittle fracture is not a concern for the stainless steel cask materials. The behavior of aluminum at -40^{o}F is discussed below.

The linear elastic fracture mechanics analysis was performed for aluminum 6061 fuel cells. The analysis enveloped worst-condition stresses (in this case, it was a 30-ft drop hypothetical accident condition) to calculate the critical flow size. The results lead to the conclusion that brittle fracture is not a concern for this design. This conclusion is also applicable to normal conditions.

Behavior of concrete at -40^{o}F will be addressed by testing during the final design phase. The concrete selected here is designed to avoid volume increase during freeze conditions.

The cask will be drained and vacuum dried before transportation; therefore, freezing liquid inside the vessel cavity is not a concern. The freezing of water between the impact limiter and cask body will be evaluated in the final design.

2.6.3 Pressure

The effects on the package due to a reduced external pressure only applies to the lid, outer shell, and bottom plate. In all cases, external pressure was taken as 0 psi for conservatism. The pressure stresses, allowable limits, and margins for these components are listed in Table 2-8.

Table 2-8
PRESSURE STRESS SUMMARY

Component	Location	Primary Membrane Stress Intensity, psi	Temp., °F	Allowable Stress Margin	
				psi	%
Lid	Internal	7,475	200	49,800	>500
Bottom plate-outer	Internal	3,568	200	25,050	>500
Outer shell	Internal (due to concrete)	718	200	16,700	>500

2.6.4 Vibration

Ninety-nine percent of the time of railcar movement, vertical and horizontal vibrations are less than 0.5 G (Reference 2.8). Since these vibrations are small, they are expected to have a minimal impact on the cask hardware. This will be documented in the final design.

2.6.5 Water Spray

Due to the materials used in the cask design, the water spray requirements have no effect on the system's structural integrity. The impact limiters, which are wooden, are sealed from the environment to prevent performance degradation due to water absorption into the wood.

2.6.6 Free Drop

The free drop from 1 ft corresponds to a 20 G load on the cask body based on the goal of current impact-limiter design. The cask components were analyzed using a unit load (1 G) to calculate stresses. These stresses are multiplied by 20 to determine normal operating condition stresses. Each component is discussed separately.

Basket

Of the various basket components, the cells are the most critical items. These cells must operate elastically for all normal conditions and maintain essential geometry for accident conditions. As such, the cells have received the bulk of the design/analysis attention. The other basket component analyses have been delayed until the final design because the stresses are expected to be very low.

The analysis method for both the PWR and BWR cells is the same. Consequently, the following discussion pertains to both analyses. The results are summarized in plots and tables.

Both cells were modeled with the ANSYS computer program. For the preliminary analysis, three-dimensional models of individual cells were used. The three-dimensional model determines the strength contribution of unloaded portions of the cell walls.

The element mesh is somewhat coarse to reduce run times and model complexity. For preliminary design, overall system response is more important than the discrete calculation of stresses in the various radii and corners that a finer mesh allows.

Each model took full advantage of symmetry based on the type of loading which, in this case, is normal to the drop angle. The axial symmetry is based on typical fuel assembly loading patterns within the cells. The two models are shown in solid form in figures 2-12 and 2-13.

For the current analysis, the cell orientation was chosen normal to the impact angle. As such, the model is symmetrical along the line of the top and bottom center ribs (Figure 2-12) for the PWR cell and along the thin plate section of the BWR cell (Figure 2-13).

The length of 10 in was chosen based on axial symmetry. Review of various PWR and BWR assembly designs revealed that the span between spacer grids is approximately 20 in. Therefore, an axial cell length of about 20 in supports each spacer grid. Taking this one step further, a 10-in length is used to represent this 20-in span by again taking advantage of symmetry.

The loading on the cell models simulates a maximum weight fuel assembly within the cell and the weight of the loaded cells above it. These loads are distributed to simulate the actual conditions.

The following comments pertain to the various cell loadings. To model the effect of the cells and assemblies above the modeled location (figures 2-14 and 2-15), the cumulative weight is applied evenly to the modeled cell ribs. Results show that the distributed weight above the bottom cell is unevenly distributed between the center rib and the outer ribs.

The other cell loading simulates the fuel assembly weight within the cell itself. It was conservatively assumed that all of the fuel assembly weight is applied to the cells through the spacer grids and end fittings. This gives very high localized loading under the grids. As soon as the fuel rods touch the cell wall, the loading begins to drop.

The cells represent a very difficult set of boundary conditions. To simplify the problem and allow for a linear elastic analysis, the cell was fixed from motion in the y-direction along the bottom of the cell. This models a cell on the bottom of the stack in the basket adjacent to the formers. Symmetric boundary conditions were used where applicable.

The results of the analyses show that both cell types meet the criteria of 1-ft free drop. For both cases, the worst stresses occur under the point where the fuel assembly load is applied. The worst PWR cell stresses were evaluated at the basket periphery where the temperatures are less than 260°F. These stresses diminish in areas farther away from the grid contact point. Each cell exhibits a large safety margin (Table 2-9). The stress contour plots are given in figures 2-16 and 2-17.

Table 2-9
CELL STRESSES
Normal Operation, 1-ft Side Drop

Cell type	Max. Disp., in	Max . Stress, psi Primary Membrane + Bending	Temp., °F	Allowable Stress, psi	Safety Margin, %
PWR	0.0218	7,840	260	13,290	70
BWR	0.0076	7,480	250	13,650	82

The displacements of the cells due to the specified loading are elastic under normal operation. The displacements (at the cross-section under the fuel assembly contact point) are shown in figures 2-18 and 2-19.

As part of each analysis, the stability of each design was determined. The cell stability as a function of G and the maximum stresses, displacements, and safety margins are shown in Table 2-10.

Table 2-10
CELL STABILITY RESULTS
1-ft Side Drop

Cell type	Impact Acceleration, G	Stability, G	Margin, %
PWR	20	129	545
BWR	20	590	2,850

Stresses of the cell for the axial load are expected to be very small, and the analysis will be performed in the final design.

Cask Inner and Outer Shells

A preliminary analysis shows the adequacy of the inner and outer shells to withstand the 1-ft drop without damage. As previously mentioned, the impact limiters keep the cask loads to 20 G during this event. End drop behavior has been left to the final design. A simple beam-theory analogy was made to determine the stresses and displacements. The stress calculations on the inner shell were based on imposed displacements of the outer shell.

The various stresses induced in the shells due to the 1-ft drop are summarized in Table 2-11. The listed stresses include the maximum pressure stresses (Pi =30 psig outer shell, Pi =150 psi inner shell) along with the drop stresses. Due to the large size and comparatively thin shell, a typical bending stress reversal across the neutral axis is unlikely; therefore, the stress limits are based on using a shape factor of 1.0 and a stress limit of 1.0 S_m.

Table 2-11
FREE DROP STRESS RESULTS
1-ft Side Drop

Component	Stress Intensity, psi Primary Membrane + Bending	Temp., °F	Stress Allowables, psi	Safety Margin, %
Outer Shell				
ID	9,259	200	16,700	80
OD	9,629	200	16,700	73
Inner Shell				
ID	11,367	300	16,700	47
OD	11,517	300	16,700	45

Closure Lid and Bottom Forging

The lid and the bottom forging of the cask were evaluated for their capabilities during the free drop. These stresses were calculated for 20-G impact end drops. This value is conservative because the forgings are supported over a large portion of their diameter by the impact surface rather than at the edges as analyzed here. The loads are the sum of the weight of the cask internals: Formers, assemblies, shield plug, and the lid weight. The load imposed on the bottom forging is the same except for the weight of the lid.

The stresses in the forgings for a side drop are considered insignificant because of the small load on these components in this direction.

As with the shell stresses, the end forging stresses are calculated with maximum pressures applied to create worst-case conditions. Table 2-12 summarizes the stresses for the lid and bottom forging.

Table 2-12 CLOSURE LID AND BOTTOM FORGING STRESSES				
Component	**Stress Intensity, psi Primary Membrane + Bending**	**Temp., °F**	**Stress Allowables, psi**	**Safety Margin, %**
Lid	37,818	200	49,800	32
Bottom forging - outer	21,823	200	25,050	15

Closure Lid Bolts

The closure lid bolts, made of Inconel 718, have been designed to minimize stresses and provide maximum holding power and reliability. The bolt analysis includes thread shear stresses, normal stresses in the bolt shank, and bearing stress (including criteria for "near free edge") under the bolt head, and the stress concentration factor per Section III of ASME Code. The bolt stresses due to an end drop are considered. For a properly designed bolted joint, there will be no joint slippage that could induce shear in the bolt. This joint will not slip since a shear lip on the cask body protects the lid. Therefore, the side drop is not considered relevant in the bolt analysis.

The important limits for the bolt are that the stresses remain below yield. The bolt analysis used the more stringent requirements of the ASME code (Section III subsection NB). The results of the analysis are presented below.

Table 2-13 CLOSURE LID BOLT STRESS RESULTS Pressure + 1-ft Drop				
Stress Location	**Stress, psi Primary**	**Temp., °F**	**Stress Allowables, psi**	**Safety Margin, %**
Primary/shank	44,550	200	96,000	115.0[1]
[1]This stress limit is per ASME Code Section III, Subsection NB which is 2 S_m.				

Shield Plug/Basket Components/Ring Flange

The stresses of the shield plug, fuel basket components, and the ring flange are expected to be small during the free drop. To this point, the emphasis has been on verifying the major cask components to ensure their integrity. The analysis methods will be similar to those used in the previous analyses. The results are expected to show the acceptability of these designs.

2.6.7 Corner Drop

This test applies only to wood or fiberboard packages per 10CFR71. The BR-100 cask is not made of these materials and is also in excess of the 220-lb limit specified as applicable to this test.

2.6.8 Penetration

Due to the thick-walled steel outer shell and the lack of fragile external features, the 1-m (40-in) drop of a 13-lb steel cylinder onto the cask has negligible consequences.

2.6.9 Compression

This test does not apply to the BR-100 cask. The overall cask weight is well in excess of the 5,000-kg limit specified in 10CFR71.

Figure 2-12
PWR Cell Finite Element Model

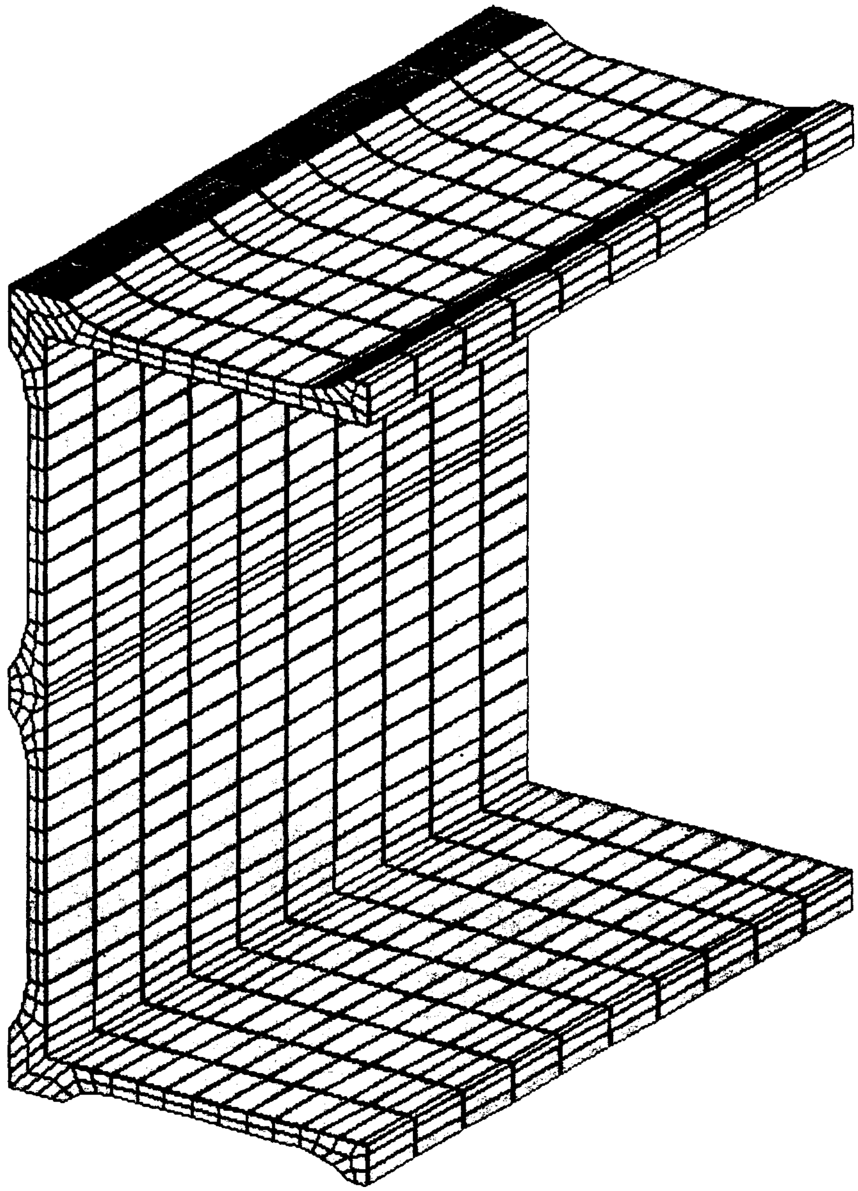


Figure 2-13
BWR Cell Finite Element Model

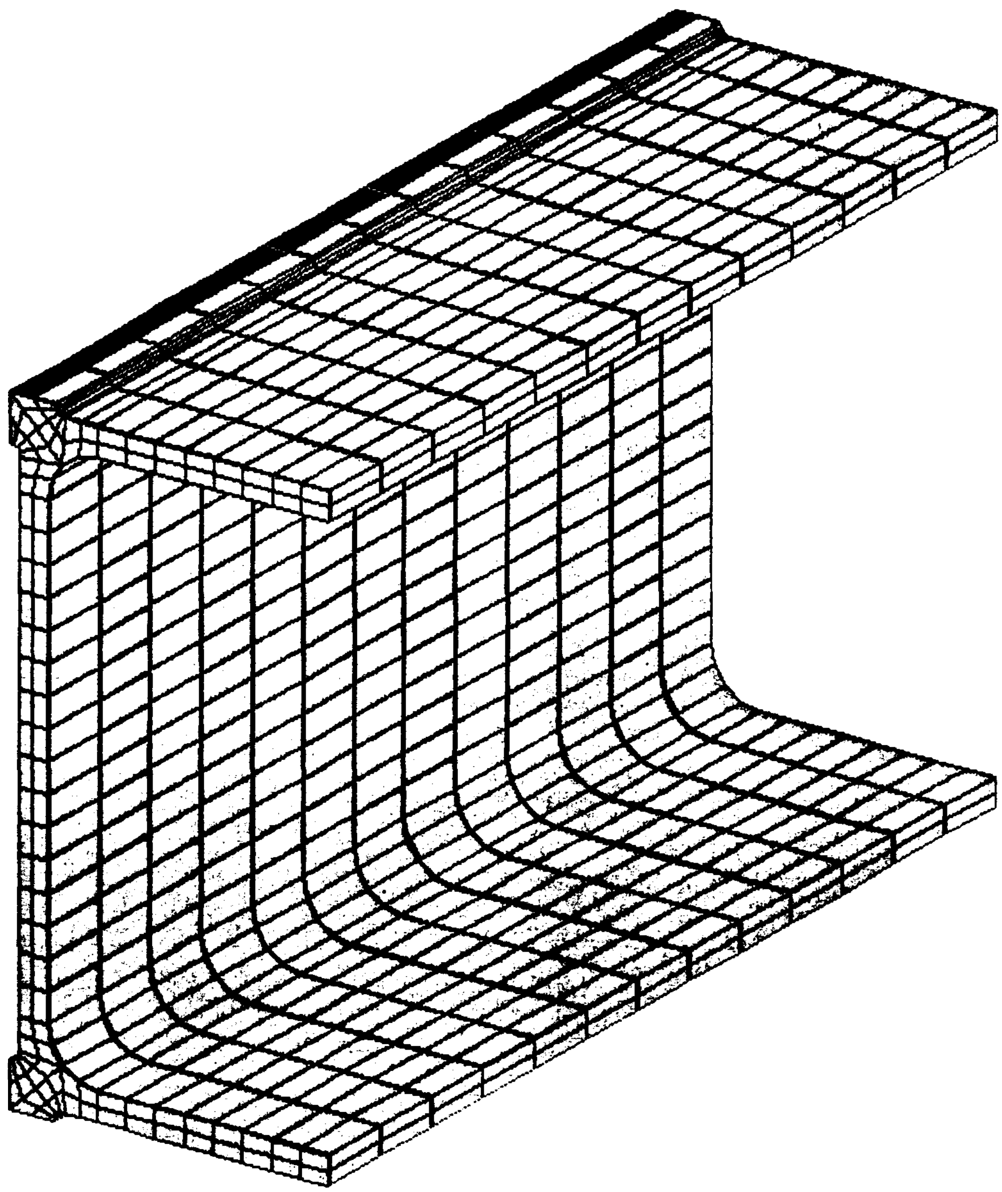


Figure 2-14

PWR Cell Loading

Side Impact

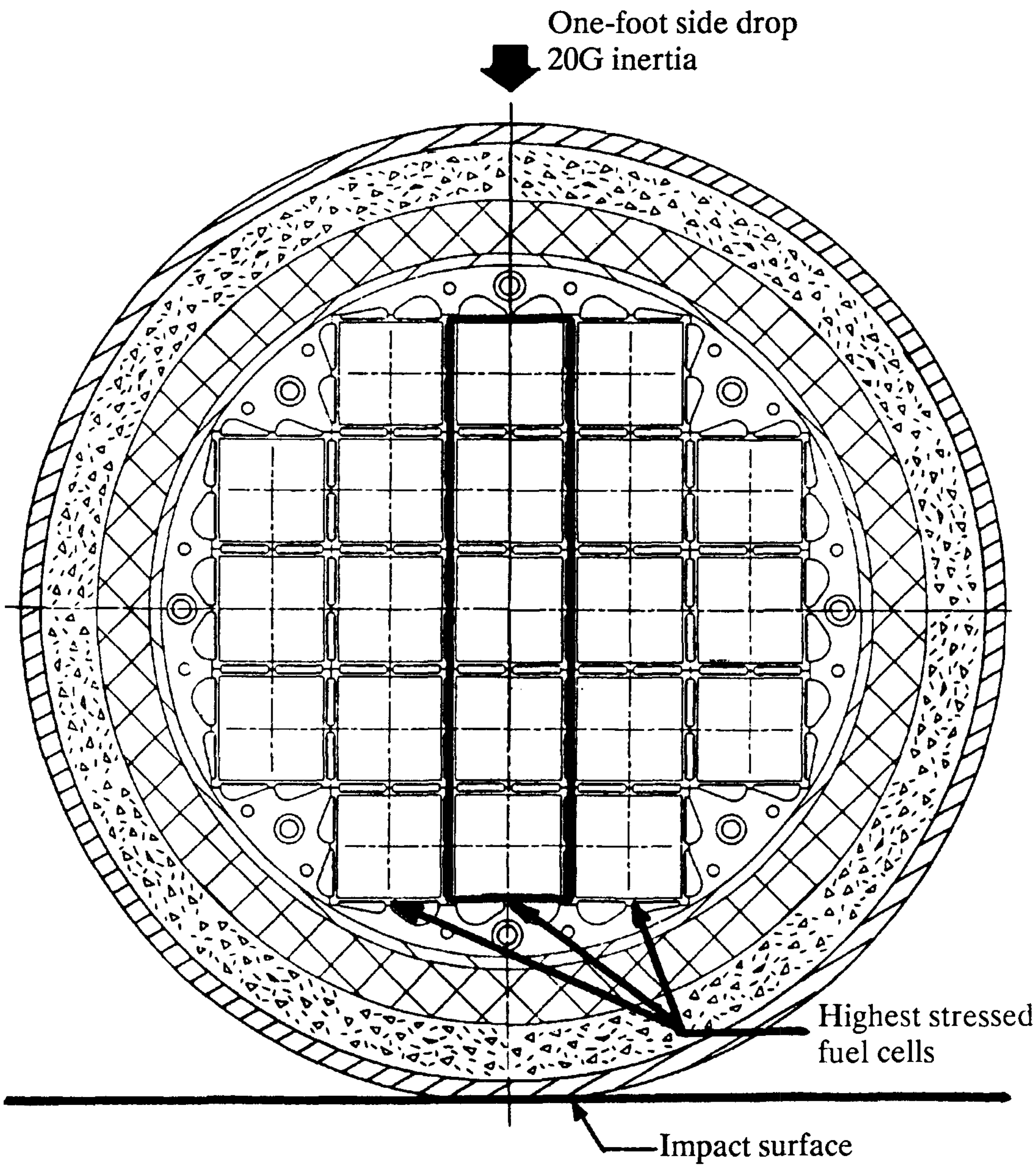


Figure 2-15

BWR Cell Loading
Side Impact

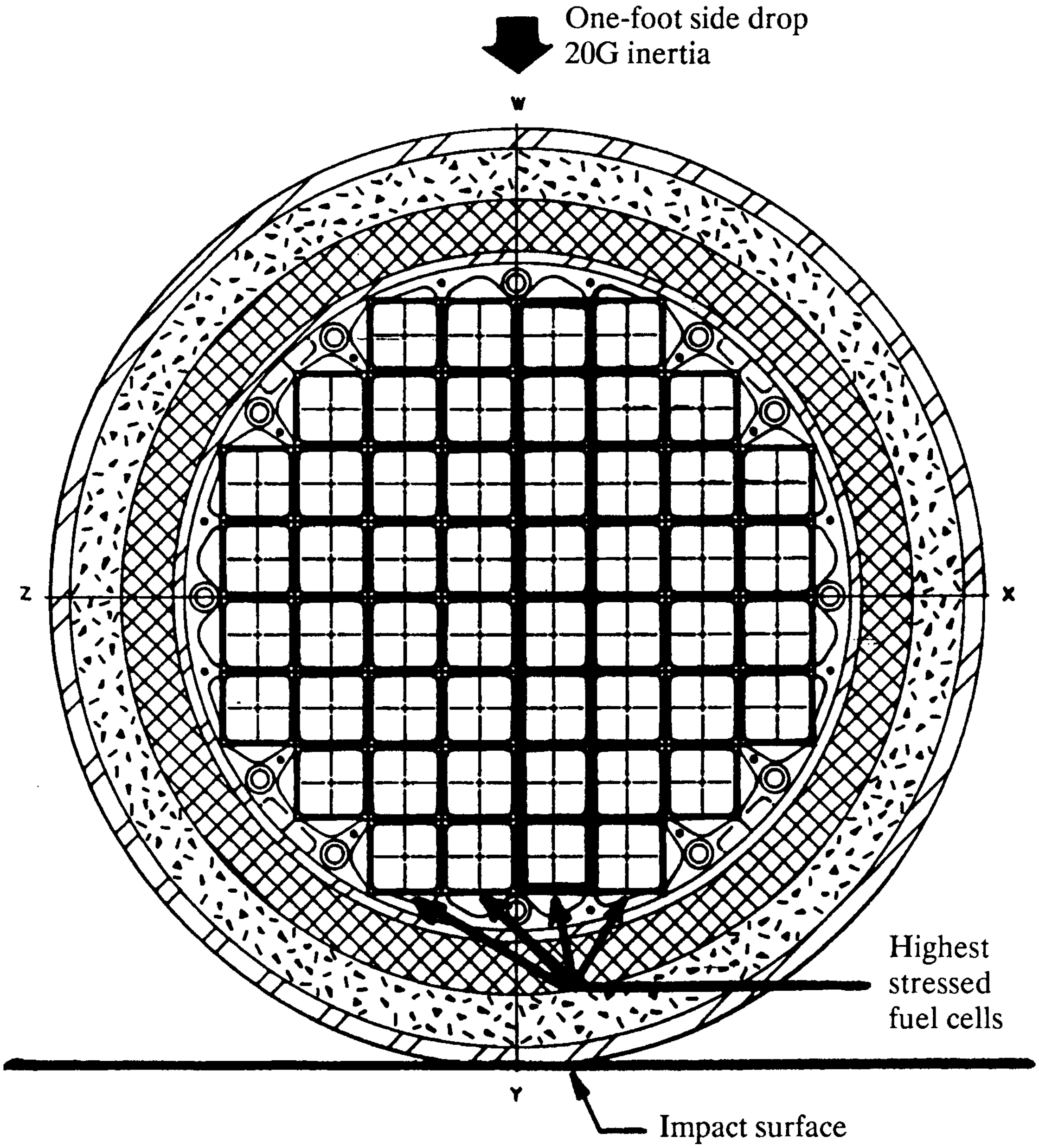
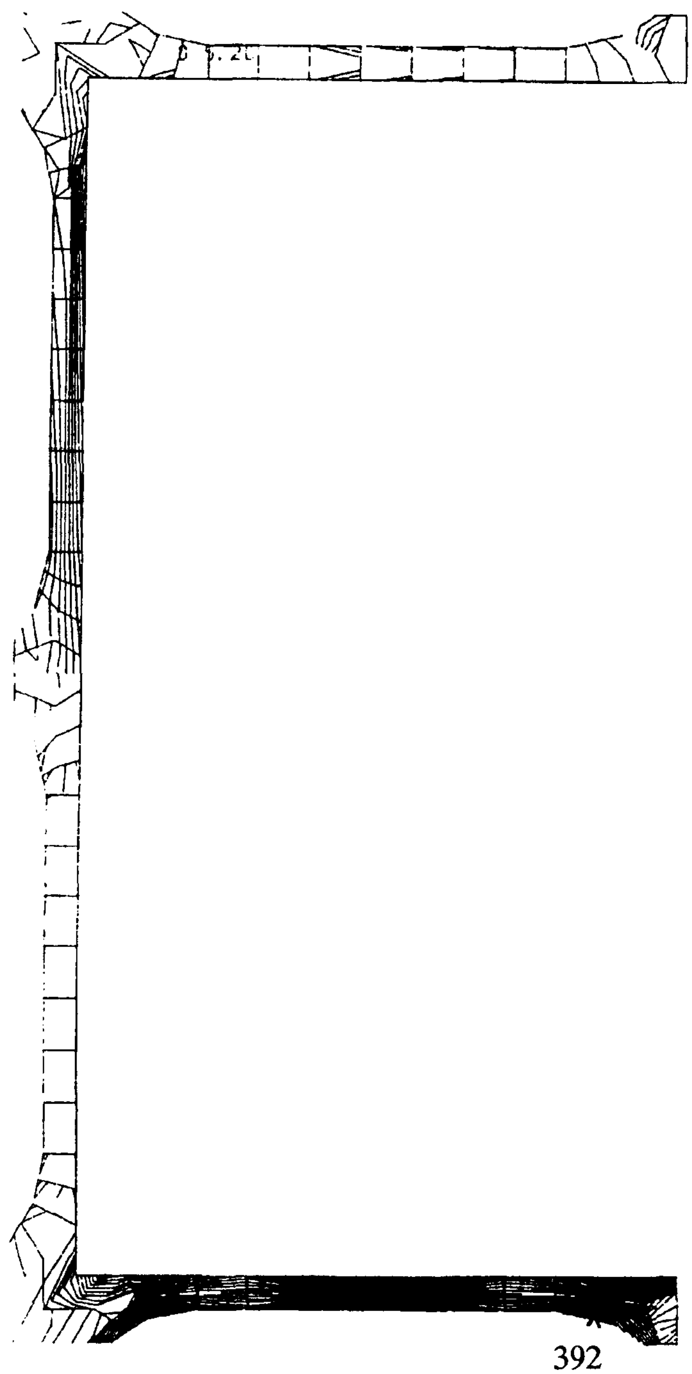


Figure 2-16

PWR Cell

Maximum Stress Distribution
Cross-Section View

Step = 1 Iter = 1 Time = 0



Load, 3-D Ribbed Model - Normal Impact

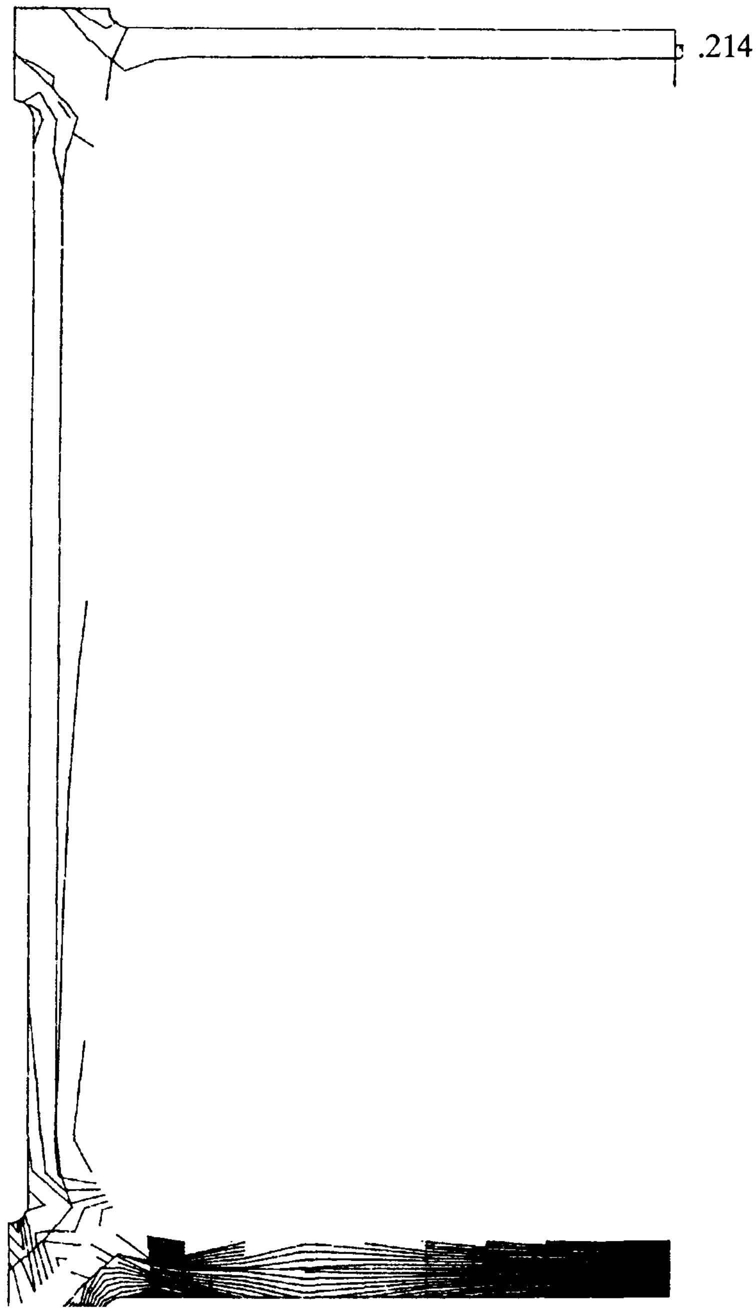
Figure 2-17

BWR Cell

Maximum Stress Distribution

Cross-Section View

Step = 1 Iter = 1 Time = 0



Load, 3-D BWR Cell Model - Normal Impact

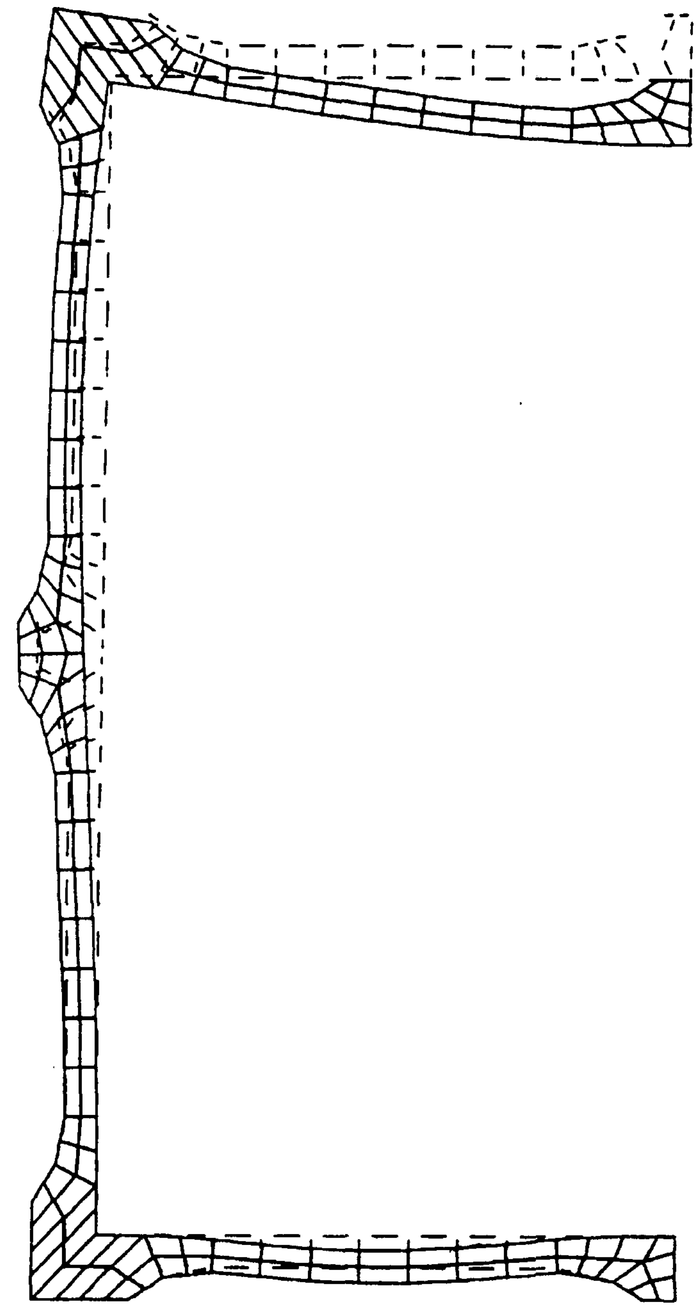
Figure 2-18

PWR Cell

Maximum Displacement Profile

Cross-Section View

Step = 1 Iter = 1 Time = 0



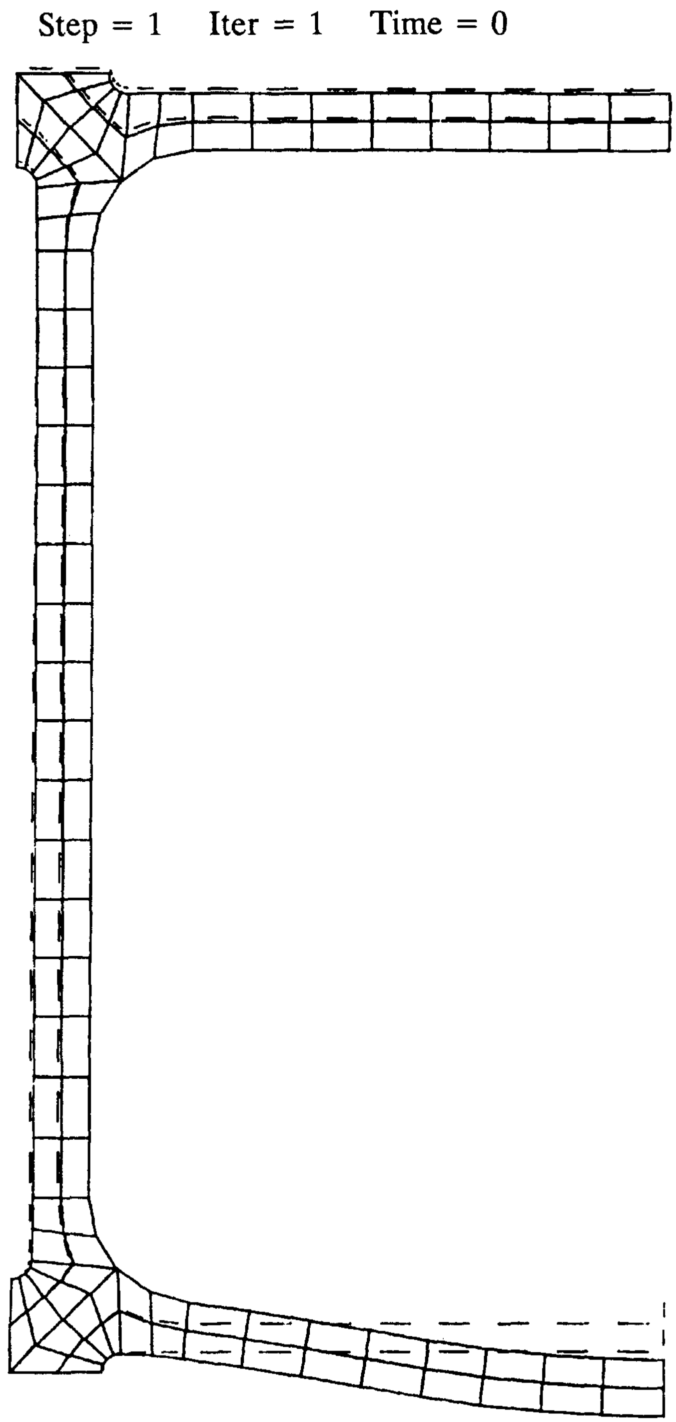
Load, 3-D Ribbed Model - Normal Impact

Figure 2-19

BWR Cell

Maximum Displacement Profile

Cross-Section View



Load, 3-D BWR Cell Model - Normal Impact

2.7 Hypothetical Accident Conditions

The BR-100 shipping cask, when subjected to the hypothetical accident conditions specified in Appendix B to 10CFR71, is expected to meet the standards specified in 71.73 of 10CFR71, as demonstrated in the following paragraphs.

In the preliminary design, the integrity of the structure is evaluated using conservative analytical or empirical methods. For the final design, however, detailed analytical methods will be employed. Testing on a quarter-scale model will be performed. Full-size or scaled prototypes will be tested separately. The testing results will supplement any earlier analyses on the same topic.

The ASME Boiler and Pressure Vessel Code, Section III, is used in determining the allowable limits. Allowable stress limits are presented in Table 2-3. The planned material for the cask shell (304L stainless steel) is an ASME Class 1 material as is the alternate material (XM-19 stainless steel). The conditions under which the alternate material would be used are outlined in Section 2. 0. The structural strengths of the lead and concrete layers of the shell are not considered, but their weights are considered in structural analyses. Both the BWR and PWR fuel cells are extruded aluminum 6061, which is presently an ASME Class 3 component material. However, as stated in Section 2.1.2.2, the design, fabrication, examination, and testing criteria of ASME Section III, Class 1 materials will be met for the material. This testing will permit the use of Class 1 allowable limits for the aluminum. These limits have been applied in the preliminary analysis.

The hypothetical accident conditions include:

1. Free drop - A 30-ft drop on an unyielding, horizontal surface,
2. Puncture - A 40-in drop of a cask onto a 6-in diameter mild steel cylinder of 8 in or longer,
3. Thermal - Exposure of the cask for 30 min or longer to a thermal accident environment of 1,475^{o}F, and
4. Immersion - A water head of 200 m.

2.7.1 Free Drop

<u>Analysis</u>

In the preliminary analysis, the performance of the cask is evaluated using quasistatic analyses of components, assuming conservatively high G levels. The G levels are based on calculated load-deflection characteristics of the impact limiter, which is used in an energy balance between the kinetic energy of the drop and the energy dissipated by the limiters. The goal of the impact-limiter design is to limit acceleration to 80 G during side impact. Details of the impact-limiter analysis are presented in appendices 2.10.1 and 2.10.2. Since these methods are conservative, very small design margins appear for some components. In the analysis of the shell structures, internal pressurization corresponding to the rupture of all fuel rods is superimposed on the loading due to the drop cases. Other conservatisms in the analyses include not taking credit for concrete strength or fuel basket strength. Also, the impact energy is absorbed only in the impact limiters and not in any other hardware.

In the preliminary analysis, only the side-drop and end-drop cases are considered. In the final design, a detailed, dynamic, nonlinear analysis of the cask structure (shells) is planned including drops at oblique angles. From the dynamic analysis, stresses in the cask structures will be determined as well as more realistic values for the G levels to be applied to the fuel cells and other structures. Quasistatic methods are planned for the evaluation of stresses in the fuel cell and components other than the shells.

Computer program PRONTO-2D will be used in the development of the cask dynamic model for the shells, including both structural layers as well as the concrete and lead layers. A description of program PRONTO-2D is included in Appendix 2.10.3.3.

Computer code ANSYS has been used in the preliminary analyses and will be used further in the final analyses for the evaluation of stresses in structures other than the shells. A description of program ANSYS is included in Appendix 2.10.3.1.

2.7.1.1 Side Drop

The side drop has been evaluated using the maximum 80-G forces to be available through the impact limiters. Linear elastic analyses have been performed for components in the cask body to provide a conservative upper bound on the stresses that may be expected on the cask components.

Components Analyzed

The components analyzed under the effects of the 80-G lateral impact load are described below along with the method of analysis. The resulting stresses and design margins are presented in Table 2-14 and are discussed below.

1. Cask outer shell - The cask outer shell has been analyzed for bending stresses assuming that the outer shell acts as a simply-supported beam. The stresses due to internal pressurization (water vapor in concrete) are superimposed on the bending stresses.
2. Cask inner shell - The cask inner shell has been analyzed in a manner similar to the outer shell. The stresses due to internal pressurization (fuel rod rupture) are superimposed on the bending stresses.

3. PWR fuel cell - The PWR cell was analyzed for stability as well as stress levels using a linear elastic model of the cell and an eigenvalue buckling analysis. In the stress calculation, a single cell was considered with the weight (x 80) of all cells above it as well as its own payload (x 80) applied. The method of application of the loads is outlined in Section 2.6.6. The worst-case PWR cell stress was evaluated at the basket periphery where the temperatures are less than 260°F. Because the eigenvalue buckling analysis does not account for structural imperfections, a safety factor of two is built into buckling margins presented in Table 2-14. This factor of safety is conservative with respect to ASME Code Case N-284 buckling criteria where a factor of safety of 1.34 is specified for Level D service limits.
4. BWR fuel cell - The BWR cell was analyzed using methods similar to those employed in analyzing the PWR cell.

2.7.1.2 End Drop

The end drop has been evaluated using the maximum 60-G forces to be provided through the impact limiters. This value provides a conservative upper bound on the stresses that may be expected on the cask components.

<u>Components Analyzed</u>

The components analyzed under the effects of the 60-G axial impact load and the method of analysis are described below. The resulting stresses and design margins are presented in Table 2-14. The effect of lead slump will be evaluated in the final design.

1. Cask lid - The cask lid has been modelled using classical methods. The lid is treated as a pinned-edge circular plate with the impact of the cask payload considered as a uniformly distributed load.
2. Cask bottom plate - The cask bottom plate has been modelled using classical methods. It is treated as a fixed-edge circular plate with the impact of cask payload treated as a uniformly distributed load.
3. Closure lid bolts - The closure bolts have been analyzed using classical bolting analysis methods. The bolts are assumed to act in pure tension as a result of the end impact.

2.7.1.3 Corner Drop

The corner drop has not been addressed in the preliminary design. The integrity of the shell structure subjected to the corner drop is to be evaluated in the final design. This will be accomplished by the use of the nonlinear, finite-element modelling of the shell structure applied in conjunction with the ILAN program (Impact Limiter

ANalysis) which calculates the impact-limiter load versus deflection characteristics for all incident angles.

2.7.1.4 Oblique Drops

Analysis

Oblique drops have not been addressed in the preliminary design. At present, the development of an analytical package (included in the ILAN computer program) is underway to determine the worst-case impact angle. Upon completion of this program, the worst-case impact angle will be considered in the final analysis.

Testing

A quarter-scale model of the cask is to be tested for at least three free-drop cases. In each case, the model is to be dropped from 30 ft onto an unyielding surface. In the first case, the cask model is to be dropped onto its side. In the second, the model is to be dropped onto either its top or bottom end, depending on which of these cases is determined to cause the worst-case stresses in the cask components. In the third test, the quarter-scale model is to be dropped with the center of gravity over the impacting corner of the impact limiter. If, based on the final analysis, the oblique drop is expected to cause higher impact forces than the corner drop, then an oblique drop case will be added. The drop angle will be the worst-case oblique drop angle, as determined analytically.

2.7.2 Puncture

Analysis

The puncture of the cask has been evaluated using empirical equations by Nelms (Reference 2.9) and Sakamoto (Reference 2.10). These equations are used to calculate the outer vessel thickness required to resist puncture. In this analysis, no credit is taken for the concrete strength or the strength of the inner vessel. The minimum required thickness is calculated for both 304L and XM-19 stainless steels as follows:

Nelm's Equation

$$t = (W/S)^{0.71}$$

where

t = Shell thickness, in,
W = Cask weight (200,000 lb for BR-100),
S = Ultimate tensile strength of shell, psi.

Material	Ultimate Strength (psi)	Thickness (in)
304L	66,200	2.19
XM-19	99,500	1.64

Sakamoto's Equation

$$E/S_U = (0.003 + 0.047\ t/D + 0.002\ d/D + 0.006\ r/d)\,t^{(1.585 - 0.11r)}\,d^{(1.465 + 0.077r)}$$

where

- E = Puncture energy (kg-m),
- S_u = Ultimate strength,
- t = Thickness,
- D = Curvature of Shell (2083 mm for BR-100),
- d = Punch diameter = 152.4 mm,
- r = Punch edge radius = 6.4 mm,
- E = Weight x drop height = 90910 kg x 1.016 m, = 92365 kg-m.

Sakamoto's equation is solved for t for the 304L and XM-19 stainless steels. The results are tabulated as follows:

Material	Ultimate Strength	Thickness
304L	66.2 ksi (50.0 kg/mm/mm)	39mm (1.54 in.)
XM-19	99.5 ksi (70.1 kg/mm/mm)	26mm (1.02 in.)

The cask design thickness is 1.75 in.

Also, the stresses in the outer shell have been calculated considering the cask bending due to puncture reaction under its own weight. The results of this calculation are summarized in Table 2-14.

In the final design, a puncture analysis will be performed using a three-dimensional, finite-element computer program, ABAQUS. ABAQUS has the capability to handle a layered structure (where sliding can occur between two surfaces) during a rapid, dynamic event such as the impact on a mild steel rod. A brief description of ABAQUS is provided in Section 2.10.3.4. BWFC plans to perform a series of punch tests on three- and four-layered 12-in-diameter specimens. The layers will be constructed from steel-concrete-lead-steel to simulate the cask body. The ABAQUS computer program will be benchmarked against these puncture tests.

Testing

The quarter-scale model will be subjected to the puncture test (1-m drop onto a 1- to 1.5-in-diameter mild steel mandrel).

2.7.3 Thermal

Heat

The thermal stresses in the shell structures have been considered assuming that the retained moisture in the concrete layer between the inner and outer shells is fully vaporized. This condition results in a pressurization of 30 psig (internal to the outer shell and external to the inner shell). The results of these calculations are presented in Table 2-14.

Cold

Young's moduli and yield strengths of the various materials vary inversely with temperature, making the elastic analyses that have been presented for normal operating temperatures conservative in regard to deformation and stresses at low temperatures. A potential concern is brittle fracture. The stainless steels considered in this design are known to exhibit ductile behavior at -40°F.

The fuel cells are made of an aluminum 6061 (ASME SB-221) extrusion with T6511 temper. A linear elastic fracture analyses was performed to obtain the critical flaw size for the fuel cells. The analysis was performed per Reference 2.11 proposed criteria. The fracture toughness data were obtained from the 1988 edition of Battelle's Structural Alloys Handbook (Reference 2.12) and are tabulated below:

Temperature, °F	K_{IC}, ksi$\sqrt{in}$
-40	28.5
70	26.0

The fracture-toughness data are not provided in Battelle's handbook for higher temperatures. However, the ductility of aluminum 6061 is lowest at 77°F and increases with temperature. Based on this, the fracture toughness values are expected to be higher for temperatures up to 300°F.

The maximum hypothetical stress in the fuel cells occurs during 30-ft drop events and is:

31,360 psi for PWR fuel cells and

29,920 psi for BWR fuel cells.

The thickness of fuel cells is:

0.25 in for PWR fuel cells and

0.27 in for BWR fuel cells.

Using these values, the linear elastic fracture mechanics analysis was performed. The results are presented in Figure 2-19A. The critical flaw size for the PWR fuel cell is

0.075 in. This flow size is higher than the permitted ¼ t (quarter thickness) or 0.0625 in. The BWR fuel cell design is bounded by the PWR fuel cell. Based on this, it is concluded that brittle fracture is not a concern for this design.

2.7.3.1 Summary of Temperatures and Pressures

Bounding values for temperature and pressure have been used in both the normal operating and accident analyses. These conditions are addressed in Section 2.6.1.1, and a summary of temperatures is presented in Table 2-6, while pressures are summarized in Table 2-7.

2.7.3.2 Thermal Stresses

Since the same bounding values for temperature and pressure have been used for both normal operation and hypothetical accident conditions, the treatment of thermally induced stresses for the accident conditions is the same as for the normal operating conditions. These conditions are discussed in Section 2.6.1.2. Thermally induced stresses are not expected to be a problem but will nonetheless be evaluated for the final design.

2.7.4 Water Immersion

In the preliminary design, the cask has been analyzed for 200-m immersion by considering the external pressurization of the cask outer shell. This analysis is based on ASME code guidelines, as outlined in Section III, NB-3133.3. The results of this analysis are presented in Table 2-14. Also, for the final analysis, buckling per ASME code case N-284 will be evaluated.

2.7.5 Summary of Damage

This evaluation is not applicable to the preliminary design, since no testing has been performed. An assessment of damage will be provided in the final report.

Table 2-14
MARGIN OF SAFETY SUMMARY
Hypothetical Accident Condition

Component	Material	Temp °F	Condition	Predicted Stress, psi	Allowable Stress, psi	Margin, %
Lid	XM-19	200	Pressure	21,301	99,500[5]	367
			60-G impact (+ Pressure)	98,506	99,500[5]	1
			Puncture (+ Pressure)	24,520	99,500[5]	306
Bottom plate - outer	304L SS	200	Pressure	10,169	60,120[2]	491
			60-G impact (+ Pressure)	56,845	60,120[2]	6 (304L)
	Note 6			56,845	99,500[5]	75 (XM-19)
			Puncture (+ Pressure)	30,653	60,120[2]	96
Outer shell	304L SS	200	Pressure	6,823	40,080[3]	487
			80-G impact (+ Pressure)	37,529	40,080[3]	7 (304L)
	Note 6			37,529	69,650[4]	86 (XM-19)
			Puncture (+ Pressure)	12,369	40,080[3]	224
Inner shell	304L SS	300	Pressure	4,614	40,080[3]	769
			80-G impact (+ Pressure)	39,597	40,080[3]	1 (304L)
	Note 6			39,597	66,010[4]	67 (XM-19)
			Puncture (+ Pressure)	30,529	40,080[3]	31
Inner Shell	304L SS	300	Po = 30 psi concrete Vaporization	Based on ASME Code, Section III		393
Outer shell	304L SS	200	200-m immersion	Based on ASME Code, Section III		13
PWR cell	6061 Al	260[8]	Buckling	G-level to buckle - 129 G[1]		61[1]

Continued

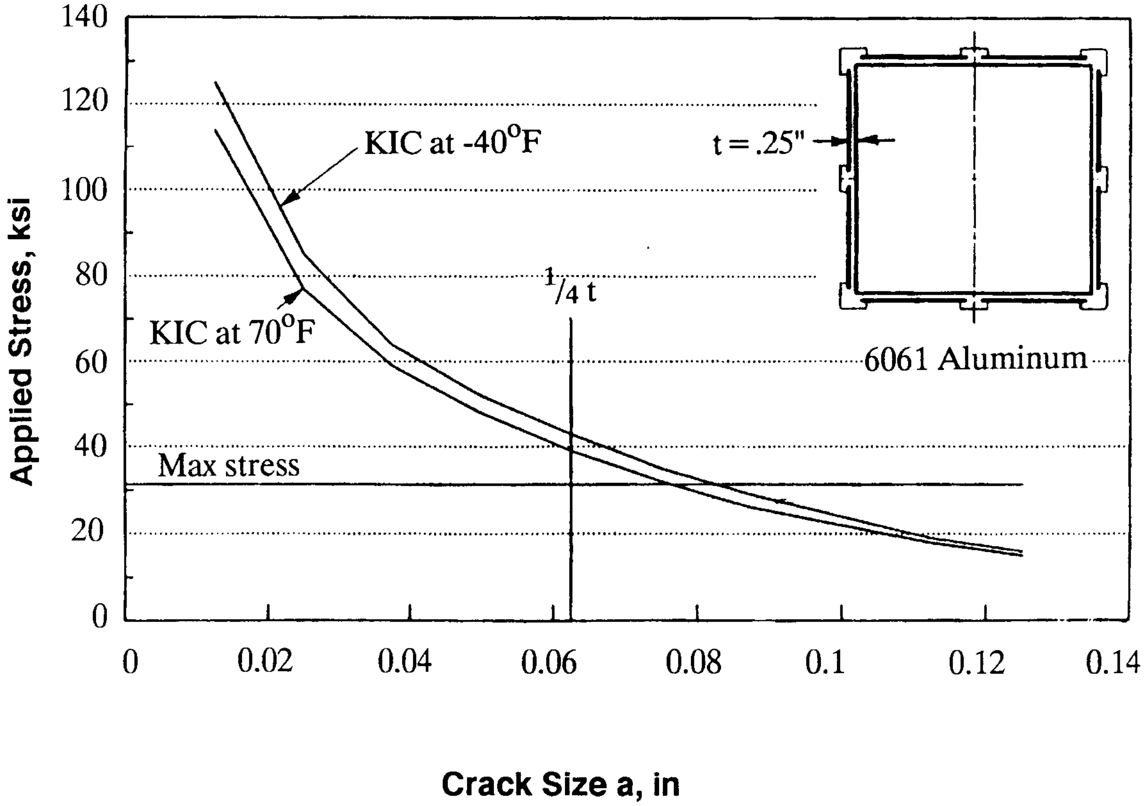
Table 2-14, Continued
MARGIN OF SAFETY SUMMARY
Hypothetical Accident Condition

Component	Material	Temp °F	Condition	Predicted Stress, psi	Allowable Stress, psi	Margin, %
PWR cell	6061 Al	260[8]	80-G impact, horizontal	31,360	31,898[2]	2
BWR cell	6061 Al	250	Buckling	G-level to buckle - 590 G[1]		638[1]
BWR cell	6061 Al	250	80-G impact, horizontal	29,920	32,760[2]	9
Closure bolts	Inconel 718	200	60-G impact, vertical primary stress	46,616	96,000	106

[1]These values reflect a factor of safety of two applied to the calculated critical buckling conditions.
[2]Allowable stresses are 3.6 S_m for materials at the given temperature.
[3]Allowable stresses are 2.4 S_m for materials with the given temperature.
[4]Allowable stresses are 0.7 S_u for materials at the given temperature
[5]Allowable stresses are S_u for materials at the given temperature.
[6]Values for the XM-19 shell material are shown in addition to the 304L baseline material. More discrete analyses should increase the 304L margins, but XM-19 is available as an economical, proven alternate material.
[7]Pressure is primary stress, pressure + puncture or 30-ft drop is primary + bending stress.
[8]These temperatures are at the location of the fuel basket, with the highest loading at the periphery of the fuel basket.

Figure 2-19A

Critical Crack Size for PWR Fuel Cell



2.8 Special Form

The BR-100 cask makes no claim for radioactive material in special form. Therefore, this section is not applicable.

2.9 Fuel Rods

During normal conditions, the maximum temperature of the center pin cladding of the center fuel assembly is predicted to be 364.2°F for PWR and 285.4°F for BWR design basis (hottest) fuel loading. Under thermal accident conditions, the maximum fuel pin cladding temperature is not expected to go beyond 470°F. Work performed by Pacific Northwest Laboratory indicates that fuel cladding will maintain sufficient mechanical integrity below 716°F (380°C) to prevent failure from mechanical reasons (Reference 3.13).

The fuel basket is made up of individual fuel cells, formers, upper and lower grids, tie rods, and straps. The individual fuel assembly is housed in a fuel cell. The fuel basket is enclosed in a cask body. The diametric clearance between fuel basket and cask body is almost 0.015 in in normal operating conditions. Fuel assemblies are displacement-limited in both normal and accidental conditions. The ductility in the spent fuel cladding is sufficient to accommodate these motions; this will be verified in the final design/analysis efforts.

BWFC expects that the cladding will maintain sufficient mechanical integrity during normal and accident conditions to provide containment.

2.10 APPENDIX

The following appendices are supplied:

2.10.1 Impact Limiter Design
2.10.2 Impact Limiter Testing
2.10.3 Description of the Computer Codes
2.10.4 References

2.10.1 Impact Limiter Design

2.10.1.1 Introduction

The impact limiters of the BR-100 cask must provide sufficient energy-absorption capabilities to limit acceleration loads to the cask body and interior components during drop accidents. There are three types of structural impact loads applicable to transportation casks as defined in 10CFR71 regulations: A free-fall drop accident from 30 ft onto an unyielding surface, a penetration drop from 40 in onto a stationary penetrator mounted to an unyielding surface, and a 1-ft normal handling condition drop. The impact limiters also must provide thermal protection to the cask lid seals during the hypothetical thermal accident.

The BR-100 impact limiters will satisfy the design requirements by incorporating the crushing characteristics of wood to absorb the impact energy. Wood is particularly well-suited to impact and crushing events. A Kevlar composite skin will contain the wood and prevent shifting. The contained wood will provide the BR-100 cask a safe and cushioned impact in normal and accident events.

2.10.1.2 Design Requirements

The BR-100 impact limiters will be designed to limit the maximum inertial impact loads of the cask to 80 G radially and 60 G axially during a 30-ft drop accident at any orientation. The energy associated with the 30-ft drop will be absorbed without excessive damage to the impact limiters nor detachment from the cask body. Local deformations are expected to occur during impact, but the impact limiter will be deemed satisfactory if thermal protection is maintained and the attachment mechanism is functional.

The maximum inertia load of the cask shall be limited to 20 G during the 1-ft handling accident. All angles of impact will be considered.

2.10.1.3 Design Strategy

The incorporation of composite materials in the impact limiters necessitates characterization by both a materials and component test development program.

The goal of the program is to utilize the high strength-to-weight ratios that composite materials offer in a functional design that is significantly lighter than conventional designs. The target weight is 4,000 lb to 4,500 lb per impact limiter. A "design by test" strategy is being used to evolve a successful and safe design. Several quarter-scale models will be tested, and the results of the tests will be analyzed and used to redesign future test models.

Three levels of testing will be used to evolve an impact limiter design. Figure 2-20 shows the design strategy and the levels used to arrive at a final design. At the beginning of the development program, two impact limiter concepts were identified as starting points from which to begin the evolution of the design process. These concepts are identified as concepts A and B and are shown on Figure 2-20. Concept C is an advanced conventional design that originally was to be used for comparison and as a fall-back design. Concept C has been dropped due to cost and schedule constraints.

Both concepts A and B incorporate Kevlar skins, balsa wood, and redwood. The primary difference between the concepts is the strategy by which the thermal protection to the lid seals is accomplished.

In concept A, the outer surface of the impact limiter is covered with a thermal shield. The shield material will be designed to withstand the hypothetical thermal accident condition. The shield will prevent impact-limiter wood ignition by providing an oxygen barrier between the wood and the atmosphere. The impact limiter wood core will act as a thermal insulator to prevent the lid seals from exceeding their maximum operating temperature.

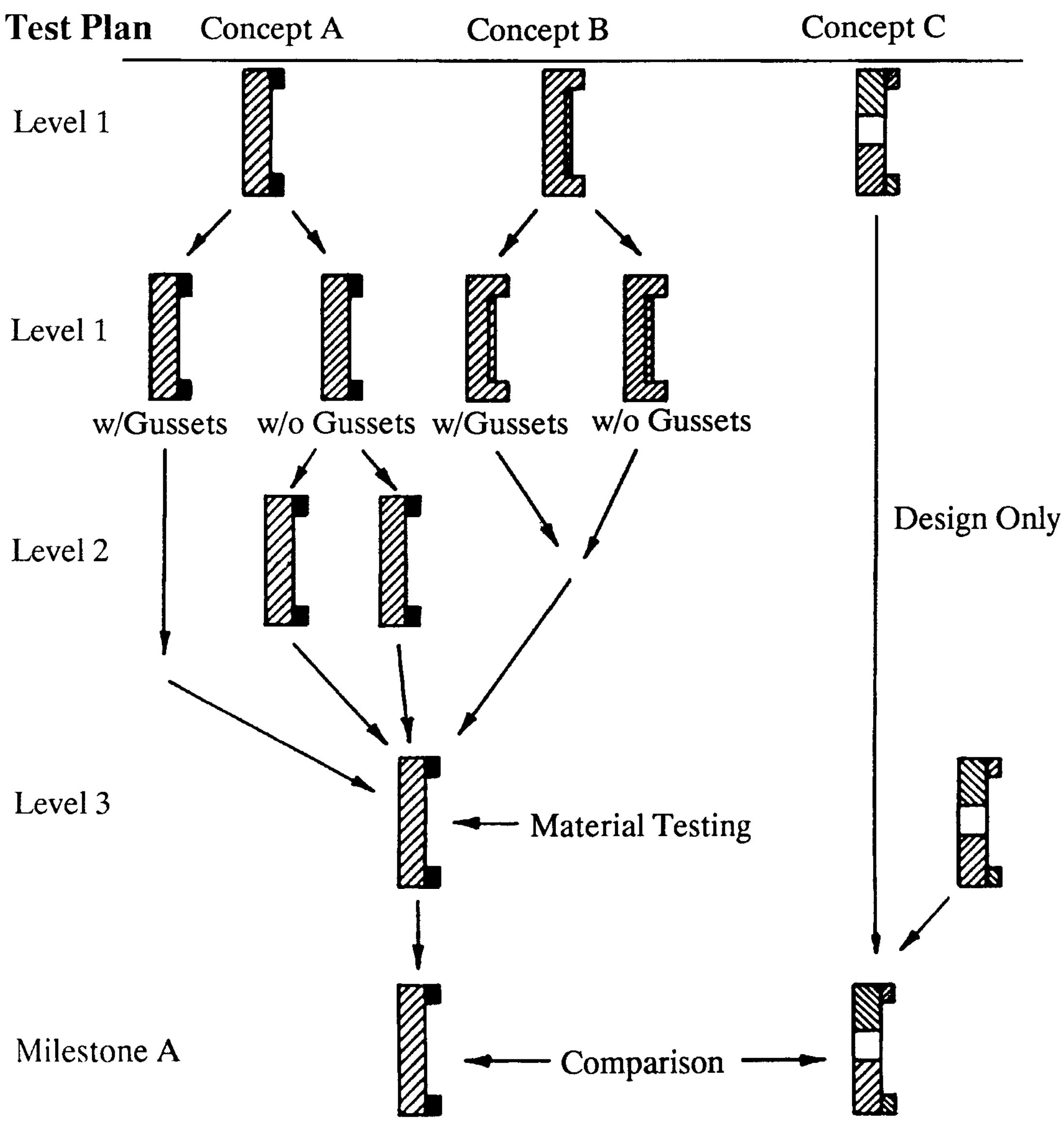
Concept B is similar to A, but the thermal shield is located inside the impact limiter instead of on the outer surface. In Concept B, the wood outside of the thermal shield is allowed to burn. The wood between the shield and closure lid is protected from ignition by the shield. The inside wood will be sized in thickness to ensure seal thermal protection. The advantage of concept B over A is weight savings due to less shield material being required.

Two candidate materials for the thermal shield appear promising. High-temperature ceramic fibers such as silica or silicon carbide may be incorporated directly into the outer Kevlar laminate. The ceramic fabric may provide a sufficient oxygen barrier to inhibit the wood core from igniting and burning. The matrix material is expected to melt and burn to some extent; however, the main objective is to limit the oxygen transport to the wood core.

The second (fall-back) thermal shield is a steel barrier. It is expected that the steel barrier will weigh more than a ceramic shield; however, the predictable high temperature/ structural behavior of steel makes it a good fall-back material.

The levels are designated as Levels I, II and III. The design process begins at Level I testing, which primarily focuses on the structural behavior and adequacy of the Kevlar/wood composite using simple scoping specimens and simplified model tests.

Figure 2-20
Impact Limiter Design Test Strategy



The primary reasons to perform scoping studies were to gain a quick evaluation of the performance of Kevlar composites in a cost-effective manner and to obtain "hands-on" fabrication experience with composites.

The initial scoping studies have been completed. The studies indicated that Kevlar is indeed a promising material for impact limiter use. The results of the scoping studies are presented in Section 2.10.2.

Level I testing also includes several test models approximately one-quarter scale in size. The purpose of these models is to arrive at a Kevlar casing design that successfully contains the wood core during an impact event. Several parameters such as skin thickness, attachment schemes, and bonding techniques will be investigated. When possible, innovative concepts that take full advantage of Kevlar's unique abilities will be incorporated. Where possible, simplifications to the design of Level I models will be made to reduce fabrication time and costs. At the conclusion of the Level I testing, a design capable of meeting the structural requirements will be determined.

A total of six test models will be fabricated and tested in Level II. The primary focus will be the detailed design of the attachment mechanisms, thermal performance, and puncture protection of the impact limiter design. The fabrication methods for the models will more nearly represent full scale production methods. Before fabrication of the Level II models, a series of component tests will be performed to evaluate the most promising attachment, thermal protection, and penetration protection features. These component tests will be designed to evaluate only the parameters of interest.

The weight of the models will be carefully monitored during the fabrication process and optimized wherever possible. Inspection and fabrication procedures will evolve in this program.

Four impact limiter models will be fabricated and tested in Level III. These tests will be classified as safety-related and will be used to benchmark computer codes and obtain test results for licensing purposes. All design requirements are expected to be verified in Level III tests. Fabrication methods will be as similar to full-scale production as reasonably achievable.

The results of all impact limiter model tests will be analyzed and incorporated into the analysis/design code. Babcock & Wilcox is developing a computer code that will model a full-scale drop event based on the force deflection characteristics of model tests. The output from the computer code, ILAN (Impact Limiter ANalysis) will include the forces, accelerations, velocities, displacements, and other variables for the entire impact event, including the secondary impact (if one exists).

Currently, the equations for the rigid body motion of the impact event have been modelled and will be verified shortly. The objective of the ILAN code is to utilize the results of model tests by developing analytical equations to model the test phenomenon and incorporate these analytical models into ILAN for future test iterations. A more thorough presentation of the ILAN program is presented in Section 2.10.1.5.

Safety-related materials verification and testing will provide the material properties used in the verification models. Such variables as the wood moisture content and grain angle effects on strength will be quantified in a controlled testing program. The parameters that affect the performance of Kevlar composites will be quantified.

2.10.1.4 Design Description

The impact limiter core is made of balsa wood and redwood. These frequently used and well-understood woods will be the energy absorption medium in an accident. Balsa wood and redwood have been selected because of their high specific energy absorption capabilities.

Epoxy-impregnated Kevlar laminates are used as the structural skins and internal gussets to confine the wood core during impact. Kevlar was selected because of its high specific strength and toughness compared to other materials. DuPont has developed two types of Kevlar. The high modulus fiber is Kevlar 49 and the lower modulus fiber is Kevlar 29. Both fibers exhibit the same tensile strength; however, Kevlar 29 is better suited to an impact event. Kevlar 29 has nearly double the strain-to-failure ratio of Kevlar 49; 4.0% to 2.2%, respectively. Applications of the toughness of Kevlar are apparent in bullet proof vests and other impact-tolerant devices, many of which are almost exclusively made with Kevlar. Boat hulls and motorcycle helmets extensively use Kevlar due to its high impact toughness.

A unique application of Kevlar/epoxy is being developed by Babcock & Wilcox to secure the impact limiters to the cask body. The attachment design appears to be an ideal application for Kevlar due to its high specific strength and excellent strain-to-failure properties. The oil industry incorporates Kevlar into mooring lines used to secure oil tankers in a similar type of application.

In some designs, Kevlar can be used with no matrix material. Typically, these applications involve only tensile loads. For compression and out-of-axis fiber loadings, a matrix material must be used to support the "composite." The matrix acts as the load transfer medium from fiber to fiber. There are many possible matrix materials ranging from plastics to metals. In fact, there is literally an explosion of new matrix materials to suit every conceivable application. For this program, an epoxy resin was selected primarily for its excellent cloth wetting ability, its relatively high service temperature (250^{o} + F), and its excellent structural/laminating properties. The epoxy system used throughout the development program is Magnolia Plastic's 2026 resin and 359 hardener. Although this system is a good selection, this epoxy was not meant to be the optimum choice for the matrix material (that would require a very expensive selection, evaluation, and testing program). The selection was made on the basis that the chosen epoxy system should meet the criteria of wetability, service temperature, and strength mentioned above. The design requirements can be met with this epoxy (or a slight modification to this epoxy). If at a future date an optimal matrix material is desired, one that may enhance the overall performance of the impact limiters, a selection evaluation can be undertaken.

2.10.1.5 Performance Analysis of Impact Limiters

BWFC has developed a cost-effective computer code to predict the cask accelerations for all possible angles of impact based on different impact limiter design concepts. This code, ILAN, is a combination of empirical formulas that model test results and theoretical equations of motion. The empirical formulas are developed outside ILAN and added to the code where applicable. Test results are analyzed, and empirical formulas are developed and documented. Finally, the empirical formulas are added to the ILAN code for future evaluations.

ILAN was written in the Quick Basic programming language (version 4.0). The code uses a time-step iteration routine to systematically "march" through the impact event. At the conclusion of each discreet time step, the crush depth, accelerations, velocities, rotations, and all other significant parameters are updated to reflect the effect of the impact on the cask.

For analysis purposes, the impact limiter was divided into three regions. Region I is defined as the central portion of the impact limiter. All wood inside the maximum diameter of the cask body is considered Region I. Region II is defined as the wood that is outside the cask body but does not overhang onto the cask side. Finally, Region III is the wood that overhangs or engages the cask body. These regions are shown in Figure 2-21.

The impact limiter is divided into these regions so that all angles of impact can be conveniently accommodated. Within each of the regions, a common wood grain orientation will typically be used. For example, all the wood in Region III is oriented radially outward to provide maximum strength in the side drop. The wood in Region I is oriented parallel to the cask body axis for maximum strength in an end drop.

The computer program uses the following algorithm to calculate the force-deflection characteristics of the impact limiter. The footprint area for a given time step is calculated based on the initial velocity of the impact end (the "nose"). The footprint area is then divided into a maximum of eight discrete segments per region. The program then calculates the crush strength for each of these segments based on the orientation of the wood relative to the impact angle. Hankinson's formula is used to predict the strength of the wood as a function of crush angle. When more than one region is crushed, both regions are calculated and accounted for. The footprint subdivision is shown in Figure 2-21.

ILAN assumes that all regions develop the full strength of the wood in the region based on crush angle. Of course, this is not true in practice. Some flexing and shifting of the wood core will occur. Rather than try to bound the error that exists by guessing the strength of the "unbacked" regions, test results will be analyzed and incorporated into ILAN to account for cracking and movement of the wood.

At present, the computer code assumes that all deformations occur at the exterior surface of the impact limiter. This scenario is not necessarily true, particularly under the end-drop conditions. Hopes are that test results will assist in formulating how the impact limiter crushes in near end-drop orientations. These results will be utilized in ILAN.

No contribution of the Kevlar skin or gussets is included in the computer code. This is a reasonable assumption given the out-of-plane properties of the skins. However, the possible contribution of the strength of the gussets will be evaluated as testing progresses.

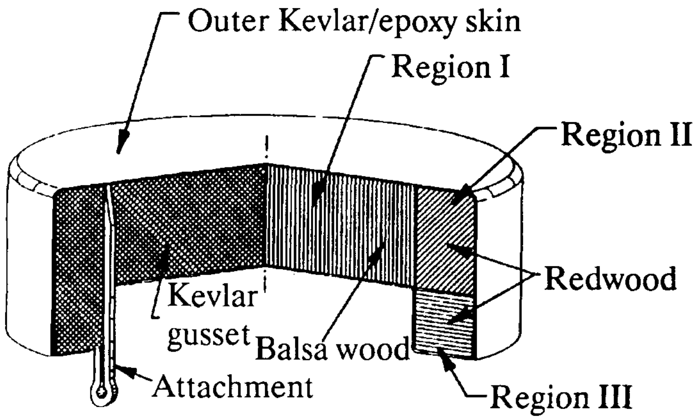
2.10.2 Impact Limiter Testing

2.10.2.1 Introduction

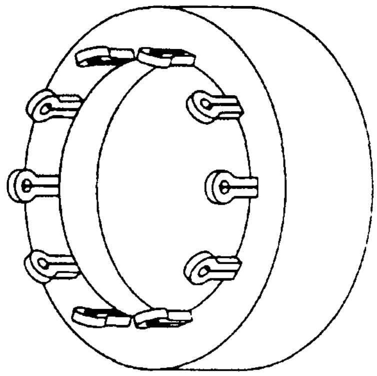
An impact limiter testing program has been established to provide test data from scoping tests and quarter-scale model tests for impact limiter design purposes. This is a "design by test" development program.

The strategy by which the impact limiters will be designed and tested is shown in Figure 2-22. A design will be fabricated and tested based on the analysis of previous test data. The model will be tested and analyzed to aid in designing a more optimal impact limiter. Empirical formulas will be developed to correlate actual test results

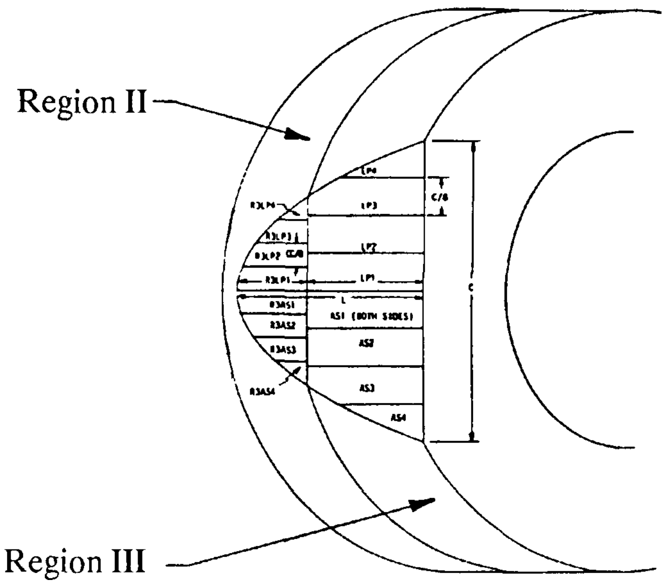
Figure 2-21
Impact Limiter Design



Impact Limiter Section



Impact Limiter Attachment Design



Impact Limiter Footprint Area For Regions II and III

to mathematical models. These empirical formulas will then be incorporated into computer codes to form the iterative loop that is shown in Figure 2-22.

Babcock & Wilcox has developed its own computer code, ILAN, to model and predict the performance of an impact event such as a 30-ft drop, based on test results. ILAN will predict the dynamics of the cask impact in terms of accelerations, velocities, displacements, and rotations for all angles of impact. The program also includes the secondary "slapdown" impact.

Before the beginning of model impact limiter fabrication and testing, it was felt considerable information could be gained from simple, economical scoping tests; therefore, a series of scoping tests were conducted. The objectives of the scoping tests are discussed in Section 2.10.2.2.

With the successful completion of the scoping tests, the decision to move forward into quarter-scale model tests was made. At the time of this report, one impact limiter model has been tested and the results are discussed in Section 2.10.2.3. The quarter-scale testing program employs both static and dynamic tests.

The testing program has been divided into three testing levels. Level I focuses on the structural adequacy of the impact limiter as a whole. Inertial impact loads, displacements, and overall integrity of the models are the primary objectives of this level of testing.

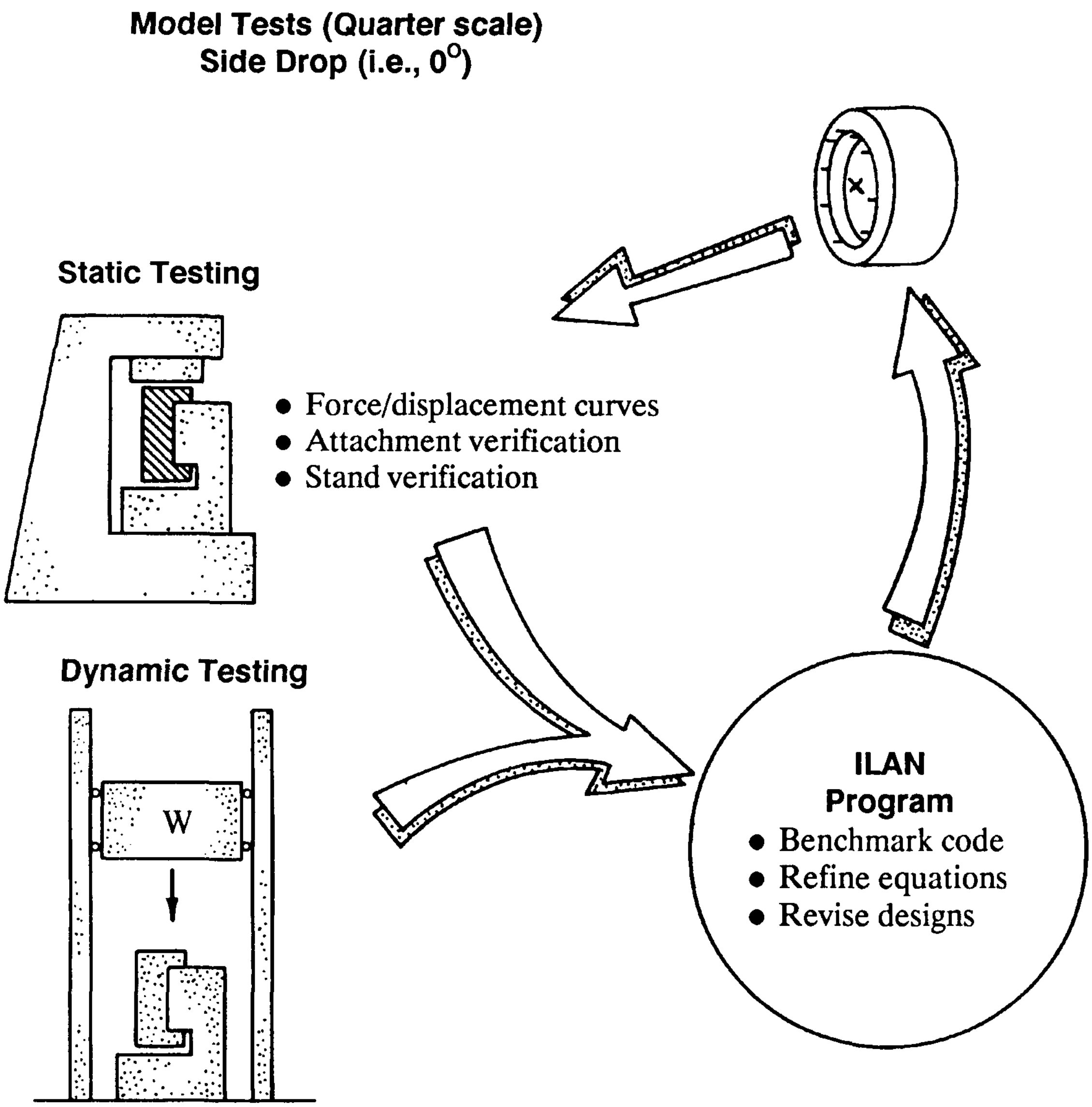
The first four models will be tested statically in a side-impact orientation. This orientation will be used first because the side-to-shallow-angle drops produce the most severe decelerations during the 30-ft impact event. Because the worst case slapdown angles are expected to be quite small (i.e., 5^{o} to 15^{o}), the successful performance of a model in a side-drop orientation using slapdown energies will also provide adequate energy absorption capability at actual slapdown angles.

The fifth and sixth models will be tested statically in a 45^{o} orientation. This orientation will likely be near the most severe for the impact limiter itself due to the "splitting effect" of the cask body during impact.

The remaining two models of Level I will be tested dynamically in a drop fixture specially designed and built for BR-100 impact limiter testing. The models will be tested at 0^{o} and 45^{o}. These dynamic tests will provide the first comparison between static and dynamic crushing.

Figure 2-22

Impact Limiter Testing Cycle



Level II testing will address the detailed design of the impact limiters. The thermal protection, puncture resistance, and attachment mechanism of the design will be incorporated into Level II designs. A total of six models will be fabricated. Testing orientations will include 0^o and 45^o static and dynamic tests. At the conclusion of Level II testing, the impact limiter design should be capable of satisfying the design requirements with perhaps only minor "tweaking" to obtain desired performance.

The final level of testing is intended to serve as the "benchmark" tests for use in benchmarking the ILAN computer code. Static and dynamic loads and orientations of 0^o, 45^o, and 90^o will be used. The force-deflection characteristics of the impact limiters will be modeled into ILAN to verify satisfactory G levels and displacements. This level of testing will require four models.

A materials test program will be conducted in parallel with the impact limiter test program. This program is being conducted to establish the characteristics of the materials used in the impact limiters and to determine the parameters within which these materials must operate (see Table 2-15).

Table 2-15
MATERIALS TEST

Test Type	Variations
Balsa wood and redwood compression tests	Wood-grain orientation Moisture content Density Temperature
Kevlar/epoxy tension tests	Temperature Stain rate Laminate structure Water absorption
Kevlar/epoxy burning tests	

2.10.2.2 Scoping Tests

A series of static and dynamic scoping tests has been performed using small balsa wood and redwood specimens. The objectives of the scoping tests were to evaluate the performance of Kevlar composite structural skins and to obtain "hands-on" experience with composite fabrication. Axial crushing of the specimens provided crush performance data on a variety of wood/shell combinations. The matrix of test cases is shown in Table 2-16.

Table 2-16
SCOPING TEST MATRIX

Test	Materials	No. of Balsa Specimens	No. of Redwood Specimens
Static	No skin material	5	5
	Kevlar skin (3-ply)	3	2
	Kevlar skin (6-ply)		2
	Stainless steel skin	4	3
Dynamic	No skin material	1	
	Kevlar skin (3-ply)	2	
	Kevlar skin (6-ply)		1
	Stainless steel skin	1	

The specimens consisted of wood cores that were 3 in in diameter and 3 in in length. The wood cores were oriented with the grain parallel to the length. Some specimens were crushed within a rigid, thick-walled aluminum tube to evaluate the wood properties alone (with no skin). The aluminum tube acted only to contain the wood from splitting apart and did not add to the force required to crush the wood. These specimens were meant to be the benchmark for wood-only crushing properties. A total of five balsa wood (ranging in densities from 6.5-8.1 lb/cu ft) and five redwood (22.4-25.5 lb/cu ft) specimens were crushed with no skin containment. Table 2-17 shows the calculated densities for all the wood cores used in the scoping tests.

Table 2-17
SCOPING TESTS
Wood Core Densities
Lb/Cu Ft

Wood Specimens	B1	B2	B3	B4	B5	B6	B7	B8	B9	B10	B11	B12
Balsa Wood	6.9	6.9	7.1	8.1	7.2	6.5	6.6	7.4	10.4	9.0	10.2	7.7
	R1	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**	**R11**	**R12**
Redwood	23.0	25.5	24.0	22.4	24.6	23.9	24.6	22.1	24.2	25.1	25.3	24.2

The wood cores were fabricated using a precision lathe. Design tolerances were held to within 0.010 in. The fabrication of the stainless steel skin involved the welding of a 0.0295-in thick sheet, 3 in in width over a 3-in-diameter rod. The Kevlar skin was fabricated by waxing a 3-inch-diameter aluminum rod. Kevlar cloth was impregnated with the epoxy matrix and was wrapped three or six times around the surface of the rod depending on the desired ply number. Upon cure of the composite, the rod and skin were placed in a freezer for 20 min to allow the aluminum rod to contract and thus allow easy removal of the composite tube. The composite tube was then sectioned on a lathe into 3-in lengths. Both steel and Kevlar skins were slip fitted over the wood cores for testing.

A 120,000-lb testing machine was used to crush the specimens. The setup is shown in Figures 2-27 and 2-28. The force-displacement curves for the balsa wood and redwood specimens with no skin are shown in Figures 2-25 and 2-26. Both the balsa wood and the redwood, when crushed with no skin material, behaved as expected. Balsa wood maintained a nearly "flat" crushing force of approximately 8,000 lb, which corresponds to a crush stress of 1,130 psi. The "lockup" of the balsa wood begins when the crush depth has reached about 2.3 in (out of the starting height of 3 in). The strain-to-lockup corresponds to 76%, which was expected.

Figure 2-27 compares the average balsa wood only, Kevlar skinned, and steel-skinned force-displacement curves. A total of three Kevlar and four steel-skinned specimens were tested. The average values for each group are shown in Figure 2-27. For comparison purposes, note that the three-ply Kevlar skin weighs approximately one-fourth that of the steel skin. The Kevlar-skin specimens appear to have about one-half the elastic modulus of the rigidly contained, wood-only specimens. The thickness of the three-ply skin was approximately 0.040 in. The elastic modulus of the steel skinned specimens is only slightly higher than the Kevlar specimens. The Kevlar skin would, therefore, appear to have a higher specific modulus than steel, since the Kevlar only weighed one-fourth that of the steel.

The steel skin does contribute to the overall strength of the specimen as compared to the lighter Kevlar. However, because the Kevlar skin did indeed contain the wood to absorb the crushing energy, it performed its intended function. For this reason, no crush tests were performed with the six-ply Kevlar skins on balsa wood.

The unskinned redwood specimens also behaved as expected. Lockup of the wood occurs at about 60% strain. The average crushing force is nearly constant at 40,000 lb, which corresponds to a crush stress of 5,650 psi for the five specimens tested.

To contain the redwood specimens, Kevlar skins with six plies (layers) of cloth were fabricated. These skins weighed about half that of the steel skins and were about 0.080 in in wall thickness. The comparison between average redwood, redwood and Kevlar, and redwood and steel is shown in Figure 2-32. Both Kevlar and steel skinned specimens exhibit a reduction in the elastic modulus. The Kevlar specimens actually appear to have a higher elastic modulus than the steel specimens. The "joggle" in the steel curve at around 12,000 lb is due to a local failure in the weld of one steel skin that is averaged into the curve. However, the Kevlar skin does appear to be at least as stiff as the steel skin at only one-half the weight.

The Kevlar skin also provides considerably more crush strength over the unskinned redwood and the steel/redwood curves in the region of crush, less than about 0.6 in. The composite skin contributes to the crush strength of the specimens. The result is that, for a desired crushing strength, a lighter (hence weaker) wood may be used to absorb the impact energy. At approximately 1 in of crushing, the composite skin began to slowly tear. The tearing of the skin was complete at 1.6 in. This is not necessarily considered to be a failure of the composite skin because the skin did contain the wood almost to the lockup strain of the wood, and the area under the curve (energy absorbed) is satisfactory.

The most important feature of Figure 2-32 is evident in a comparison of the area under the curve for Kevlar-skinned specimens and steel-skinned specimens. For strains up to 60%, or 1.8 in, the composite skin has a nearly equal area under its curve as the steel-skinned curve. The composite curve provides nearly equal energy absorption at only half the weight of the steel skin.

Dynamic scoping tests were performed to evaluate the behavior of Kevlar composites in a dynamic event. Kevlar composites had not been dynamically tested, and there was a need to know whether the Kevlar would "shatter" under an impact load. Five specimens were tested. A 170-lb weight was dropped onto the specimens from a height of 36 in or 72 in. Kevlar skins were used on three of the specimens. The results of the testing indicated that the composite skin behaves identically as in static testing as far as the crushing/wrinkling pattern is concerned. There was no indication of any brittle failure or shattering during the composite tests.

The dynamic tests also confirmed that an increase in strength is observed during dynamic events as compared to static events. This was noted by comparing the permanent displacement of the dynamic specimens at a given energy absorption to the corresponding static specimen displacement at the equal energy. As much as a 50% reduction in displacement was noted for some specimens. The tests did not measure the maximum displacement before the elastic "spring-back" as would have been performed in a precision test. These were intended to be simple scoping tests. The composite skin contained the wood cores with no anomalies.

Presently, a follow-on test program is being prepared to evaluate the effect of wood-grain orientation on the crush strength of balsa wood and redwood. Plans include sufficient specimens to characterize the commonly used Hankinson equation.

Figure 2-23
Scoping Test Apparatus
Wood Only

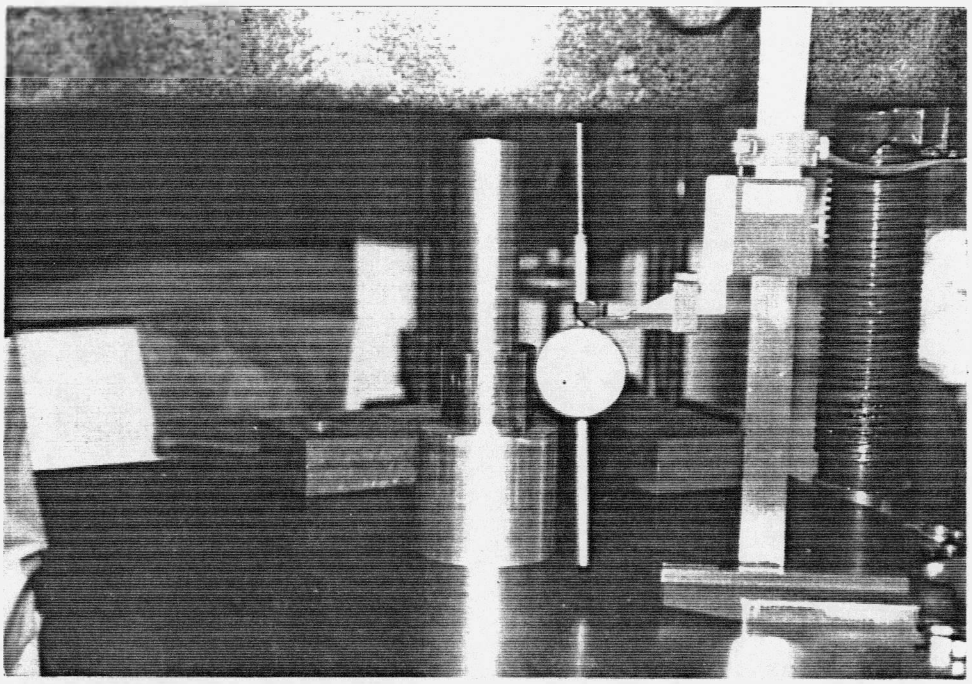


Figure 2-24
Scoping Test Apparatus
Kevlar Wood Specimen

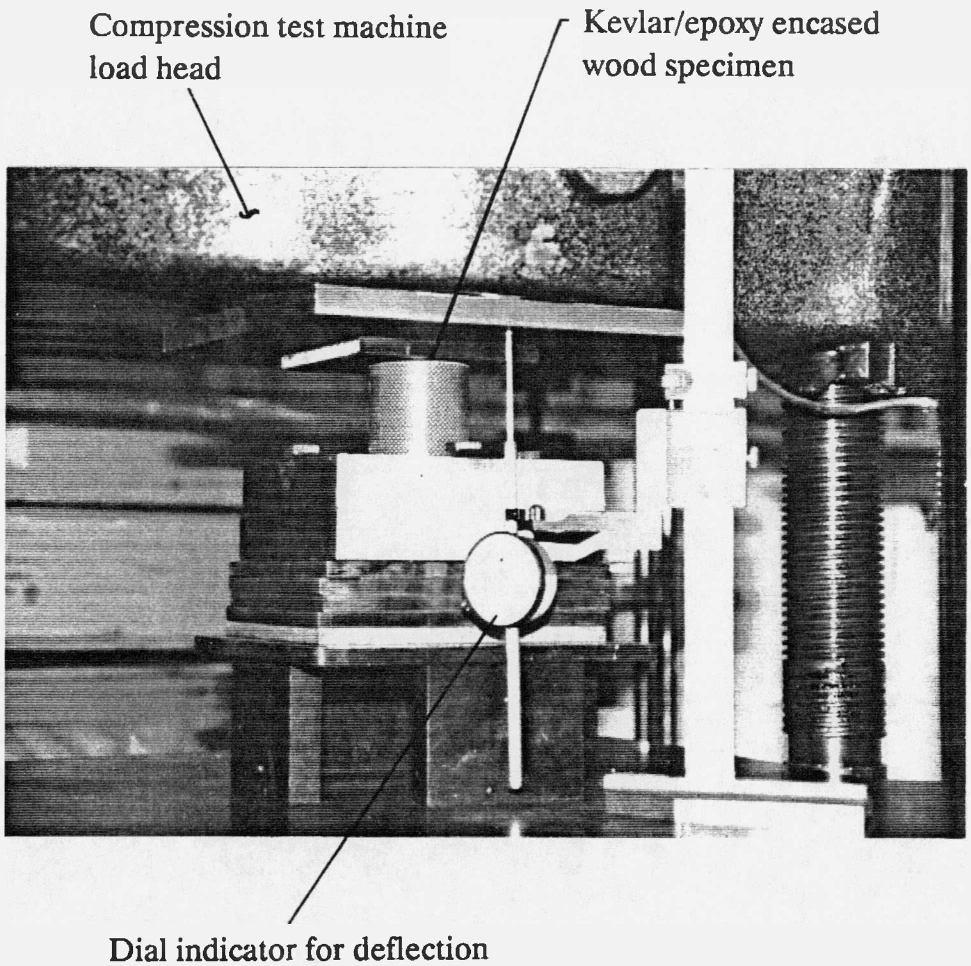
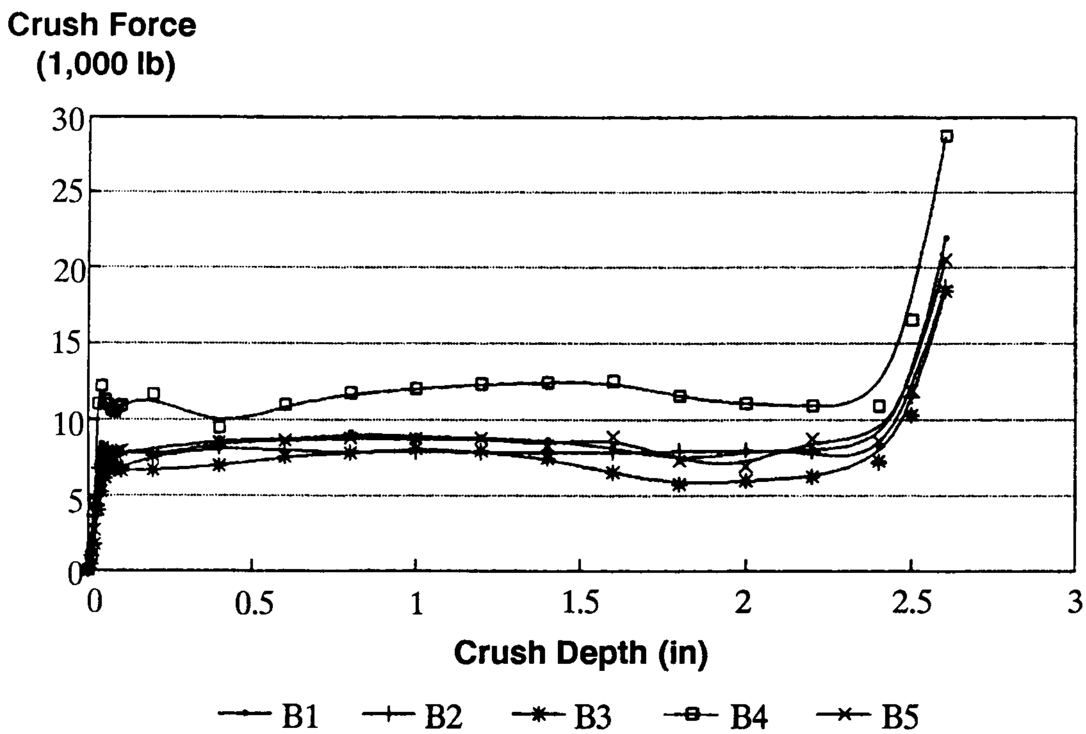


Figure 2-25

Force-Displacement Curve
Balsa Wood

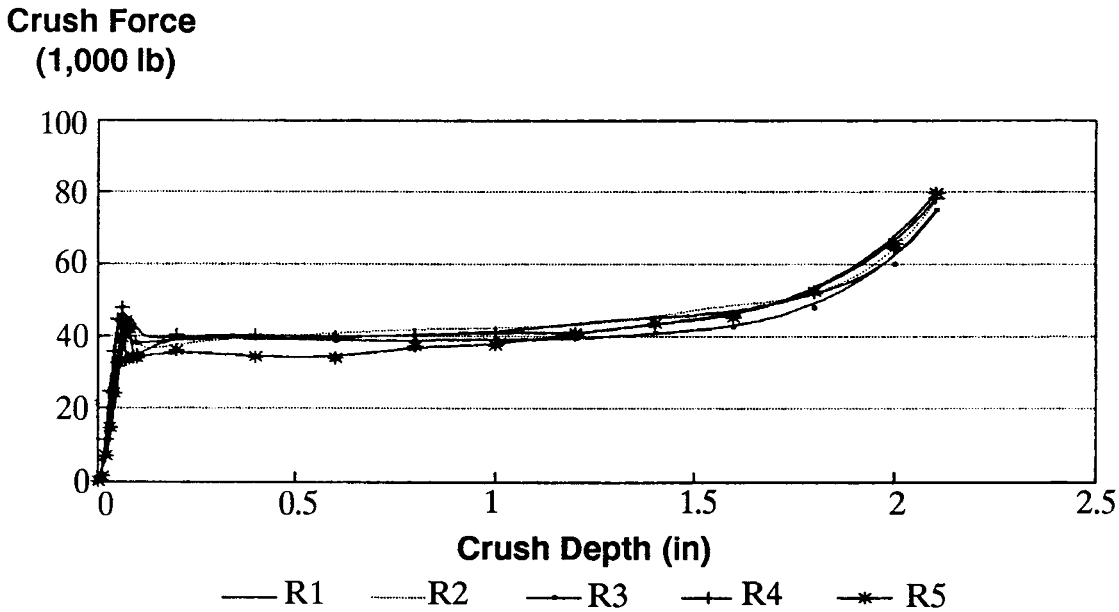


3-in diameter specimens, 3 in long

Figure 2-26

Force-Displacement Curve

Redwood

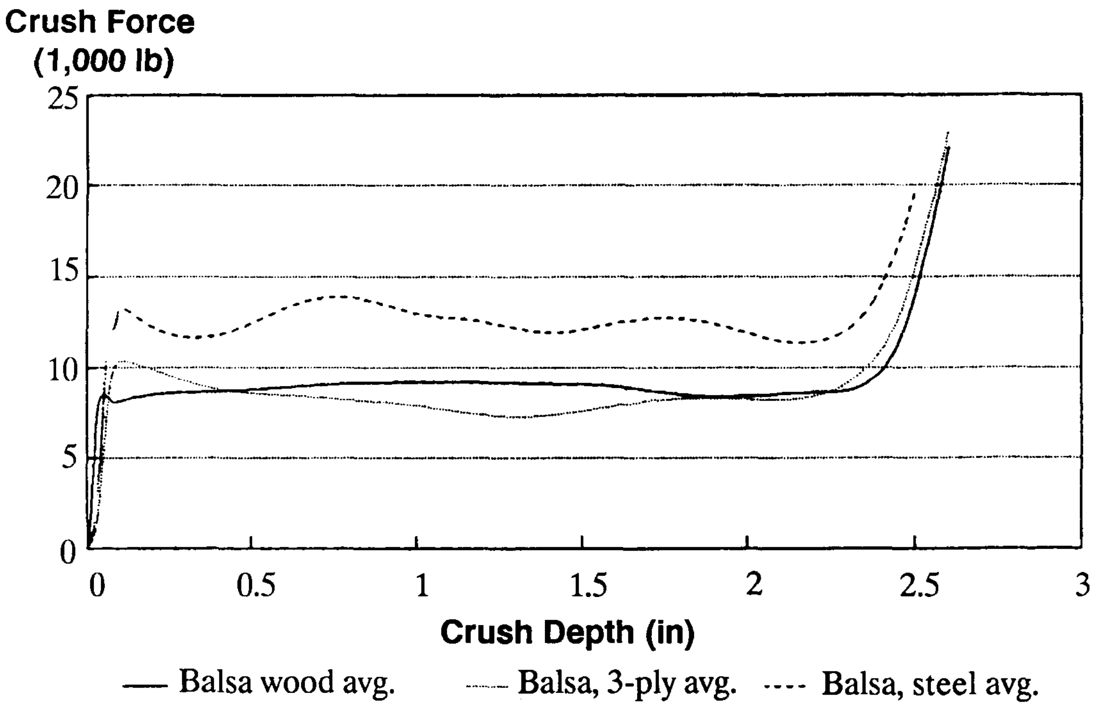


3-in diameter specimens, 3 in long

Figure 2-27

Force-Displacement Curve

Balsa Wood, Kevlar Skin, Steel Skin

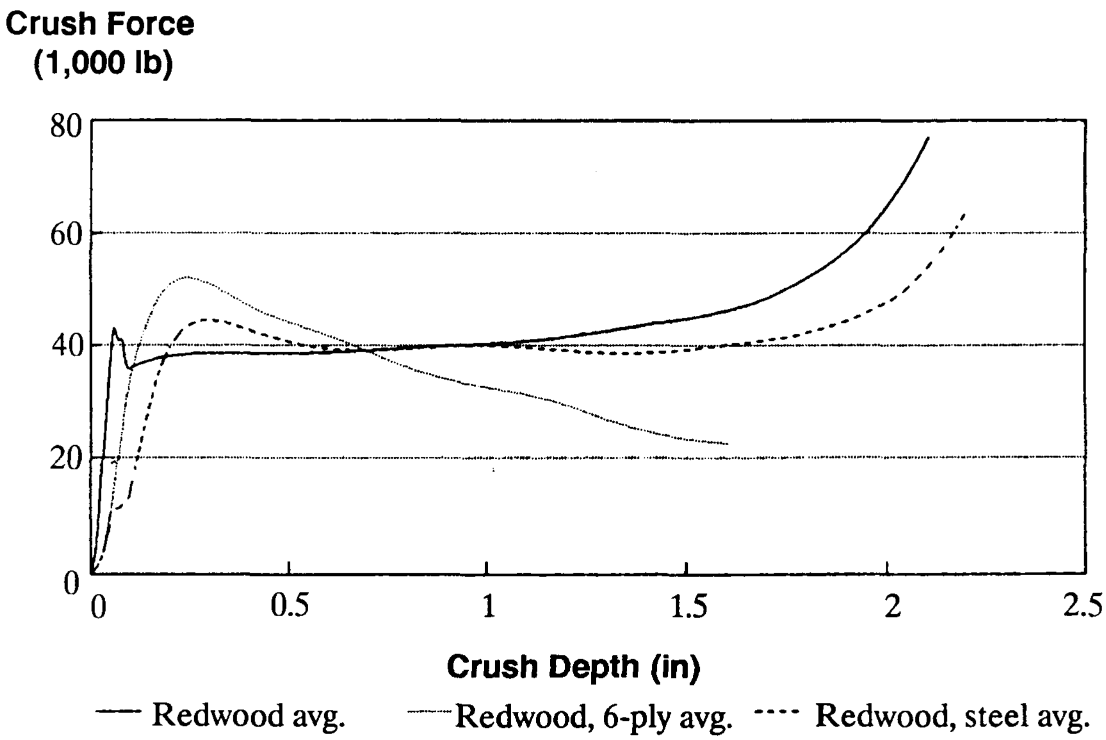


3-in diameter specimens, 3 in long

Figure 2-28

Force-Displacement Curve

Redwood, Kevlar Skinned, Steel Skinned



3-in diameter specimens, 3 in long

2.10.2.3 Quarter-Scale Model Tests

The first of 18 planned quarter-scale impact limiter models has been tested at Lehigh University. This section presents the results of the test. In summary, the test model did not perform as well as expected due to a premature tearing of one area of the composite skin. Two minor design changes appear to accomplish an adequate fix. The first change is the obvious increase in skin thickness in the torn region, and the second change is the bonding of components during fabrication to provide increased strength and stiffness.

The design of the first impact limiter test model was based to a large extent on previous Robatel impact limiter designs, the primary difference being the replacement of low carbon steel components with Kevlar composites. The design of the impact limiter is shown in figures 2-29 and 2-30. The outside diameter of the limiter is 30 in, which is one-fourth that of the currently planned full-size limiter. Both inner and outer composite skins were fabricated on precision wood molds. Three wood blocks were cut and bonded to produce each of ten "pie-shaped" core blocks. Resorcinol wood glue (waterproof) was used for all wood bonding.

The Kevlar attachments to hold the impact limiter to the cask body are shown in Figure 2-21. The design and use of composites for the attachment mechanism is unique to this application, and BWFC plans to apply for patent on the final attachment design.

The impact limiter was attached to a specially-designed support stand that oriented the impact limiter as if it were in a side drop. Ten shoulder bolts that were ½ in in diameter were inserted through the composite attachment to secure the impact limiter to the stand. Instrumentation was then positioned to measure the head movement and a strip chart recorded the force as a function of head deformation. After completion of the first test, the impact limiter was rotated by 180° and tested again. A photograph of Lehigh's 5-million-lb Baldwin testing machine is shown in Figure 2-31.

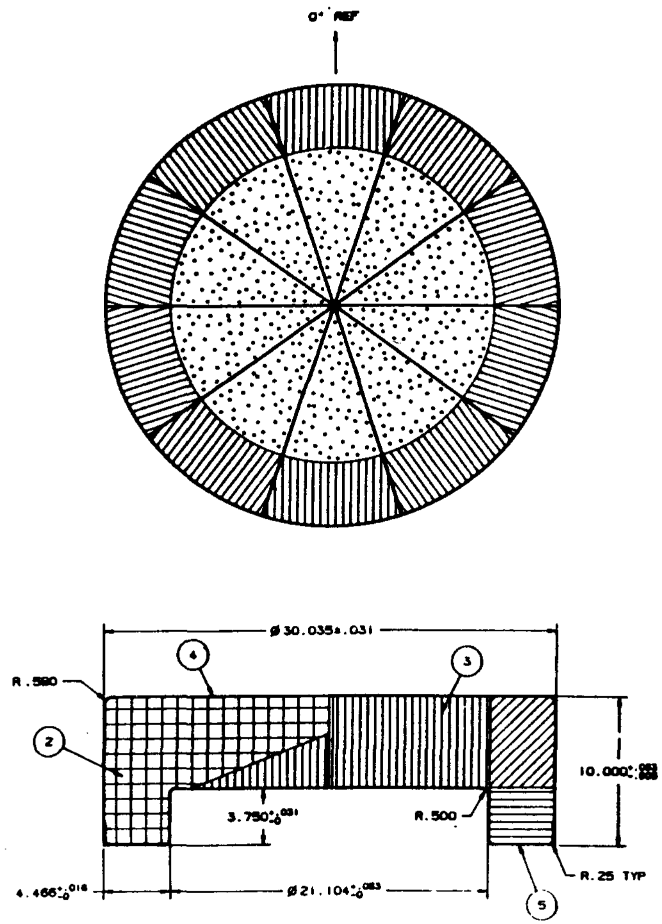
The force-displacement curves for the first impact limiter are shown in Figure 2-32. The test curves are bordered by two constraints within which the impact limiters must be designed to operate. The deformation of the impact limiter must not exceed the lockup deformation for the most critical area. In a side drop orientation, as was used, this deformation corresponds to approximately 2.7 in. The G limit for the full size cask is radially limited to 80 G, so the model is limited to 320 G due to scaling laws. The horizontal line at 525,000 lb corresponds to the 320 G limit for the model.

The final design constraint for this impact limiter test was that it absorb the required energy of the side-drop orientation. As shown in Figure 2-33, Test 1A absorbed 31.5% of the required energy and Test 1B absorbed 24% before the test was terminated. Clearly the impact limiters would have absorbed more energy if the crushing had been allowed to continue. However, due to the premature tearing of the composite skin, the test was terminated while the impact limiter was still structurally intact and "examinable." If the test had been allowed to continue, the wood condition at the time of tearing would have been lost.

The two crosshatched areas on Figure 2-32 represent the total energy required to be absorbed in a side drop. The triangular area is included to show a desirable loading curve that results in the minimum deflection of the impact limiter. In reality, this linear slope is not achievable due to the nonlinearly increasing crushing footprint. The second crosshatched area contained by flattening the curve is the more expected load-deformation curve based on constant stress from the wood core.

Both tests appear to follow the curve to the first 0.25 in. The goal of the next impact limiter test will be to double the load-carrying capability of the impact limiter so that as the structure loses its stiffness the loading curve maintains sufficient load to absorb the full energy. By bonding all ten wood sections to the skins and gussets, the maximum load-carrying capability is expected to increase significantly.

Finally, Kevlar structural composites continue to be very promising for use in an impact limiter. The weight of the first test model was 77.6 lb, which correlates to 4,970 lb for a full-size impact limiter. This represents a significant weight savings over previous impact limiter designs. Future test models may require additional Kevlar plies in high-stress areas. However, no effort has been made to optimize weight reductions by such means as vacuum bagging the composites, employing unidirectional cloth to double the strength of the cloth for a given load orientation, or simply reducing the laminate thickness in low-stress areas. Efforts to optimize the design will occur during the middle of the development program.



(1) IMPACT LIMITER TEST PIECE ASSEMBLY

BILL MATERIAL

1	-	1192032	001	D	IMPACT LIMITER TEST PIECE	——
2	10	1192033	001	D	GUSSET	SEE NOTE 2
3	10	1192033	002	D	WOOD SECTION	SEE NOTE 2
4	A/R	1192032	002	D	OUTER SKIN	SEE NOTE 2
5	A/R	1192032	003	D	INNER SKIN	SEE NOTE 2

NOTES:

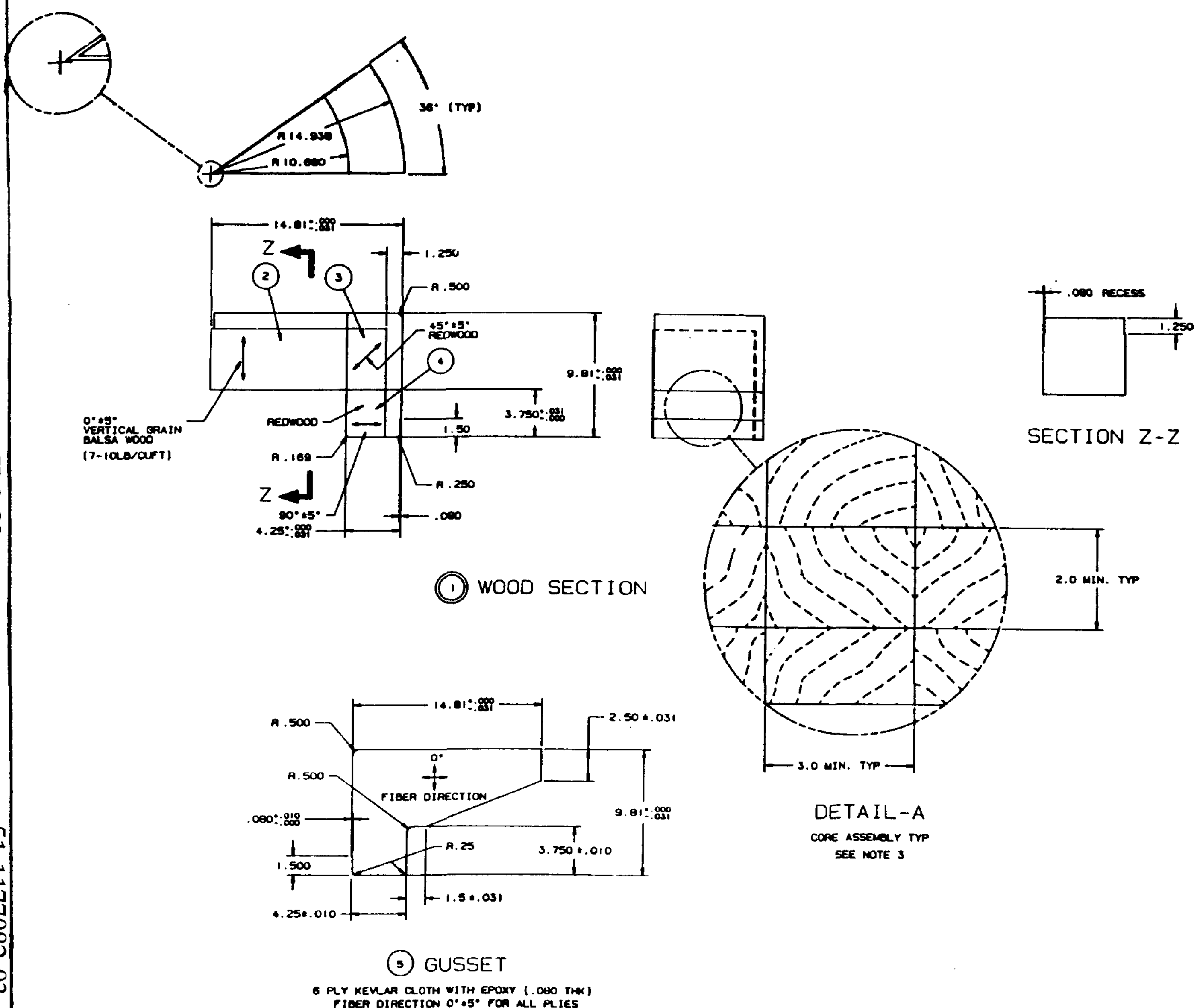
1. ALL DIMENSIONS IN INCHES AT 60° F.
2. MATERIALS:
   A. MATERIALS FOR ITEMS 2 AND 3 GIVEN ON DETAIL DRAWING.
   B. OUTER SKIN, ITEM 4 AND INNER SKIN, ITEM 5, CONSIST OF 6 PLIES OF 8 OZ./SQ. Yd. (NOM.) WOVEN "KEVLAR" CLOTH (BY DUPONT) AND EPOXY TO .080 THK. (NOM.). PLY ORIENTATIONS TO BE: 0°,60°,120°,180°,240° AND 300° WITH TOL. ±10°.
   C. ITEMS 2,3 AND 4 ARE ASSEMBLED ON A JIG, THEN BONDED TOGETHER BY RESORCINOL GLUE.
3. THE WOODEN CORE CONSTRUCTION AND SUBASSEMBLY ARE DESCRIBED IN NOTE 3 AND SHOWN IN DETAIL "A" ON DRAWING NO. 1192033D.
4. ESTIMATED WEIGHT 80 LBS. (CALCULATED).

Figure 2-29

J. WOOD

BR-100 CASK
IMPACT LIMITER
TEST PIECE
ASSEMBLY

1192032 D 0



BILL MATERIAL

1	-	1192033	001	0	WOOD SECTION	———
2	10	1192033	002	0	BALSA WOOD SEGMENT	SEE NOTE 2
3	10	1192033	003	0	REDWOOD SEGMENT	SEE NOTE 2
4	10	1192033	004	0	REDWOOD RISER	SEE NOTE 2
5	10	1192033	005	0	GUSSET	SEE NOTE 2

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68° F.
2. MATERIALS:
   A. BALSA WOOD (7-10 LBS/CUFT.)
   B. REDWOOD
   C. KEVLAR (BY DUPONT) WOVEN CLOTH.
   D. EPOXY - MAGNOLIA PLASTICS: #2026 RESIN, #350 HARDENER.
   E. ADHESIVE - RESORCINAL GLUE.
3. WOOD CORE CONSISTS OF RECTANGULAR WOODEN BLOCKS JOINED BY GLUE (SEE NOTE 2E) WITH TRANSVERSE GRAIN ORIENTED AT APPROXIMATELY 90° TO EACH OTHER AS SHOWN.

Figure 2-30

J. WOOD

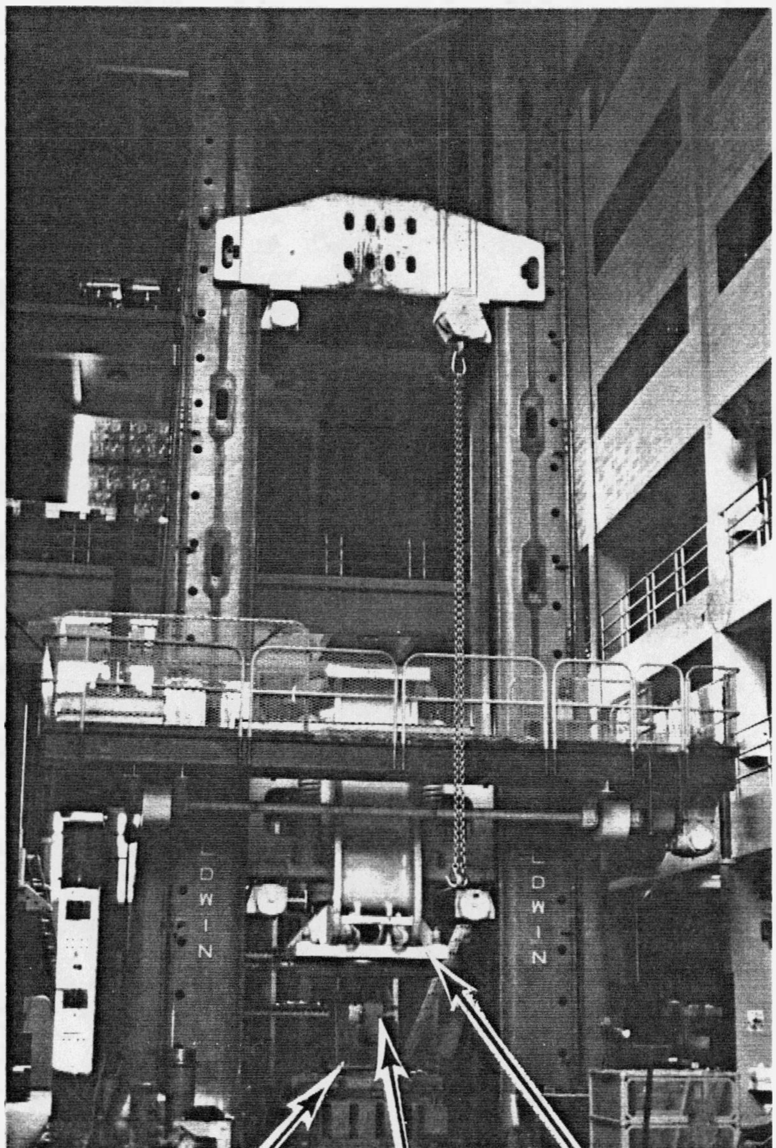
BR-100 CASK
IMPACT LIMITER
TEST PIECE
DETAILS

1/4

1192033D 0

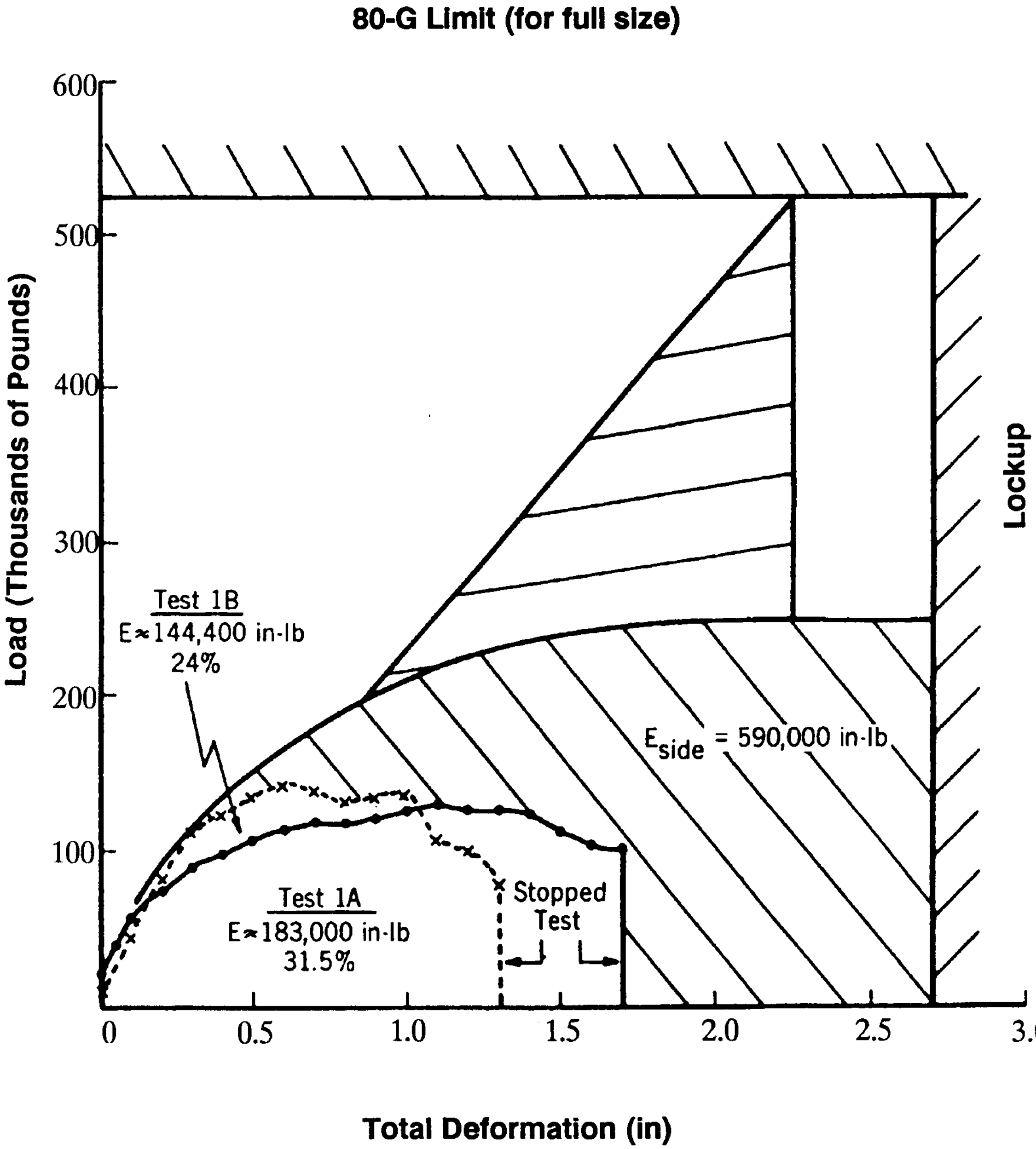
Figure 2-31

Lehigh University 5 Million Pound Test Machine
Impact Limiter Test in Progress



Test stand
Quarter-scale impact limiter
Baldwin machine load head

Figure 2-32
First Static Test
Quarter-Scale Model



2.10.3 Description of the Computer Codes

2.10.3.1 ANSYS

ANSYS is a general purpose, finite-element program for solving a wide variety of engineering analysis problems, including one-dimensional fluid flow, transient heat transfer, and structural statics and dynamics. ANSYS employs the latest finite-element technology for the solution of several classes of engineering problems. ANSYS has a large library of elements and an extensive selection of material properties, both linear and nonlinear. The software services a wide spectrum of uses, from the linear elastic analysis of two- and three-dimensional solids to applications in which nonlinear material and geometric effects dominate and must be included in conjunction with sophisticated geometric modelling. The regime of application can vary from static to structural dynamic problems. Mesh generators and extensive pre- and postprocessing graphics help in establishing the correct analysis.

Since 1970, this program has been extensively used by analysts in the nuclear, chemical, building, and electronic industries. This extensive use has led to a high degree of reliability in the computer results obtained.

The ANSYS program may be used to analyze a large number of problems, including two- and three-dimensional frame structures, piping systems, two- and three- dimensional solids, as well as many other problems. Related to the previous list are the static, dynamic, thermal, and fluid problems associated with each analysis.

Several types of analyses are available with the ANSYS program. These include the following:

<u>Static</u>

Used to solve for the displacements, stresses, and strains in structures under the action of applied loads. Includes elastic, plastic, creep, and swelling options. Options are available for including large deflection and stress stiffening effects in solutions.

<u>Mode-Frequency</u>

Used to solve for the resonant frequencies and mode shapes characterizing a structure. Full or reduced (in-core matrix condensation) analysis options are available. The structure may be subjected to a seismic loading or force loading for a spectrum analysis option. With this option, stresses and displacements are output in addition to the eigenvalues.

Harmonic Response

Used to determine the steady-state solution of a linear elastic system under a set of harmonic loads of known amplitude and frequency. Damping may be included in the system. Complex displacements or amplitudes and phase angles are output. When several frequencies are to be analyzed, a reduced harmonic response analysis is also available. The reduced analysis uses the technique of dynamic matrix condensation to allow a rapid and efficient response versus frequency solution. Stresses may also be calculated at specified frequencies and phase angles.

Nonlinear Transient Dynamic

Used to determine the time-history solution of the response of an arbitrary structure to a known force, pressure, or displacement-forcing function. The mass, damping, and stiffness matrices may vary with time and may also be functions of the displacements themselves. Nonlinear effects such as friction, plasticity, and large deflections may be included.

Reduced Linear Dynamic

Used to determine the time-history solution of the response of a linear elastic structure to a known force and/or displacement forcing function. The matrix representing the system is reduced to the degrees of freedom required to characterize the response of the system. A semilinear analysis option includes the use of interfaces (gap) between any pairs of these master degrees of freedom or between any master degree of freedom and ground. Stresses may be calculated at specified times.

Heat Transfer

Used to solve for the steady-state or transient temperature distribution in a body. Conduction, convection, radiation, and internal heat generation may be included. Heat transport effects due to flowing flux are also available. Material properties may be stored and used for steady state and nonlinear stress solutions. A time-step optimization procedure is available for transient solutions.

Substructures

Used to assemble a group of linear elements into a single super element to be used in another ANSYS analysis type or to determine the response of individual elements within the super element after it has been used in another ANSYS analysis type.

To accomplish the types of analyses previously listed, the finite-element library of elements numbers more than forty for static and dynamic analyses, thirteen for heat transfer analyses, three for thermal fluid analyses, three for thermal-electric analyses, and two for wave motion analyses. The structural element types include spars, pipes and elbows, beams, fluid elements, plane and axisymmetric membranes, plates, shells, and solids. Harmonically loaded axisymmetric elements are available for nonaxisymmetric loadings. Most element types contain at least one element having complete plastic, creep, and swelling capabilities. Plane and solid isoparametric elements are available. Additional structural elements include masses, springs, dampers, sliding interfaces, gap interfaces, and cables. Arbitrary stiffness, mass, and damping matrix elements are also available. The heat transfer element types include conducting bars, plates and solids, convection, and radiation links. All heat transfer elements may be deleted or replaced by geometrically equivalent structural elements for thermal stress evaluation.

The general mesh-generation routine produces geometries consisting of single or intersecting regions of planes, shells, or solid elements. Intersecting surfaces may be planes, cylinders, cones, spheres, toruses, ellipsoids, or hyperboloids. The intersecting lines between the surfaces are automatically calculated. Interactive solution and plotting capabilities are available.

Loading input for structural analyses may be nodal forces, body forces, displacements, pressures, or temperatures. These inputs may be sinusoidal, random, or an arbitrary function of time for the linear and nonlinear dynamic analyses. Mode-frequency analyses may include force spectrum or response spectrum loadings. Loading inputs for heat transfer analyses include internal heat generation, convection or radiation boundaries, and specified temperatures or heat flows. These inputs may be arbitrary functions of time for transient analyses. Boundary conditions may have step or ramp changes between specified load points.

Structural analysis outputs are usually forces, displacements, stresses, and strains. Heat transfer analysis outputs are temperatures and heat flow rates.

In the solution of plasticity and creep problems, an incremental technique is used. Plastic stress-strain curves may be input for up to five temperatures. The von Mises yield surface is used with the Prandtl-Reuss flow relations. Unloading and reversed loading is handled by these same techniques. The stress-strain curve upon reversed (or cyclic) loading may be assumed to be any of the following:

- The virgin stress-strain curve (offset to account for the previous plastic strain)
- Kinematic hardening
- Isotropic hardening
- Classical Bilinear Kinematic hardening
- Tenth-Cycle Empirical hardening

The viscoelastic equations are the power type equations for creep strain in metals. Both primary and secondary creep equations are available to the user. Either a formulation in which the stresses decay due to creep (as in thermal stresses) or a formulation in which the stresses are independent of creep (as in primary stresses) may be selected. Many common primary and secondary creep equations are included in the ANSYS program.

Irradiation induced creep equations are also included. Irradiation induced swelling is available for the analysis of nuclear reactor components. The swelling is not stress dependent and is treated in a manner similar to thermal strains.

Inelastic material properties may be included in the static and the nonlinear dynamic analyses. Orthotopic material properties may be included in all plane and solid elastic structural elements and in all heat transfer elements. All elastic material properties may be up to fourth-order polynomial functions of temperature. A curve fitting routine is available for tabular property input. Linear interpolation is also available. Plastic stress-strain curves may be input for up to five temperatures. Convection film coefficients and emissivities (radiation) may be temperature dependent.

An important feature of the ANSYS program is the capability of solving for the response of a large structural system by a technique called "dynamic matrix condensation" (Guyan reduction). In this procedure, the user specifies a set of "master" degrees of freedom that he feels will characterize the system being analyzed. The mass, damping, and stiffness matrices are reduced to these master degrees of freedom. The reduced solution may then be expanded to include the full degree of freedom set. This technique is available as an option in the mode-frequency analysis and is used directly in the reduced linear dynamic, the reduced harmonic response, and substructure analyses.

In structural dynamics, ANSYS can perform a dynamic nonlinear analysis of a structural system that includes gap elements, friction elements, and elasto-plastic material characteristics. Time dependent loadings are applied and the direct integration technique is used.

2.10.3.2 PATRAN

PATRAN is a pre- and postprocessing code that can be used to develop analytical models for the thermal evaluations (P-THERMAL) and structural finite-element analysis (ANSYS and FESAP) codes.

The models are developed using a series of commands to define and combine a series of simple geometric shapes into a complex three-dimensional model.

The same process that is used to develop the structural model is used to develop the thermal model. The two geometric models, structural and thermal, can be the same. The boundary and initial conditions that are used to complete the definition of the physical problem are also applied in PATRAN.

In addition to its preprocessing capability, PATRAN provides the engineer with extensive postprocessing capabilities.

PATRAN provides the design engineer a cost-effective method to develop and evaluate the finite-element models in a short period.

2.10.3.3 PRONTO 2D

PRONTO 2D is a two-dimensional transient solid dynamics code for analyzing large deformations of highly nonlinear materials subjected to extremely high strain rates. This Lagrangian finite-element program uses an explicit time-integration operator to integrate the equations of motion. Four-node uniform-strain quadrilateral elements are used in the finite- element formulation. A number of new numerical algorithms have been developed for the code. An adaptive time-step control algorithm is employed to greatly improve stability as well as performance in plasticity problems. A robust hourglass control scheme that eliminates hourglass distortions without disturbing the finite-element solution is included. All constitutive models in PRONTO are cast in an unrotated configuration defined using the rotation determined from the polar decomposition of the deformation gradient. An accurate incremental algorithm was developed to determine this rotation. A robust contact algorithm was developed to allow for the impact and interaction of deforming contact surfaces of quite general geometry.

2.10.3.4 ABAQUS

ABAQUS is a finite-element program for general use in nonlinear as well as linear structural analysis. While the program is well suited for linear analysis, the overall program design is dominated by features especially suited for nonlinear problems. The program is intended to be used as a tool in production analysis and, as such, emphasizes ease of use, reliability, flexibility, and efficient solution procedures. The theoretical formulation is based on the finite-element stiffness method with some hybrid formulations included to handle hydrostatic type stress fields.

ABAQUS can solve a wide range of structural problems. Geometry modeling can include structures (rods, beams, and shells) and continual (one-, two- and three-dimensional continuum) elements. Material models are provided for metals, rubber, plastics, composites, concrete, and soils. Material response can be highly nonlinear, dependent on history and an isotropy. Very general elastic, elastic-plastic, and elastic-viscoplastic models are provided. An elastic-plastic fracture theory is also included for concrete. Boundary conditions can include prescribed kinematic conditions, prescribed foundation conditions, and intermittent contact between various structural components. Loading conditions can include point forces, distributed loads, and thermal loading. Follower force effects for pressure, centrifugal and Coriolis accelerations, fluid drag, and buoyancy are included where appropriate. Very general capabilities are provided for modeling the interaction between bodies, including one- and two-dimensional gap type elements, interface elements between a deforming structure and a rigid body, and slide lines for general interaction between deforming bodies.

ABAQUS provides static and dynamic, linear and nonlinear stress analysis; transient and steady-state heat transfer analysis; fully coupled seepage flow/stress-displacement analysis for soils; and fully coupled temperature/stress analysis. Modal extraction is provided for frequency determination and eigenvalue buckling load estimation. Response spectra and time history response can also be computed based on natural modes. The program provides a complete fracture mechanics design evaluation capability, including "line spring" elements for modeling part-through cracks in shells, and fully automated J-integral calculations for any structure. Deformation theory plasticity models are provided to obtain fully plastic crack solutions in support of the "engineering fracture mechanics" approach to inelastic fracture analysis.

Additional features include the capability to handle both symmetric and nonsymmetric matrices, and ABAQUS automatically uses the nonsymmetric matrix scheme when the user's input implies that it is needed. ABAQUS offers two approaches for obtaining convergent solutions to nonlinear and transient problems; direct user control of incremental step size and automatic control by ABAQUS where step sizes are chosen to maintain a solution within user-selected tolerances. Analysis procedures can also be arbitrarily mixed to provide flexibility in solution schemes. For example, a nonlinear dynamic step may follow a nonlinear static solution to determine initial conditions, and eigenvalue extractions can include initial stress and deflection effects.

The overall analysis capabilities provided by ABAQUS make it an excellent tool for use in general linear and nonlinear structural analysis.

2.10.3.5 ILAN

ILAN is a BWFC-developed computer program that calculates force-deflection characteristics of wooden impact limiters for different angles of impact. The code uses Hankinson's formula to calculate wood crush force for different angles of wood grain orientation with respect to impact angle. ILAN, by using the rigid body equation of motion, calculates forces, accelerations, velocity, and displacement for an impact for both primary and secondary impact (slap down). A brief description of the computer program is provided in Section 2.10.1.5.

2.10.4 References

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3.0 THERMAL EVALUATION

The goal of the thermal evaluation of the BR-100 spent fuel shipping cask is to make certain that the materials used in the construction of the cask and the contents shipped within the cask remain within specified thermal limits. These limits are imposed to ensure that the structural integrity of the cask components are not degraded to unsafe limits and that the cask will remain as a viable radiation barrier to the public during loading, shipment, and unloading.

This chapter is divided into a number of sections: 3.1 (Discussion) provides an overview of the BR-100 from a thermal viewpoint; 3.2 (Summary Of Thermal Properties of Materials) briefly describes the material properties used in thermal analyses; 3.3 (Technical Specification of Components) describes the component technical specification; 3.4 (Thermal Evaluation for Normal Conditions of Transport) evaluates thermal operation during normal conditions; and 3.5 (Hypothetical Accident Thermal Evaluation) describes the cask thermal response to hypothetical accident conditions. An appendix is provided that describes the analytical methods used to derive some of the temperatures and provides a description of the computer codes used in the thermal analyses. This chapter demonstrates that the BR-100 spent fuel shipping cask meets or exceeds thermal design goals by providing significant thermal margins.

3.1 DISCUSSION

A rail or barge cask that is used to transport comparatively large quantities of spent fuel must function reliably under relatively large environmental ambient temperature extremes during normal operation and suitably reject and dissipate heat from external sources under accident conditions. These thermal conditions are specified in 10CFR71.71 comprising:

Normal Conditions of Transport

- Heat - Ambient temperature of 100°F (38°C) in still air including effects of solar heating.

- Cold - Ambient temperature of -40°F (-40°C) in still air and shade.

Hypothetical Accident Conditions

- Thermal - Exposure of the cask to a heat flux not less than that of a radiation environment of 1,475^{o}F (800^{o}C) with an emissivity coefficient of at least 0.9 for 30 min.

The low temperatures affect the choice of cask materials. The higher temperature extremes introduce some additional considerations. For example, the outer surface temperature of the cask must not exceed a specified limit to prevent burns or injuries to personnel working on or near the cask. Higher temperatures can cause a reduction in structural strength, also impacting the materials selected for the cask. Finally, the cladding temperature of the spent fuel being transported must be maintained below an acceptable limit to reduce the probability of cladding failure and the subsequent release of fission products. Preserving the structural integrity of the cask components and minimizing the release of fission products are also the primary objectives under accident conditions. These normal operation and accident conditions impose a significant level of importance on the heat removal and rejection characteristics of a cask that is required to transport large quantities of fuel.

The BR-100 cask was designed to comply with the concerns and constraints listed above. The resulting design was successful in that significant thermal margins exist for the transport of both BWR and PWR design basis spent fuel assemblies. Some of the methods that were used to minimize the BR-100 temperatures are listed below.

Cask Surface Temperature

The surface temperature of a cask under normal operating conditions is a function of the environment ambient temperature, the heat generation rate of the fuel within the cask, the solar energy absorbed, the cask surface finish, and the cask surface configuration (the potential use of external fins). External fins were determined to be unnecessary for the BR-100 design and were deleted because they add to cask weight and complicate the decontamination process.

Heat is transferred from the surface by both thermal radiation and natural convection. When this cask is moving, forced convection either augments or replaces the natural convection mode of heat transfer. Since forced convection is a stronger mode of heat transfer than natural convection, the greatest cask temperatures occur when the cask is motionless and natural convection and thermal radiation are the only modes of heat transfer from the surface.

Thermal radiation comprises approximately two-thirds of the surface heat flow. Therefore, surface properties are very important. It was found that the cask thermal performance can be substantially improved by coating the surface with white paint.

White paint was selected for the surface finish because it has a low absorptivity in the solar spectral range and a high emissivity in the infrared range. Thus, little solar energy is absorbed, while the cask efficiently radiates energy to the environment. The white paint selected has a maximum absorptivity of 0.16 in the solar range and a minimum emissivity of 0.90 in the infrared range (Reference 3.12). Note that the white paint also seals the outer surface and eases the decontamination process.

Cask Wall Temperature

Cask wall temperatures under normal operating conditions are a function of the cask outside surface temperature, the thermal conductivity of the wall materials, and the heat generation rate of the spent fuel within the cask. The BR-100 cask wall materials were selected primarily based on structural and shielding considerations. The efficiency of the heat flow through these materials was not, however, ignored. For example, concrete is being used as a cask wall material primarily because it is a good neutron absorber. Concrete has a relatively low thermal conductivity compared to the other cask wall materials and thus restricts heat flow. Copper fins were embedded in the concrete to increase the effective thermal conductivity of this layer and improve the heat flow through it. This concrete-copper fin arrangement is a patented Robatel design (Ref. 3.1).

Concrete also provides superior thermal performance during hypothetical thermal accident conditions. A thermal diode allows for the efficient flow of heat from the cask under normal operating conditions but impedes the flow of heat into the cask during an accident. The thermal diode characteristics of concrete are due to the water contained in the concrete. When the temperature of the concrete begins to rise, the water within the outer layer of concrete begins to change phase. The steam created in this process is vented outside the cask through engineered penetrations in the outer wall. With this arrangement, the heat will be efficiently dissipated while the cask internal components and spent fuel are maintained at a relatively low temperature.

Cask-Basket Gap Heat Transfer

A diametral gap exists between the BR-100 cask wall inner surface and the basket outer surface. This gap is maintained to facilitate the removal of the entire basket from the cask. The hot cask-basket diametral gap ranges from 0.0 to a maximum of 0.050 in (0.13 cm). Heat is transferred across this gap by gaseous conduction and thermal radiation. Thus, the temperature change across the gap is a function of the width of the gap, the thermal conductivity of the gas within the gap, the characteristics of the bounding surfaces, and the heat generation rate of the fuel within the cask.

When the basket and cask wall are in contact, another heat transfer mode contributes to the total gap conductance. This mode is known as contact conductance and significantly reduces the thermal resistance of the gap. It can be seen, therefore, that the greatest basket temperatures occur with the widest 0.050 in (0.13 cm) gap.

Helium was selected for the BR-100 fill gas. The thermal conductivity of helium is several times greater than other candidate fill gases and it is inert, so it will not contribute to the corrosive deterioration of the materials within the cask. The thermal radiation across a gap is enhanced by increasing the emissivity of the bounding surfaces. Blackening the stainless-steel inner cask surface is not economically feasible. The emissivity of this surface is estimated to be 0.20 (Ref. 3.14), which is lower than desired. However, using helium as the fill gas and maintaining the hot gap to a maximum of 0.050 in (0.13 cm) reduced the need to blacken this surface.

The aluminum basket components within the cask are hard anodized. The emissivity of these surfaces is estimated to be 0.85 (Ref. 3.15), which makes them very good radiators. The hard anodized finish also improves the wear characteristics of the aluminum and protects against corrosion. In addition to controlling the gap width, fill gas, and bounding surface characteristics, the heat flux distribution at the cask-basket interface is also very important in reducing temperatures. The outer basket surface adjacent to the cask wall was designed with a relatively uniform profile in the circumferential and axial directions. This design eliminates any significant temperature gradients and minimizes the temperature change across the gap as well as the stainless steel inner cask wall. The thermal conductivity of stainless steel is lower than desired, but the design practices above eliminate any significant temperature changes associated with the heat flow through this material.

Basket Temperatures

The primary mode of heat transfer through the basket is conduction. Temperature changes from conduction are a function of the material thermal conductivity, the heat flow cross-sectional areas, and the heat generation rate of the spent fuel within the cask. The BR-100 basket is constructed with aluminum, which has very good thermal conductivity. The thermal conductivity of the B_4C-aluminum Cermet poison plates affixed to the basket cells is also estimated to be relatively good. The cross-sectional areas of the basket heat flow paths have been maximized whenever possible to enhance the basket heat transfer characteristics.

Lesser secondary modes of heat transfer through the basket are thermal radiation and natural convection. As noted previously, all basket surfaces are hard anodized to significantly increase the emissivity and make the surfaces good radiators. The use of helium as the BR-100 fill gas maximizes the natural convection heat exchange.

<u>Fuel Cladding Temperatures</u>
The spent fuel cladding temperatures are a function of the bounding basket wall temperatures, the fill gas thermal conductivity, the cladding and basket surface finish, and the fuel heat generation rate. Although the cladding surface finish cannot be controlled, the hard anodized basket finish is an excellent thermal radiation absorber, and using helium as the BR-100 fill gas maximizes the natural convection mode of heat transfer. These practices minimize the fuel cladding temperatures.

The combined selection of the BR-100 construction materials and surface finishes, together with design practices directed toward reducing temperatures, have been successful in that significant thermal margins exist for the transport of both PWR and BWR spent fuel. The BR-100 thermal performance under normal operating conditions (10CFR71.71) is summarized in Table 3-1. Baseline in Table 3-1 refers to the base fuel condition specified by the Department of Energy. Limiting refers to the fuel condition (burnup/wt %/years cooling) that first causes the cask temperatures to first reach one of the three thermal design limits described in Section 3.4.2. The limiting condition in Table 3-1 was based on the concrete thermal design limit.

The cask BWR and PWR thermal rating is 14.6 and 17.6 kW, respectively. These ratings were constrained by the 250°F (121°C) concrete limiting temperature. The different BWR and PWR ratings are due to the different end-of-life axial peaking characteristics of the two fuels. The allowable temperature limits are listed in Table 3-1. The peak concrete and aluminum basket temperatures represent BR-100 material limits and are discussed in more detail in section 3.4.2.

A peak spent fuel cladding temperature limit of 716°F (380°C) has been documented previously (Reference 3-13). This limit, however, has been conservatively reduced by BWFC to 680°F (360°C) to further ensure the integrity of the cladding.

The personnel barrier temperature limit has been established as 180°F (82°C) in 10CFR71.43(g). Personnel barrier temperature predictions were not generated for the preliminary design. However, initial scoping calculations indicate that the BR-100 personnel barrier peak temperature will be well below this limit even under the limiting cask heat load conditions. The temperature distributions generated by analysis of the BR-100 preliminary design are presented in more detail in section 3.4.2.

3.2 SUMMARY OF THERMAL PROPERTIES OF MATERIALS

An effort was made during the design of the BR-100 cask to select ASME construction materials with well-defined thermal properties. In addition, materials were selected that would not change appreciably with time. The thermal properties of the materials used for the BR-100 design are all accurately known except for the Robatel borated concrete and the B_4C-aluminum Cermet. Table 3-2 contains a listing of the BR-100 thermal property values. The concrete and Cermet properties listed in Table 3-2 must be considered to be preliminary, and extensive testing efforts have been launched to accurately define these properties under both normal operating and accident conditions and as a function of time. Note that several values of thermal conductivity are listed for the concrete in Table 3-2. These values correspond to the loss of water from the concrete which begins at 284°F (140°C) and would occur during a hypothetical accident. Concrete is the only BR-100 material that is expected to change substantially during such an accident. The release of steam from the concrete is instrumental in keeping the cask internal components and spent fuel temperatures down during an accident of this type. The water within the concrete will not diffuse or migrate significantly under normal operating conditions.

3.3 TECHNICAL SPECIFICATIONS OF COMPONENTS

Temperature predictions of minor BR-100 components such as valves, gaskets, seals, etc. were not generated for the preliminary design. These predictions will be presented in the final design report. The predictions presented in Tables 3-3 and 3-4 clearly show that the temperatures of these components will be less than their respective limits.

3.4 THERMAL EVALUATION FOR NORMAL CONDITIONS OF TRANSPORT

The thermal evaluation of the BR-100 shipping cask under normal operating conditions ensures that adequate thermal margins will be maintained. These thermal margins are evaluated and compared to the cask material temperature limits on the Robatel borated concrete, aluminum basket, and the spent fuel cladding to ensure safe operation of the cask. These maximum temperature limits, discussed in Section 3.4.2, are based on a series of numerical and analytical calculations that are described in Section 3.4.1. This section demonstrates that the BR-100 has significant thermal margin during normal operation.

3.4.1 Thermal Model

The axial location where the maximum temperatures occur in the BR-100 cask is near the midpoint. This is due to the axial distribution of the spent fuel linear heat generation rate (LHGR). A typical normalized PWR LHGR profile is shown in Figure 3-1. BWR profiles are similar. Figure 3-1 shows that the LHGR rapidly approaches a peak and then remains relatively constant over a long portion of the fuel assembly length. These LHGR characteristics minimize temperature differences and the heat flow in the axial direction. Thus, accurate temperature predictions for the middle portion of the cask can be obtained by ignoring the axial direction and conducting a two-dimensional thermal analysis of a short axial segment of the cask.

Section 3.1 noted that during the design of the BR-100 basket, an effort was made to obtain uniform heat flux conditions at the basket inner wall gap. This design feature eliminates any significant circumferential or axial temperature gradients at the inner cask wall. Since the environmental thermal conditions are considered constant outside the cask, the heat through the cask wall is nearly one-dimensional in the radial direction and the temperature distribution within the cask wall can be obtained with classical heat transfer relationships. These relationships are described in detail in Section 3.6.

An exception to the radially one-dimensional heat flow occurs within the concrete-copper fin layer. The heat flow through this layer is strongly two-dimensional. However, the temperature change across this layer can also be accurately predicted with classical one-dimensional heat transfer relationships if the layer is subdivided into two regions. The first region represents the thin 0.40-in (1.02-cm) portion of the layer between the ends of the embedded copper fins and the inner surface of the outer stainless steel shell. The heat flow through this region is not enhanced by the copper fins. Therefore, the temperature change across this region can be accurately predicted with a classical one-dimensional heat conduction relation. The second region represents the portion of the layer that contains the copper fins. The heat flow in this region is oriented in the circumferential direction. The temperature change across this region can also be predicted with a one-dimensional heat conduction relation by assuming that the copper fins are approximately isothermal and the temperature change occurs across the concrete between the fins. The heat conduction relationships used in both regions of the concrete-copper fin layer are also described in more detail in Section 3.6. Note that the Robatel concrete-copper fin layer is designed so that the temperature change across both regions of this layer is approximately equal.

The simplified one-dimensional method of predicting the temperature change across the concrete-copper fins layer was compared with an intricate two-dimensional finite-element model of this layer. The finite-element model was generated using the PATRAN and P/THERMAL codes (Refs. 3.2, 3.3) and included three pairs of copper fins. The temperature change predictions from the simplified method were found to agree within $2^{o}F$ ($1^{o}C$) of the predictions from the finite-element model.

The thermal property values described in Section 3.2 were used in generating all of the cask wall temperature predictions. The temperature distributions of the cask wall and basket-inner wall gap are presented in Section 3.4.2.

The heat flow through the BR-100 basket is strongly two-dimensional, and the temperature distribution cannot be accurately predicted with classical one-dimensional heat transfer relations. Therefore, two-dimensional finite-element models of the BR-100 BWR and PWR baskets were constructed using PATRAN and P/THERMAL. Due to the circumferential symmetry of the BR-100 basket, only a one-eighth segment of the basket was modeled. The aluminum and Cermet thermal properties described in Section 3.2 were included in the modeling effort. No distinction was made between the slight differences in the cast (former) and extruded (cell) aluminum properties. The thermal radiation and gaseous heat conduction within the basket water channels were neglected in the models. This practice introduces a slight degree of conservatism in the basket temperature predictions. A constant temperature boundary condition at the outside radius of the basket and uniform heat flux boundary conditions at the surface of the fuel assembly cells were applied. The uniform heat flux boundary condition also introduces a slight degree of conservatism to the basket temperature predictions. P/THERMAL converged very quickly with an estimated actual temperature error, as opposed to an iterative delta error, of less than 0.001°F (0.0006°C). The predicted temperature distributions of the BR-100 BWR and PWR baskets are presented in Section 3.4.2.

The maximum spent fuel cladding temperature predictions were generated with the Wooten-Epstein relation (Ref. 3.4). This relation has been shown to be somewhat conservative in comparison with more recently developed relations (Ref. 3.5). Furthermore, the Wooten-Epstein relation was developed for air rather than helium, which is the BR-100 fill gas. Helium will significantly improve the natural convection heat transfer, which accounts for approximately one-half of the heat transfer from the spent fuel cladding to the basket and will reduce the maximum cladding temperatures. An effort will be made in the final design thermal analysis to select or develop a relation that yields a cladding temperature prediction that is closer to best estimate. The predicted maximum cladding temperatures are presented in Section 3.4.2.

3.4.2 Maximum Temperatures

The current projected BR-100 cask material temperature limits are a concrete temperature of 250°F (121°C) and an aluminum basket temperature of 350°F (177°C). An extensive testing effort has been launched to confirm the concrete temperature limits and to establish concrete properties in the temperature range up to 250°F (121°C). This concrete temperature limit was set to minimize the pressure buildup due to the entrapped air and water and to maintain a concrete condition that could endure the hypothetical accident without adversely impacting the cask internal temperatures. In addition, a temperature of 680°F (360°C) is the spent fuel cladding limit.

The predicted temperatures for the BR-100 cask with a full 52 assembly load of 30 GWd/mtU 3.0 wt % ten-year-cooled BWR fuel and a full 21 assembly load of 35 GWd/mtU 3.0 wt % ten-year-cooled PWR fuel were significantly less than any of these limits. It was determined that the cask would accept a full load of 45 GWd/mtU 4.0 wt % ten-year cooled BWR fuel or a full load of 50 GWd/mtU 4.5 wt % ten-year-cooled PWR fuel before the concrete temperature limit is reached. Even at the concrete limiting temperature, substantial margins exist for the aluminum basket and spent fuel cladding. The temperature predictions for these four cases are presented in this section.

The peak assembly linear heat generation rates (LHGR) for the fuel analyzed were predicted with the ORIGEN code (Ref. 3.6). The peak LHGR corresponds to BWR fuel with 1.20 burnup peaks and PWR fuel with 1.13 burnup peaks. The BWR and PWR LHGRs are presented in tables 3-3 and 3-4, respectively. The environmental conditions that apply to all of the cases analyzed are 100°F (38°C) ambient temperature and a solar insolation of 400 g-cal/cm^2 in a 12-hour period (10CFR71.71). Using the analysis methods outlined in Section 3.4.1, the temperature distributions within the cask wall and basket-inner wall gap were predicted. These temperatures are listed in tables 3-3 and 3-4 and are plotted in figures 3-2 and 3-3. Note the rapid temperature increase across both the first concrete only region of the concrete-copper fin layer and the basket-inner wall gap. The locations shown in tables 3-3 and 3-4 represent the following cask positions:

1. 41.00 in (1.041 m) - Cask outer surface,
2. 39.25 in (0.997 m) - Interface between outer stainless steel shell and concrete,
3. 38.85 in (0.987 m) - Interface between concrete only and concrete-copper fin region of the thermal shield,
4. 34.75 in (0.883 m) - Interface between concrete-copper fin region and lead gamma shield,
5. 30.25 in (0.768 m) - Interface between lead gamma shield and inner stainless steel shell,
6. 29.25 in (0.743 m) - Inner radius of the inner stainless steel shell, and
7. 29.20 in (0.742 m) - Outer surface of the basket.

The effectiveness of the copper fins embedded in the concrete is apparent from these figures since the temperature drop across the 0.40-in (1.02-cm) concrete-only region of the neutron shield is approximately the same as the drop across the 4.1-in (10.41-cm) concrete-copper fin region. In the absence of the helium-filled cask, the temperature drop across the cask-to-basket surface would be substantially higher since approximately 95% of the gap head transfer is by gaseous conduction.

The temperature distributions within the BR-100 BWR and PWR baskets were predicted with the finite-element models described in Section 3.4.1. The basket outer radius (minimum) and maximum predicted temperatures are presented in tables 3-3 and 3-4 and plotted in figures 3-4 and 3-5. Fringe plots, showing the temperature distribution within the basket, were generated for the four cases analyzed. These plots are shown in figures 3-6 through 3-9. Note that the temperature scale included in these figures is in Fahrenheit.

The maximum spent fuel cladding temperatures for the four cases were conservatively predicted with the Wooten-Epstein relation described in sections 3.4.1 and 3.6. These temperatures are listed in tables 3-3 and 3-4. Figure 3-10 shows the maximum cladding temperature as a function of the peak assembly heat rate. The BWR and PWR temperatures in Figure 3-10 have different sensitivities to the peak assembly heat rate due to differences in the heat transfer areas, within a basket cell and radially through the cask, than those used to calculate the heat fluxes described in Section 3.6. Even with the marked conservatism in these predictions, the maximum predicted cladding temperatures are still much less than the 680^{o}F (360^{o}C) limit.

The preceding temperature predictions clearly show that the selection of the BR-100 construction materials and surface finishes combined with design practices directed toward reducing temperatures have been successful in that significant thermal margins exist for the transport of both PWR and BWR spent fuel.

3.4.3 Minimum Temperatures

The minimum temperatures that would occur in a cask are addressed in Section 3.1. The minimum temperatures occur for an unloaded cask subjected to an environmental ambient temperature of -40^{o}F (-40^{o}C) for a prolonged period of time (10CFR71.71). Under these conditions, the entire cask with all of the components would be near the limiting temperature of -40^{o}F (-40^{o}C). Material behavior is the primary concern at low temperatures. The cask materials must not deteriorate or lose their structural integrity under these conditions. All of the BR-100 materials are expected to perform well at the lower temperatures. The Robatel concrete behavior is currently being evaluated to determine the effects of low temperatures. The low-temperature limits of minor BR-100 components such as valves and gaskets have not yet been determined but will be presented in the final design report.

3.4.4 Maximum Internal Pressure

Due to the unique design of the BR-100 cask, the inner and outer shells are exposed to two different internal pressure environments.

For the inner shell, the worst case scenario assumes that all fuel rods are ruptured and releasing fission gas products. This scenario is considered for definition of the maximum normal operating pressure (MNOP as defined in 10CFR71). Preliminary calculations show pressures less than 100 psi (0.69 MPa). A 50% pressure margin for testing of the containment is used.

The maximum pressure in the concrete during normal conditions is based on the concrete temperature. Concrete testing will demonstrate that this pressure is the saturated steam pressure generated in the concrete at temperature. A maximum specified temperature of 250°F (121°C) in the concrete corresponds to 30 psi (0.21 MPa). This results in a 720 psi (4.96 MPa) stress on the outer shell and a margin in excess of 500%.

3.4.5 Maximum Thermal Stresses

Thermal stresses due to differential thermal expansion between different parts of the cask body and between the cask body and other components of the system will be evaluated during the final design.

3.4.6 Evaluation of Package Performance for Normal Conditions of Transport

The evaluation of the BR-100 cask thermal performance under normal conditions of transport was discussed in sections 3.4.2 and 3.4.3. The upper and lower temperature extremes and the peak assembly linear heat generation rate extremes are presented in these sections. The data and conclusions from those sections indicate that the thermal performance of the BR-100 cask results in large margins to all regulatory, contractual and design temperature limits.

3.5 HYPOTHETICAL ACCIDENT THERMAL EVALUATION

The Robatel borated concrete, which is used primarily as a neutron shield in the BR-100 cask, is also expected to provide wide thermal margins under hypothetical thermal accident conditions. The thermal diode characteristics of concrete and its ability to absorb substantial amounts of thermal energy were discussed briefly in Section 3.1. The latent heat of vaporization is a measure of the energy required to convert a liquid into a vapor. This characteristic permits the water in the concrete to absorb large amounts of energy without increasing the temperature. This characteristic also significantly adds to the difficulty in accurately modeling high-temperature transient heat conduction in concrete. When a high-temperature wave propagates through concrete, the water within the concrete is locally converted to steam. The temperature at which water is converted to steam is a function of pressure; therefore, the concrete heat conduction process also becomes a function of the local water pressure. The gap created by the steam generation process is expected to cause microcracking. Microcracking, along with the thermal expansion of the outer wall, would provide pathways where the steam could diffuse to the vent holes located on the outer cask shell and be lost to the environment. The steam, however, can also diffuse to the cooler portions of the concrete where it will recondense and locally increase the water concentration. These arguments demonstrate that modeling high-temperature transient heat conduction in concrete is very complex. Rather than engage in a large effort to analytically model this phenomenon, a testing effort has been undertaken to quantify these effects.

The thermal testing effort will involve subjecting a highly instrumented segment of the BR-100 cask wall to 10CFR71.73 hypothetical accident thermal test conditions. This test section is illustrated in Figure 3-11. The test segment will be approximately 12 in (30.5 cm) long, 9 in (22.9 cm) wide, and 11.75 in (29.8 cm) thick. The thickness and geometric characteristics of the various stainless steel, concrete, concrete-copper fin, and lead layers will be accurately reproduced to avoid difficulties associated with scaling in the direction of heat flow. The test sample will sequentially be subjected to the following conditions:

1. Steady-state operation with the inner stainless steel face exposed to typical maximum heat flux conditions. The local concrete temperature will not exceed 250°F (121°C).
2. Operation in a furnace preheated to 1,475°F (802°C) for 30 minutes.
3. Controlled cooldown after being withdrawn from the furnace.

The heaters mounted on the inner face will simulate the spent fuel thermal load for all of these conditions.

Temperatures will be measured at strategic locations within and on the surfaces of the sample during the heatup and cooldown phases. Only the outer stainless steel face of the sample will be subjected to the hot furnace and cool room environments during the testing. The sides and base of the sample will be highly insulated to prevent spurious heat transfer effects that would introduce experimental error.

The measured temperatures on the inner stainless steel surface (inner cask wall) of the test segment will provide the boundary conditions necessary to predict the thermal response of the BR-100 basket and spent fuel during hypothetical accident thermal test conditions. A finite-element model of the basket will be constructed to generate these predictions. The model will be similar to the model constructed to predict basket temperatures under normal operating conditions except that it will include simplified mockups of the fuel assemblies. The thermal mass of the spent fuel is a very important consideration in transient thermal analyses of this type. This thermal model will be described in detail in Section 3.5.1 of the final design report and will be used to generate the predictions required for sections 3.5.2 through 3.5.6.

Based upon the Robatel tests (Ref. 3.7) and experience with Robatel casks in France, the BR-100 cask is expected to perform in a superior manner during and following a thermal accident. As described in Reference 3.7, a 20.6-in (52.3-cm) long axial slice of a full-scale Robatel cask was tested under thermal accident conditions. The mockups of the spent fuel used in this test were electrically heated to simulate the heat that would be generated by the fuel. The test section was allowed to reach steady-state thermal equilibrium before being subjected to the thermal accident conditions. Under the steady-state conditions, the inner cask wall and peak basket temperatures were approximately 180°F (82°C) and 244°F (118°C), respectively. The accident conditions lasted for 30 minutes and the outside surface of the cask reached approximately 1,400°F (760°C). After 30 minutes, the inner cask wall and peak basket temperatures had both increased less than 15°F (8°C). These temperatures attained maximum values approximately 6 hours after the accident began, which was during the cooldown phase. The maximum temperatures reached for the inner cask wall and the peak basket were 253°F (123°C) and 309°F (154°C), respectively. Thus, the inner cask wall and peak basket temperatures had only risen 73°F (41°C) and 65°F (36°C), respectively, during the entire test period.

After the BR-100 cask has been allowed to cool for an extended period, the temperature of the components inside the concrete layer are expected to increase less than 24.4°F (13.6°C). This slight temperature increase is due to the partial dehydration of the concrete, which causes a reduction in the thermal conductivity. The cask thermal rating is not impacted by this slight increase.

The outstanding thermal performance of the Robatel cask during and following the accident is largely attributed to the thermal diode characteristics of the Robatel borated concrete. The BR-100 cask is expected to perform equally well. Thermal accident temperature predictions will be presented in the final design report to support these expectations.

3.5.1 Thermal Model

Will be addressed during final design.

3.5.2 Package Conditions And Environment

Will be addressed during final design.

3.5.3 Package Temperature

Will be addressed during final design.

3.5.4 Maximum Internal Pressures

There are two maximum internal pressures of concern: The inner shell maximum pressure and the outer shell maximum pressure. The outer shell experiences the pressure corresponding to the steam generated in the concrete. During all accident conditions except thermal, the temperature in the concrete is limited to 250°F (121°C) with a saturation pressure of 30 psi (0.21 MPa). During the thermal accident, melting of the fusible plugs occurs at 291°F (144°C). The maximum pressure in the concrete is 58 psi (0.40 MPa), which corresponds to the saturation pressure of steam at 291°F (144°C).

3.5.5 Maximum Thermal Stresses

The secondary stresses due to thermal expansion during the hypothetical thermal accident will be evaluated during the final design.

3.5.6 Evaluation Of Package Performance For Hypothetical Accident Thermal Conditions

Will be addressed during final design.

3.6 APPENDIX

The Appendix describes the heat transfer relationships that were used to generate the one-dimensional heat transfer through the cask, the Wooten-Epstein relationship used to generate the peak spent fuel cladding temperatures, and a brief description of the PATRAN and P/THERMAL computer codes used to generate the two-dimensional temperature distributions within the BWR and PWR baskets and the COBRA-SFS computer code (Reference 3.9) that is being considered for use in the final design.

3.6.1 Cask One-Dimensional Heat Transfer Relationships

The flow of heat in the cask can be closely approximated by one-dimensional heat transfer, as described in Section 3.4. The various one-dimensional heat transfer calculations in the cask are as follows: Environment-to-cask surface, through the outer stainless steel shell, across the concrete-only part of the neutron shield, across the concrete-copper fin part of the neutron shield, across the lead gamma shield, across the inner stainless steel shell, and finally across the basket-inner wall gap. The heat transfer relationships used in these calculations are discussed below.

Environment-to-Cask Surface

The flow of heat from the environment to the cask surface is by both thermal radiation and natural convection. The relationship governing the flow of heat from the environment to the cask surface is:

$$q'' = h_{conv}\,(T_c - T_{amb}) + h_{rad}\,(T_c - T_{amb}) \qquad \text{(Eq. \#3-1)}$$

where

q'' = heat flux due to the cask total thermal load and the solar insolation based on the cask outside diameter and the spent fuel heated length (W/m^2),

h_{conv} = natural convection correlation for a horizontal cylinder ($W/m^2 - {}^oK$),

$$= 1.24\,(T_c - T_{amb})^{0.3333}, \text{ (Ref. 3.8)} \qquad \text{(Eq. \#3-2)}$$

where

T_c = cask surface temperature (absolute scale, ^oK),

T_{amb} = ambient temperature set at 310.9^oK, (10CFR71.71),

h_{rad} = thermal radiation heat transfer coefficient ($W/m^2 - {}^oK$),

$$= \sigma\varepsilon\,(T_c2 + T_{amb}2)(T_c + T_{amb}) \qquad \text{(Eq. \#3-3)}$$

where

σ = Stefan-Boltzmann constant ($W/m^2 - {}^oK^4$),

ε = emissivity of the white paint that coats the cask exterior (0.90 for infrared wavelengths).

Outer Stainless Steel Shell

The temperature drop across the outer stainless steel shell of the cask can be expressed as follows, based on classical heat flow across a cylindrical layer:

$$T_o - T_i = \left(\frac{Q}{2\pi L}\right)\left(\frac{\log_e(r_o/r_i)}{k}\right) \qquad \text{(Eq. \#3-4)}$$

where

T_o, T_i = temperature at the outer radius (r_o) and the inner radius (r_i), respectively (^oK), r_o and r_i have units of m,

Q = total heat load on the cask from the spent fuel (W),

L = heated length of the fuel within the cask (m),

k = thermal conductivity of the material, from Table 3-2 ($W/m - {}^oK$).

Concrete Neutron Shield

The temperature drop across the concrete neutron shield is composed of separate components, the change across the outer 0.40 in (1.02 cm) concrete-only section and the inner section containing the copper fins embedded in the concrete. The temperature change in both regions of the neutron shield can be expressed by classical one-dimensional heat transfer relationships. The temperature change across the concrete-only section of the shield uses Equation #3-4 with the geometric and thermal property values for the concrete used. The temperature drop across the concrete-copper fin section uses the following relationship:

$$T_{ccf} - T_{cl} = \frac{q' l''}{N\,k\,l'} \qquad \text{(Eq. \#3-5)}$$

where

T_{ccf}, T_{cl} = temperature at the concrete-copper fin interface and the copper fin-lead interface, respectively (^oK),

N = total number of copper fins embedded in the concrete,

q' = linear heat rate based on the total thermal load and the spent fuel heated length ($^W/_m$),

k = thermal conductivity of the concrete, from Table 3-2 ($^W/_m - {}^oK$),

l' = radial distance over which heat transfer occurs from the attached to the unattached copper fin (see Figure 3-11) (m), and

l'' = circumferential distance between the attached and unattached copper fin (see Figure 3-11) (m).

Lead Gamma Shield

The temperature change across the lead gamma shield is calculated using Equation #3-4 based on the appropriate geometric and thermal property conditions for lead.

Inner Stainless Steel Liner

The temperature change across the inner stainless steel liner is calculated using Equation #3-4 based on the appropriate geometric and thermal property condition for stainless steel.

Basket-Inner Wall Gap

The flow of heat across the basket-inner wall gap is by both thermal radiation and gaseous conduction in the helium fill gas. The relationship governing the flow of heat across this region, based on the assumption that the heat flow area of the cask inner wall and the basket outer surface are essentially the same, is

$$\left(\frac{Q}{2\pi L}\right) = \frac{k_{He}\ (T_b - T_{cw})}{\log_e\ (r_{cw}/r_b)} + \frac{r_m\,\sigma\ (T_b^4 - T_{cw}^4)}{(1/\varepsilon_{cw} + 1/\varepsilon_b - 1)} \qquad \text{(Eq. \#3-6)}$$

where

T_{cw}, T_b = cask inner wall and basket outer surface temperatures (absolute scale, ^oK), respectively,

r_{cw}, r_b, r_m = cask inner wall, basket outer surface, and mean basket-inner wall gap radii, respectively (m),

k_{He} = helium thermal conductivity from Table 3-2 ($^W/_m - {}^oK$), and

ε_{cw} , ε_b = emissivity of cask inner wall (0.20) and basket outer surface (0.85), respectively.

The basket outer surface temperature (T_b) is the boundary condition used in the two-dimensional computer analyses using PATRAN and P/THERMAL.

3.6.2 Wooten-Epstein Relationship

The Wooten-Epstein relationship (Ref. 3.4) was used to generate the maximum spent fuel cladding temperature given the peak basket temperature. This relationship is as follows:

$$q'' = [\sigma \frac{C_1}{(1/\varepsilon_{cl} + 1/\varepsilon_{ba} - 1)} (T_{cl}^4 - T_{ba}^4) + 0.118(T_{cl} - T_{ba})^{1.33333}]\ C_F \qquad \text{(Eq. \#3-7)}$$

where

q'' = heat flux from the spent fuel based on the basket inner surface heat transfer area ($^W/_{m^2}$),

C_1 = constant dependent on the spent fuel rod array size,

$= \frac{4N}{(N+1)^2}$ for odd N,

$= \frac{4}{(N+2)}$ for even N,

N = number of fuel pins in a single row of a square spent fuel assembly,

T_{cl}, T_{ba} = cladding surface and basket surface temperatures (absolute scale, ^oR), respectively.

ε_{cl}, ε_{ba} = cladding surface and basket surface emissivity, respectively.

σ_1 = Stefan-Boltzmann constant ($Btu/hr-ft^2-{}^oR^4$).

C_F = 3.15459 ($^W/_{m^2}$)/($Btu/hr-ft^2$)

The Wooten-Epstein relationship is dependent upon the layout of the spent fuel, through the C_1 term. The fuel used for the BWR and PWR analyses were 8-by-8 and

17-by-17, respectively. The range of BWR and PWR fuel assemblies that can be shipped in the BR-100 can produce variations by as much as 10^oF (6^oC) in the peak cladding temperatures shown in tables 3-3 and 3-4 and Figure 3-10.

3.6.3 Computer Codes

Two computer codes were used in the thermal analysis of the Preliminary Design BR-100 basket. These codes were PATRAN and P/THERMAL (Refs. 3.2, 3.3). Both codes were developed and maintained by PDA Engineering of Costa Mesa, CA.

PATRAN is a preprocessing code that can be used to develop finite-element models for thermal and structural analyses. The models are developed using a sequence of commands to define and combine a series of simple geometric shapes into complex two- or three-dimensional models. The boundary conditions and initial conditions that are used to complete the definition of the physical problem are also applied in PATRAN. In addition to its preprocessing capability, PATRAN provides extensive postprocessing capabilities.

P/THERMAL is a general purpose thermal analysis program that determines the steady-state and transient response for one-, two-, and three-dimensional geometries. The code translates the finite-element information from PATRAN to a mathematically exact thermal resistor-capacitor network. The numerical solution algorithms used in P/THERMAL were developed to efficiently handle large nonlinear problems such as those encountered in the BR-100 analyses. Capabilities of the code include conduction, convection, multiple surface radiation networks, and limited convection.

An additional code being investigated for possible use in analysis of the final design is COBRA-SFS (Ref. 3.9). Originally developed to analyze fuel within a cask in a vertical position for storage, COBRA-SFS has great potential for predicting the temperature and flow distributions within the complex basket/fuel geometry of a rail cask, even during transient conditions. The most recent version of COBRA-SFS was released by Argonne National Laboratory's National Software Distribution Center in September 1989. This version must be modified further to account for the geometry effects of horizontal fuel instead of vertical fuel and must be benchmarked and validated according to B&W and DOE procedures before use in a licensing analysis.

3.7 REFERENCES

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Table 3-1
SUMMARY OF BR-100 CASK THERMAL PERFORMANCE

	Allowable Limit	BWR Fuel Limiting	BWR Fuel Baseline	PWR Fuel Limiting	PWR Fuel Baseline
Cask Heat Load	N/A	14.6	9.2	17.6	12.0
Number of Assemblies	N/A	52.0	52.0	21.0	21.0
Assembly Heat Rate (W)	N/A	281.6	177.7	837.0	574.3
Fuel Characteristics (Burnup GWd/mtU; enrichment wt %), all ten-year cooled	N/A	45; 4.0	30; 3.0	50; 4.5	35; 3.0
	Temperatures °F (°C)				
Personnel Barrier	180 (82)	N/A N/A	N/A N/A	N/A N/A	N/A N/A
Cask Surface	N/A N/A	219.7 (104.3)	184.2 (84.6)	223.9 (106.6)	194.9 (90.5)
Peak Concrete	250 (121)	241.7 (116.5)	197.6 (92.0)	246.0 (118.9)	210.1 (98.9)
Peak Basket	350 (177)	308.9 (153.8)	239.0 (115.0)	338.6 (170.3)	274.3 (134.6)
Peak Fuel Cladding	680 (360)	371.9 (188.8)	285.4 (140.8)	452.6 (233.7)	364.2 (184.6)

Table 3-2
BR-100 CASK THERMAL PROPERTIES

Material	Temperature °F	Temperature (°C)	Thermal Conductivity Btu/h-ft-°F	Thermal Conductivity (W/m-°K)	Thermal Diffusivity ft²/h	Thermal Diffusivity (m²/h)
Aluminum Alloy 6061 (Reference 3.10, page 106)	100.0	(37.8)	96.9	(167.7)	2.66	(0.247)
	200.0	(93.3)	99.0	(171.3)	2.65	(0.246)
	300.0	(148.9)	100.6	(174.1)	2.63	(0.244)
	400.0	(204.4)	101.9	(176.3)	2.62	(0.243)
B_4C-Al Cermet[a] (Reference 3.11, Page 717)	200.0	(93.3)	25.0	(43.3)	b	
	450.0	(232.2)	19.2	(33.2)	b	
	500.0	(260.0)	19.0	(32.9)	b	
Robatel borated concrete (Robatel proprietary)[a]	$T < 284.0$	(140.0)	1.04	(1.8)	0.0174	(0.0016)
	$284.0(140.0) \leq T \leq 608(320.0)$		1.04	(1.8)	0.0079	(0.0007)
	$T > 608$	(320.0)	0.35	(0.6)	0.0264	(0.0024)
Helium (Reference 3.8, page 543)	-0.7	(-18.2)	0.0784	(0.1357)	5.305	(0.493)
	199.1	(92.9)	0.0977	(0.1691)	9.489	(0.882)
	398.9	(203.9)	0.1139	(0.1970)	14.387	(1.337)
	600.5	(315.9)	0.1300	(0.2250)	20.245	(1.881)
	800.3	(426.9)	0.1451	(0.2510)	26.599	(2.471)
	980.3	(526.9)	0.1589	(0.2750)	34.024	(3.161)

[a] The thermal properties of Cermet and Robatel borated concrete will be determined experimentally. The experimental values will be used in the final design analyses.

[b] The values for the Cermet thermal diffusivity are unknown. For the preliminary design, the thermal diffusivity was not used since all of the analyses were steady-state.

Table 3-2, Continued
BR-100 CASK THERMAL PROPERTIES

Material	Temperature °F	Temperature °C	Thermal Conductivity btu/h-ft-°F	Thermal Conductivity (W/m-°K)	Thermal Diffusivity ft²/h	Thermal Diffusivity m²/h
Lead (Reference 3.3)	68.0	20.0	19.98	34.58	0.920	0.0855
	208.9	98.3	19.57	33.86	0.879	0.0816
	400.1	204.5	18.31	31.69	0.795	0.0739
	498.9	259.4	16.93	29.30	0.723	0.0672
	581.0	305.0	14.52	25.12	0.611	0.0568
	630.0	332.2	12.10	20.93	0.503	0.0467
	717.1	380.6	9.68	16.74	0.403	0.0375
	799.9	426.6	9.02	15.61	0.377	0.0350
	980.1	526.7	8.71	15.07	0.366	0.0340
	1,276.0	691.1	8.66	14.99	0.367	0.0341
Stainless steel, 304L (Reference 3.10, page 102)	70.0	21.1	8.6	14.9	0.151	0.0140
	100.0	37.8	8.7	15.1	0.152	0.0141
	200.0	93.3	9.3	16.1	0.156	0.0145
	300.0	148.9	9.8	17.0	0.160	0.0149

[a]The thermal properties of Cermet and Robatel borated concrete will be determined experimentally. The experimental values will be used in the final design analyses.

[b]The values for the Cermet thermal diffusivity are unknown. For the preliminary design, the thermal diffusivity was not used since all of the analyses were steady-state.

Table 3-2, Continued
BR-100 CASK THERMAL PROPERTIES

Material	Temperature		Thermal Conductivity		Thermal Diffusivity	
	°F	°C	btu/h-ft-°F	W/m-°K	ft^2/h	m^2/h
Stainless steel, 304L, Continued	400.0	204.4	10.4	18.0	0.165	0.0153
	500.0	260.0	10.9	18.9	0.170	0.0158
	600.0	315.6	11.3	19.6	0.174	0.0162
	700.0	371.1	11.8	20.4	0.179	0.0166
	800.0	426.7	12.2	21.1	0.184	0.0171
	900.0	482.2	12.7	22.0	0.189	0.0176
	1,000.0	537.8	13.2	22.8	0.194	0.0180
	1,100.0	593.3	13.6	23.5	0.198	0.0184
	1,200.0	648.9	14.0	24.2	0.203	0.0189
	1,300.0	704.4	14.5	25.1	0.208	0.0193
	1,400.0	760.0	14.9	25.8	0.212	0.0197
	1,500.0	815.6	15.3	26.5	0.216	0.0201

[a]The thermal properties of Cermet and Robatel borated concrete will be determined experimentally. The experimental values will be used in the final design analyses.

[b]The values for the Cermet thermal diffusivity are unknown. For the preliminary design, the thermal diffusivity was not used since all of the analyses were steady-state.

Table 3-3
BWR TEMPERATURE SUMMARY

Location[a]		Temperatures, °F (°C)			
in	(m)[b]	30/3.0 wt %[c]		45/4.0 wt %[c]	
41.00	(1.041)	184.2	(84.6)	219.7	(104.3)
39.25	(0.997)	186.8	(86.0)	223.8	(106.6)
38.85	(0.987)	192.2	(89.0)	232.8	(111.6)
34.75	(0.883)	197.6	(92.0)	241.7	(116.5)
30.25	(0.768)	201.4	(94.1)	247.9	(119.9)
29.25	(0.743)	203.4	(95.2)	251.1	(121.7)
29.20	(0.742)	212.7	(100.4)	265.8	(129.9)
Peak basket		239.0	(115.0)	308.9	(153.8)
Peak clad		285.4	(140.8)	371.9	(188.8)
		w/ft		w/ft	
Peak assembly heat rate		19.4		31.8	

[a]Location denotes the radial location from the cask center.

[b]Values in parentheses are metric. The metric units of temperature are degrees Celsius. The metric units of location are meters.

[c]30/3.0 wt % denotes 30 GWd/mtU 3.0 wt % fuel.

Table 3-4
PWR TEMPERATURE SUMMARY

Location[a]		Temperatures, °F (°C)			
in	(m)[b]	35/3.0 wt %[c]		50/4.0 wt %[c]	
41.00	(1.041)	194.9	(90.5)	223.9	(106.6)
39.25	(0.997)	197.9	(92.2)	228.3	(109.1)
38.85	(0.987)	204.3	(95.7)	237.6	(114.2)
34.75	(0.883)	210.1	(98.9)	246.0	(118.9)
30.25	(0.768)	214.6	(101.4)	252.6	(122.6)
29.25	(0.743)	216.9	(102.7)	255.9	(124.4)
29.20	(0.742)	227.9	(108.8)	271.3	(132.9)
Peak basket		274.3	(134.6)	338.6	(170.3)
Peak clad		364.2	(184.6)	452.6	(233.7)
		w/ft		w/ft	
Peak assemby heat rate		56.8		82.9	

[a]Values in parentheses are metric. The metric units of temperature are degrees Celsius. The metric units of location are meters.

[b]Location denotes the radial location from the cask center.

[c]35/3.0 wt % denotes 35 GWd/mtU 3.0 wt % fuel.

Figure 3-1

Typical Normalized PWR Axial LHGR Profile

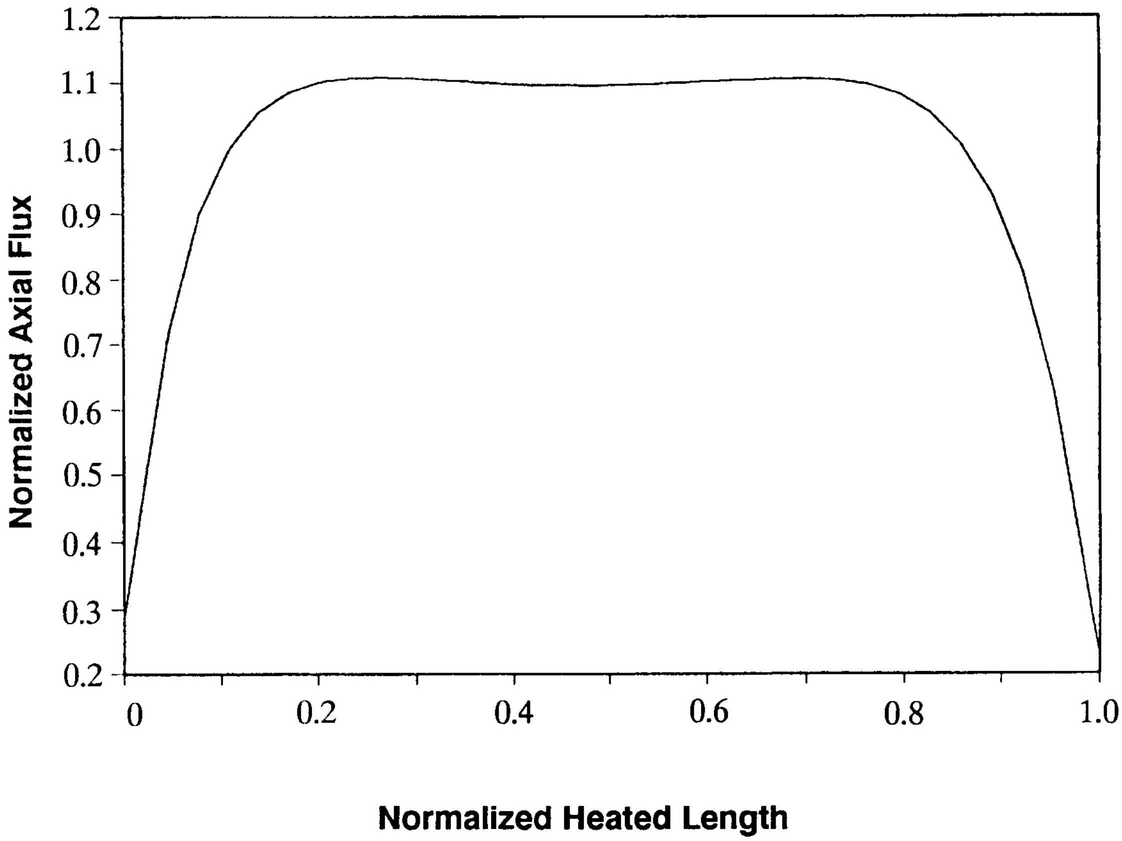


Figure 3-2

BWR Cask Wall and Basket Inner-Wall Gap Temperature Distribution

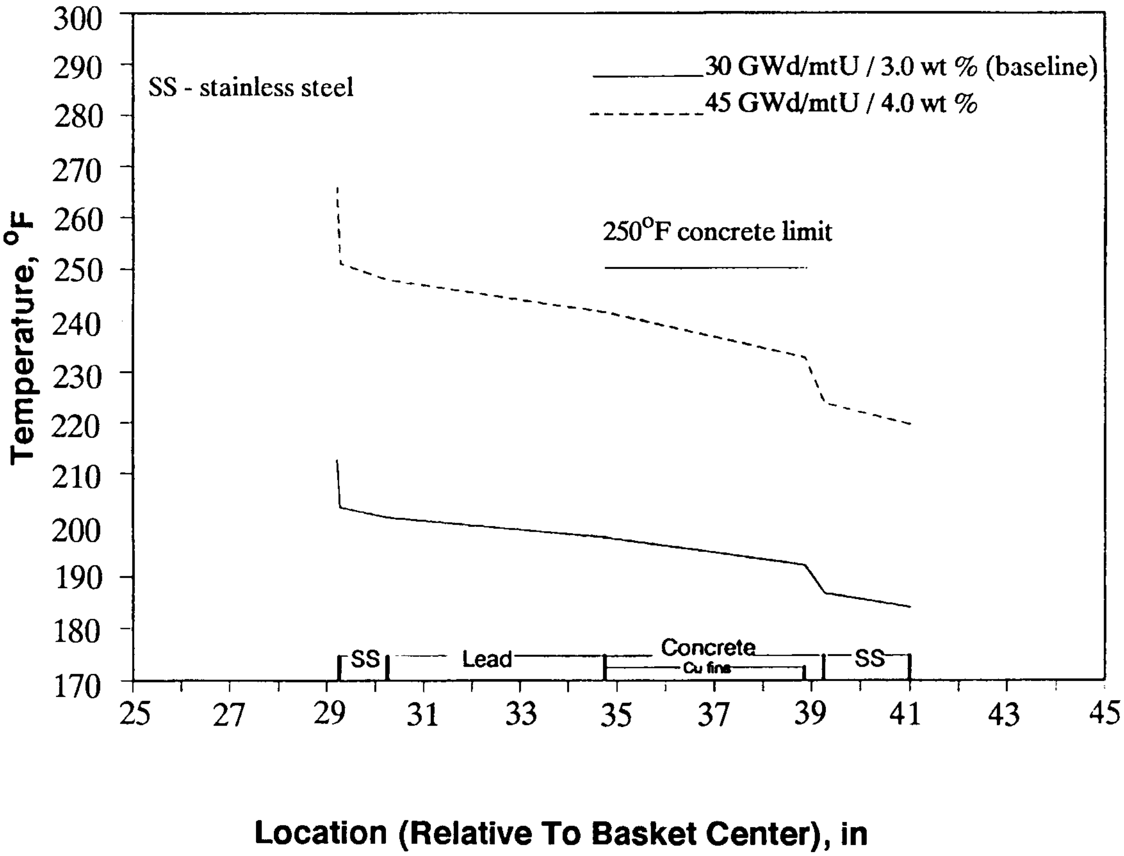


Figure 3-3

PWR Cask Wall and Basket Inner-Wall Gap Temperature Distribution

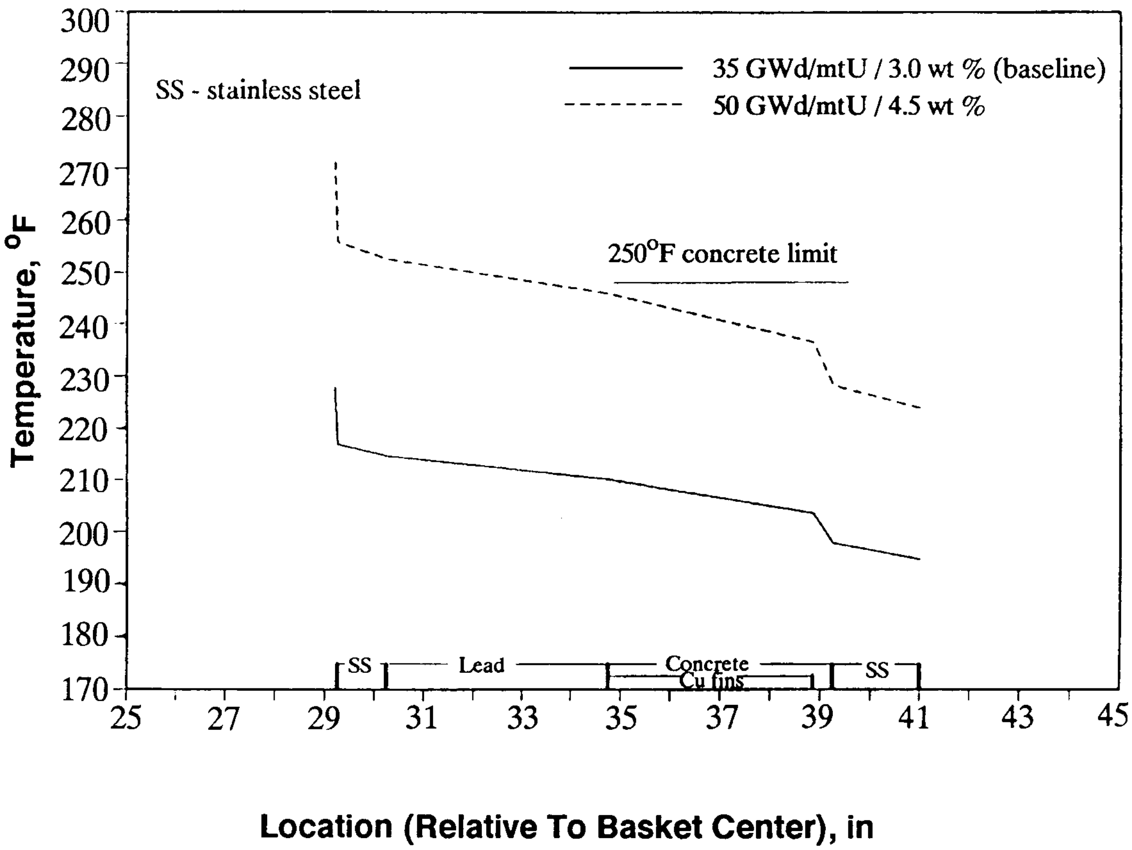


Figure 3-4

BWR Maximum Basket and Basket Outer Surface Temperatures

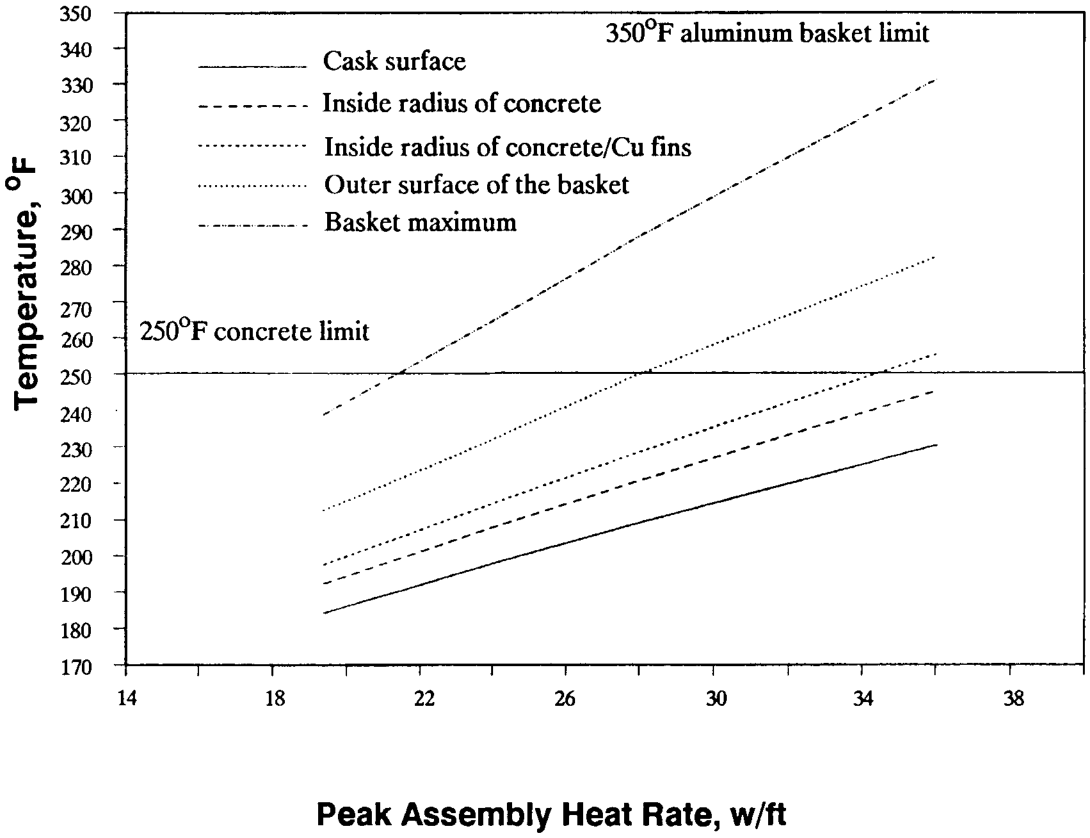


Figure 3-5

PWR Maximum Basket and Basket Outer Surface Temperatures

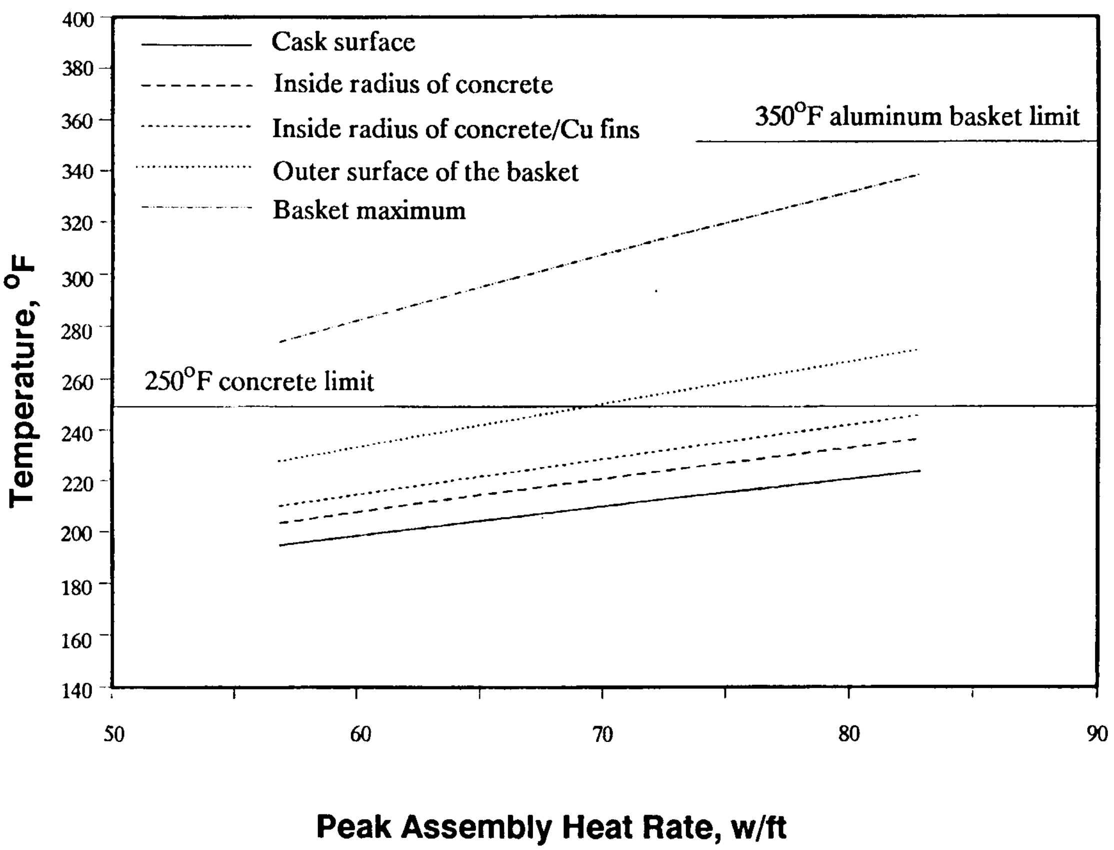
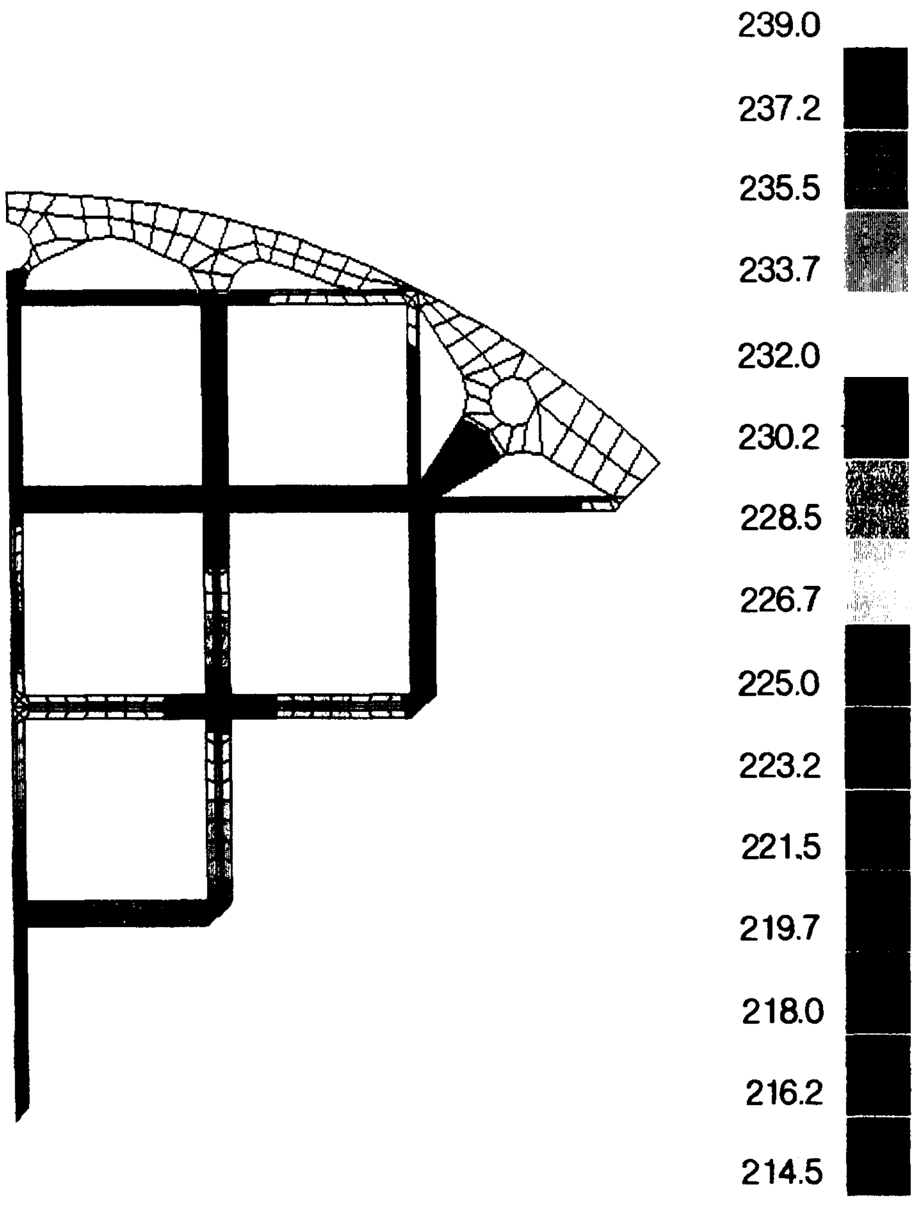


Figure 3-6

BWR Basket Midplane

30 GWd/mtU, 3.0 w/o, 10-Year Cooled Fuel

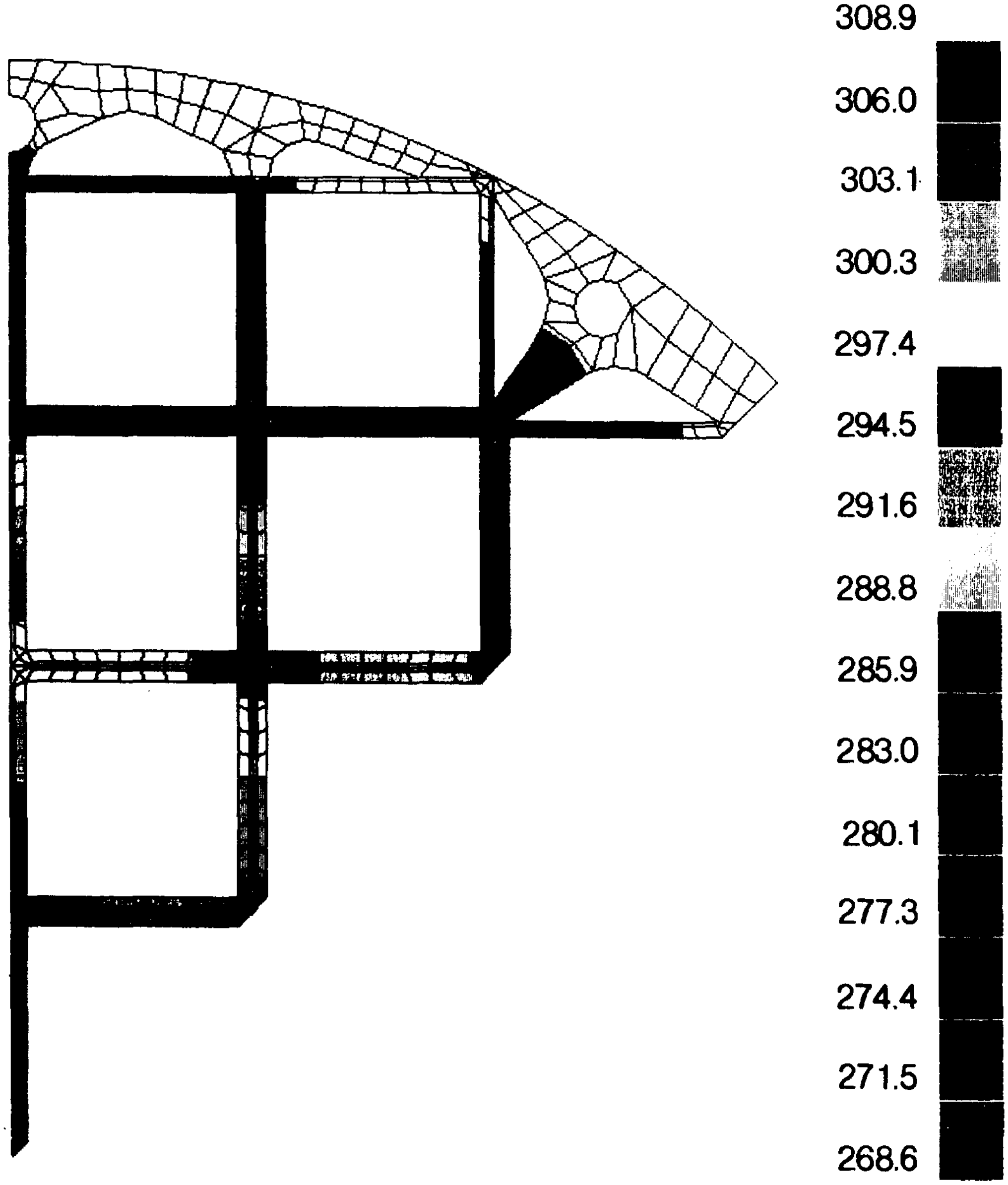


The temperature scale is Fahrenheit. The temperatures within the basket that are color coded white are between 212.7°F and 214.5°F.

Figure 3-7

BWR Basket Midplane

45 GWd/mtU, 4.0 w/o, 10-Year Cooled Fuel

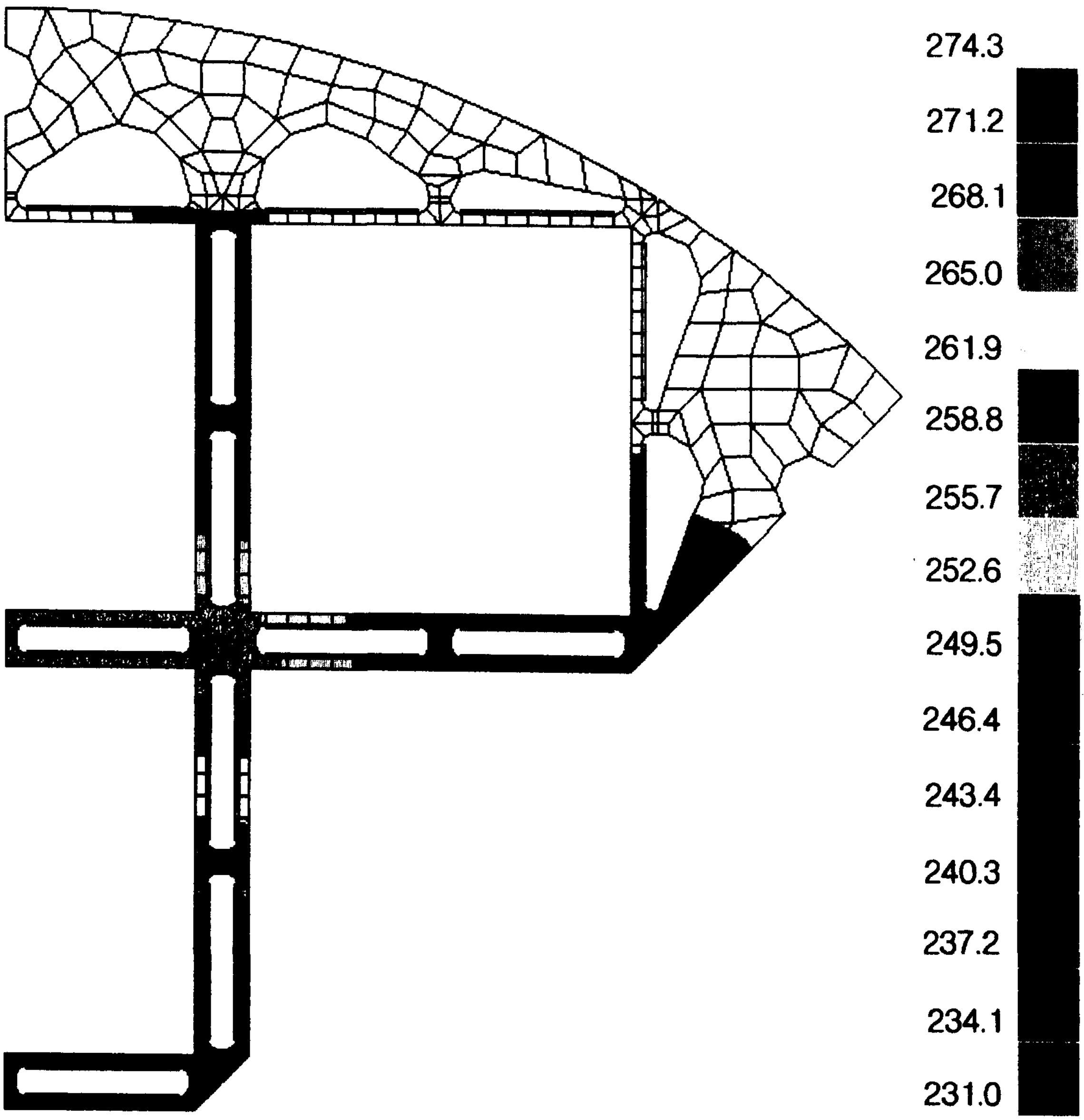


The temperature scale is Fahrenheit. The temperatures within the basket that are color coded white are between 265.8°F and 268.6°F.

Figure 3-8

PWR Basket Midplane

35 GWd/mtU, 3.0 w/o, 10-Year Cooled Fuel

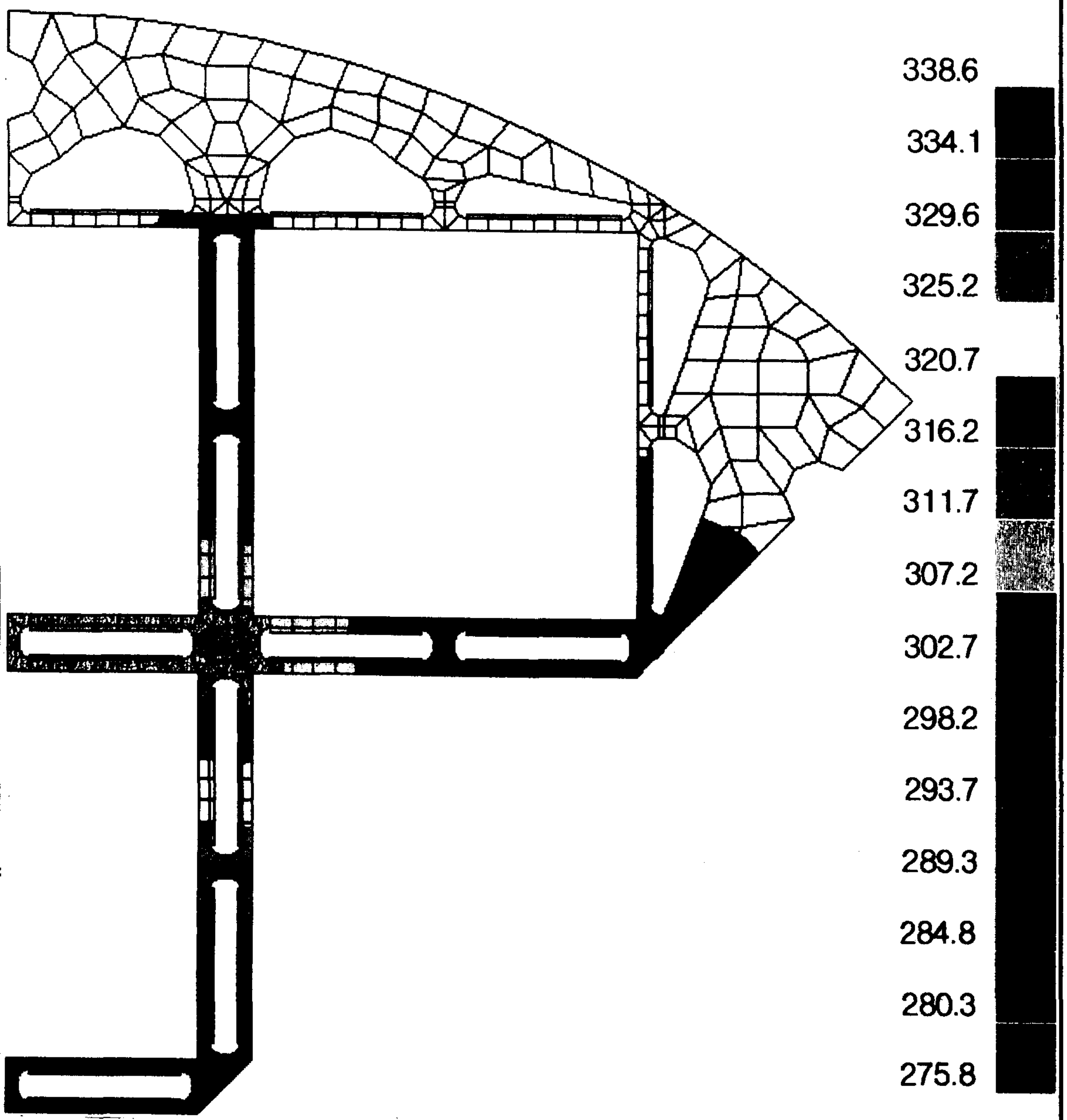


The temperature scale is Fahrenheit. The temperatures within the basket that are color coded white are between 227.9°F and 231.0°F.

Figure 3-9

PWR Basket Midplane

50 GWd/mtU, 4.5 w/o, 10-Year Cooled Fuel



The temperature scale is Fahrenheit. The temperatures within the basket that are color coded white are between 271.3°F and 275.8°F.

Figure 3-10

BWR and PWR Peak Cladding Temperatures

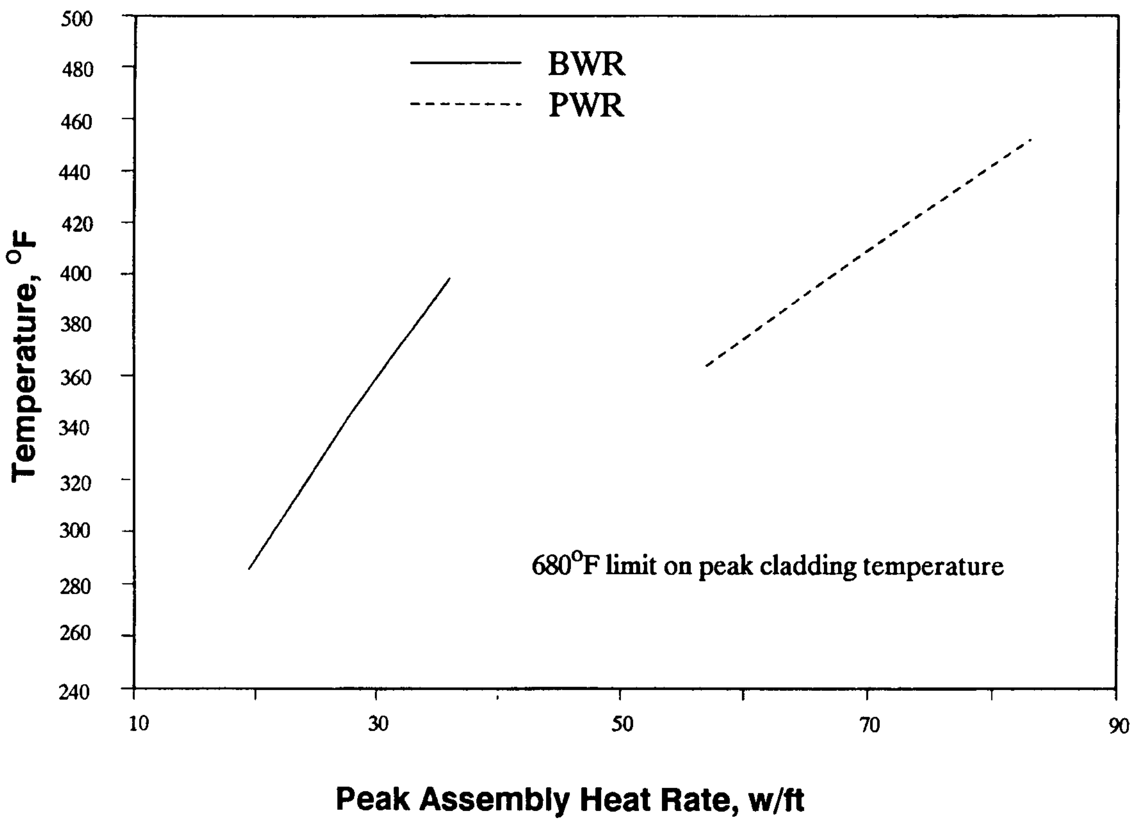
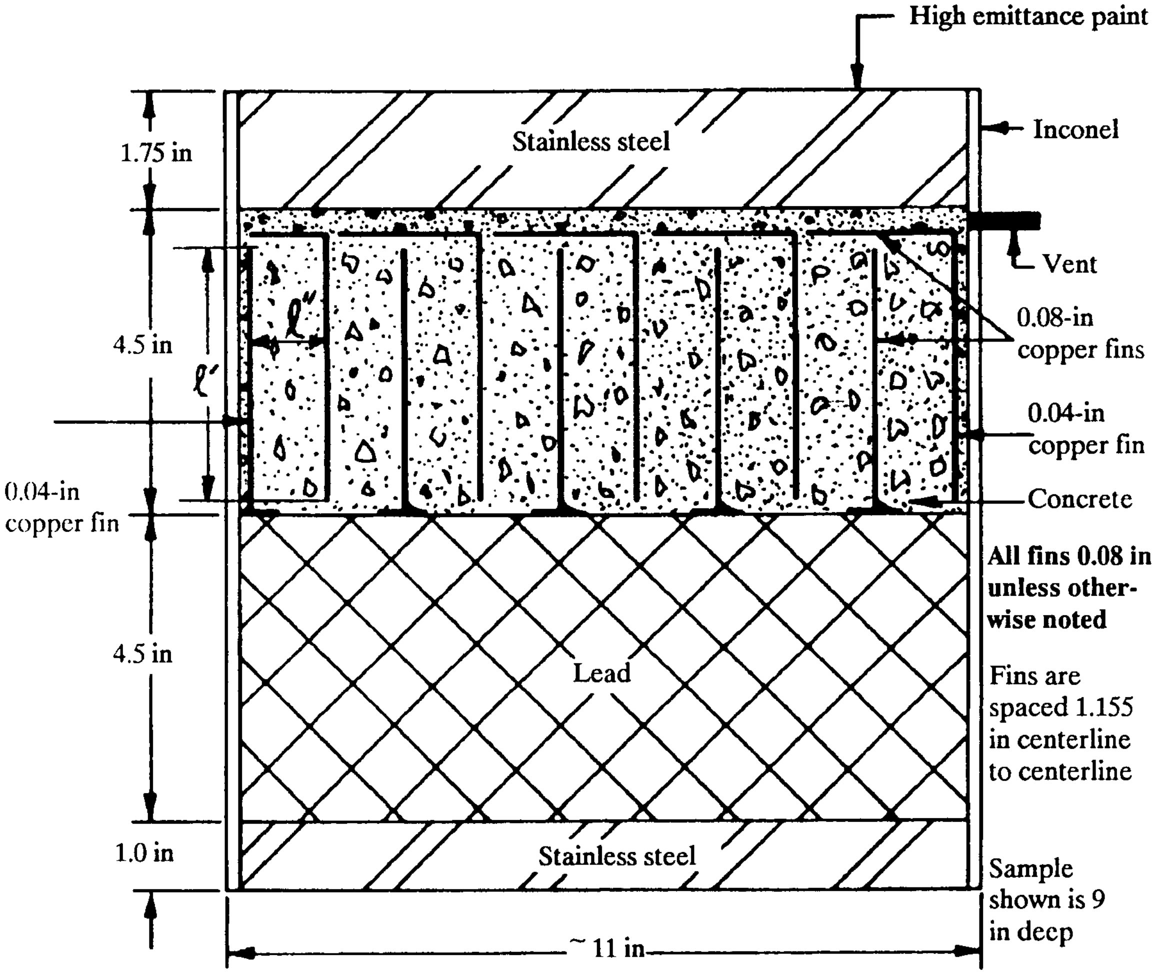


Figure 3-11
BR-100 Thermal Test Section



4.0 CONTAINMENT

This section identifies the BR-100 containment boundary with all the related design specifications (section 4.1) to present preliminary results that give BWFC confidence in the design and to explain which types of evaluations (testing and analysis) are planned during the final design stage (sections 4.2 and 4.3).

The object of the containment analysis is to demonstrate the design of the cask for a leaktight capacity as defined in ANSI N14.5. However, as results of the DOE's ongoing source term evaluation program become available, leakage testing requirements will be set to satisfy containment requirements of 10CFR71.51(a).

For preliminary design purposes, we have used quantitative structural design criteria for the main lid and bolts to evaluate the tightness of the containment vessel. During final design, the analysis and testing will allow us to demonstrate that the required leaktightness criteria will be met.

4.1 CONTAINMENT BOUNDARY

All the components of the containment boundary listed below are identified on Figure 4-1.

1. Bottom forging - 304L stainless steel forging ASME Specification SA-182, F304L,
2. Containment shell - 304L stainless steel pipe ASME Specification SA-358, Grade 304L, Class 1,
3. Ring Flange - 304L stainless steel forging ASME Specification SA-182, F304L,
4. Closure Lid - XM-19 stainless steel ASME Specification SA-240, Type XM-19,
5. Penetrations located in the lid, as described in Section 4.1.2,
6. Welds discussed in Section 4.1.3.2, and
7. Seals discussed in Section 4.1.3.1.

4.1.1 Containment Vessel

The design specifications for the containment vessel are listed below. They are classified as general design requirements, containment requirements, mechanical requirements, and structural requirements.

General Design Requirements

The containment vessel is a Class 1 component as defined in ASME Code, Section III, Division 1. Therefore, the selected materials are specified for Class 1 component use in the Code.

Containment Requirements

We will establish leakage test requirements based on results of DOE's ongoing source term evaluation program.

Mechanical Requirements

The materials constituting the containment vessel will be compatible with both a dry and wet environment. They are selected to prevent any chemical or galvanic effect leading to unacceptable corrosion in the cask cavity under loading or unloading environments or during normal transportation. The use of stainless steel precludes the need for any coating on the internal surface of the containment vessel.

The containment vessel material will be compatible with standard decontamination washing solutions (no problem is expected with stainless steel).

The finish of the containment vessel internal surface is to be specified during the final design to allow for easy decontamination.

Structural Requirements

During normal conditions as defined in 10CFR71, no plastic deformation of the containment vessel is allowed, and no yield of the bolts is allowed.

During hypothetical accident conditions as defined in 10CFR71, no gross permanent deformation of the containment vessel is allowed, and no yield of the bolts is allowed.

4.1.2 Containment Penetrations

4.1.2.1 Description of the Penetrations

There are two penetrations into the primary containment. These two penetrations ($^3/_8$ -inch and $^1/_2$ -inch diameter) are located in the closure lid. They are used for final draining of the cask (vacuum drying), pressurization with inert gas, pressure measurements, gas analysis, and cooling. They are not used for primary draining of the cask cavity, which is performed in the spent fuel pool when the lid is not in place. Both penetrations are provided with quick-disconnect mechanisms; they are grouped under a common bolted cover plate which ensures the containment through the use of two Viton O-ring seals. A seal check port provides for a check of the seals. Caps are used on the quick-disconnects to provide a redundant seal system.

4.1.3 Seals and Welds

4.1.3.1 Seals

4.1.3.1.1 Description of the seals

Two seals, one on the closure lid and one on the penetration cover plate, are part of the containment boundary. Their physical location is represented on Figure 4-2.

Main Closure Seals: Two Viton O-ring face seals per specification Parker V835-75, Viton GLT

Cover Plate Seals: Two Viton O-ring face seals per specification Parker V835-75, Viton GLT.

The penetration cover plate seals also ensure the containment function. They are protected (the cover plate is recessed into the main lid) and subject to limited performance excursions (the main concern being the external puncture accident). Their behavior will be evaluated during the final design.

4.1.3.2 Welds

Welds are located (1) between the ring flange and the containment shell, (2) between the containment shell and the bottom forging, and (3) potentially on the shell in the longitudinal direction. The circumferential containment welds are designed in accordance with ASME Code, Section III, Division 1, for use for Class 1 components. Full penetration, double-welded butt joints employing fusion welding processes are to be used in accordance with applicable ASME specifications. Appropriate nondestructive examination methods specified by the Code will be used to ensure compliance with ASME requirements.

4.1.4 Closure

The tightness of the containment vessel is ensured by 32 bolts on the closure lid and 6 bolts on the penetration cover plate. The bolt material used is Inconel 718, ASME specification SB-637, Alloy N07718, Class 1 component use. Bolt installation torque values are given in Table 4-1.

Table 4-1
BOLT TORQUES FOR POSITIVE CLOSURE

Bolt Location	Quantity	Nominal Size	Torque, lb-in
Closure lid	32	2.5-in diameter x 9 in long	80,000
Penetration cover plate	6	To be defined during final design	

The bolts are designed to ensure positive closure of the lid and maintain a minimum seal preload irrespective of the conditions (normal and accident conditions). A bolt locking mechanism will be designed during final design. The structural design criteria states is that no yield of the closure bolts is allowed (the closure bolts structural analysis is addressed in section 2).

4.2 REQUIREMENTS FOR NORMAL CONDITIONS OF TRANSPORT

The BR-100 is designed per 10CFR 71.51 so that "under the tests specified in Section 71.71 (Normal Conditions of Transport) there would be no loss or dispersal of radioactive contents, as demonstrated to a sensitivity of 10^{-6} A_2 per hour."

The normal conditions defined in 10CFR71 and the corresponding loadings of the closure lid and the bolts have been considered. The two design situations identified as the limiting cases for the containment analysis are discussed in this section: Cold environment and free drop. The other situations (hot environment, reduced and increased external pressure, vibration, and shock) are not addressed in the preliminary design because they are not expected to have significant effects on the containment analysis.

The criteria selected for preliminary design are based on structural calculations only and concern the main closure only. They are:

1. No plastic deformation of the closure lid.
2. No yield of closure bolts.
3. Conservation of compression characteristics of the seals.

Seal check ports are recessed and do not directly affect the containment.

The penetration cover plates are protected and subject to limited access. Seal check ports and penetration cover plates are not considered in the preliminary design containment analysis.

4.2.1 Release of Radioactive Material

The two scenarios analyzed for the preliminary design evaluation of the main closure (cold environment and free drop) are discussed below.

Cold Environment

Behavior testing of Viton seals at -40°C will be performed during the final design. The tests are conducted to provide compression characteristics of Viton at these temperatures and to demonstrate that the mechanical properties are maintained at an acceptable level.

Free Drop

The worst case loading on the closure lid and bolts corresponds to an end drop. The corresponding accelerations on the internals of the cask are expected to be at a maximum of 20 G.

The loading scenario considered for evaluation is as follows:

- o static loading on the inside surface of the closure lid corresponding to 20 times the combined weight of the fuel assemblies loaded in the cask and the shield plug,
- o 150 psi cask internal pressure (100 psi was used for lid analysis).

The results were (1) no yielding of the bolts, and (2) completely elastic behavior of the lid (the corresponding analysis are detailed in section 2).

Seal testing during the final design will allow BWFC to relate the elastic deformations observed to eventual leakage rates and define margins to the leakage rate limit criteria. However, the satisfaction of these two criteria with the criteria on mechanical behavior of seal material (adequacy of the seal material selected with the design) will demonstrate the tightness.

For evaluation of normal conditions per 10CFR71, a maximum pressure of 150 psi is assumed at the inside of the cask. Under normal conditions, however, the backfilling of the cask with only a partial atmosphere of helium is designed to cause inward leakage if a seal failure occurs.

4.2.2 Pressurization of Containment Vessel

No vapor or gas is expected to form in the containment vessel for the following reasons:

- o Transportation of intact fuel.
- o Use of stainless steel for the containment vessel and shield plug casing.
- o Hard anodization of all the cask cavity internals which are not stainless steel (aluminum basket).
- o Backfilling of the internal cavity with 0.5 atmosphere absolute of helium.
- o Draining and drying of the cask cavity before transportation.

The atmosphere inside the cask consists of a dry inert fill gas (helium), a partial pressure of residual water and, after hypothetical rod failure, xenon, krypton, and hydrogen. This gas mixture is not explosive.

The maximum containment pressure under normal conditions of transport is calculated to be under 100 psi based on the following assumptions:

- o All rods are ruptured.
- o All the gas released.
- o Maximum cavity gas temperature is 400°F.

Therefore, the MNOP is taken as 100 psig. Cask designs with MNOP greater than 5 psig must be subjected to a structural pressure test in accordance with 10CFR71.85(b) with a test pressure at least 1.5 times the MNOP. A maximum normal cavity pressure of 150 psig is conservatively used for the structural analysis of containment.

4.2.3 Coolant Contamination

These criteria are not applicable because the BR-100 does not use a separate cooling system. The safety of the cask is based on passive heat transfer only.

4.2.4 Coolant Loss

Not applicable for the same reason as 4.2.3.

4.3 CONTAINMENT REQUIREMENTS FOR THE HYPOTHETICAL ACCIDENT CONDITIONS

The BR-100 is designed per 10CFR71.51 so that "under the tests specified in Section 71.73 (Hypothetical Accident Conditions), there would be no escape of KR85 exceeding 10,000 curies in one week," and "no escape of other radioactive material exceeding a total amount A_2 in one week."

Hypothetical accident conditions are discussed below to present the design situation considered for the preliminary design.

Immersion - An external pressure of 290 psi is not expected to affect the containment function.

Free Drop - This condition was selected for preliminary design evaluation because it is expected to provide the maximum loadings on the closure lid and bolts.

Puncture - This condition is not considered to be limiting for the containment function. In the case of a top end puncture, the impact limiters will absorb part of the energy and even some local plastic deformations of the lid will not affect the containment. In the case of a side or bottom end puncture, the external shell is designed so that no perforations can occur and, therefore, no breach of the containment.

Thermal - This condition is limiting for the temperatures expected in the seal area. However, the seal area is adequately thermally protected to maintain the seal temperatures under their allowable limit during thermal accident conditions.

The sequence of accident conditions as defined by 10CFR71 is 1)free drop, 2) puncture, and 3) thermal.

The criteria selected for preliminary design are based on structural calculations only and concern the main closure only. They are:

1. No plastic deformation of the closure lid.
2. No yield of closure bolts.
3. Conservation of compression characteristics of the seals

4.3.1 Fission Gas Products

The inventory of free fission gas products available for release from the fuel rods is calculated with ORIGEN.

4.3.2 Release Of Contents

The free-drop condition was selected for preliminary design evaluation because it provides the maximum loadings on the closure lid and bolts. From all the free drop orientations, the worst-case loading on the closure lid and bolts correspond to an end drop. The corresponding accelerations on the internals of the cask are expected to be at a maximum of 60 G.

The loading scenario considered for evaluation is as follows:

- o Static loading on the inside surface of the closure lid corresponding to 60 times the combined weight of the fuel assemblies loaded in the cask and the shield plug.
- o An internal pressure of 150 psi in the cask.

The results of the evaluation were (1) no yielding of the bolts, and (2) no permanent deformation of the lid (the corresponding analysis are detailed in Section 2).

No adverse effect of the accident conditions is expected to affect the performance of the containment boundary structure and seals.

Figure 4-1
Containment Boundary Components

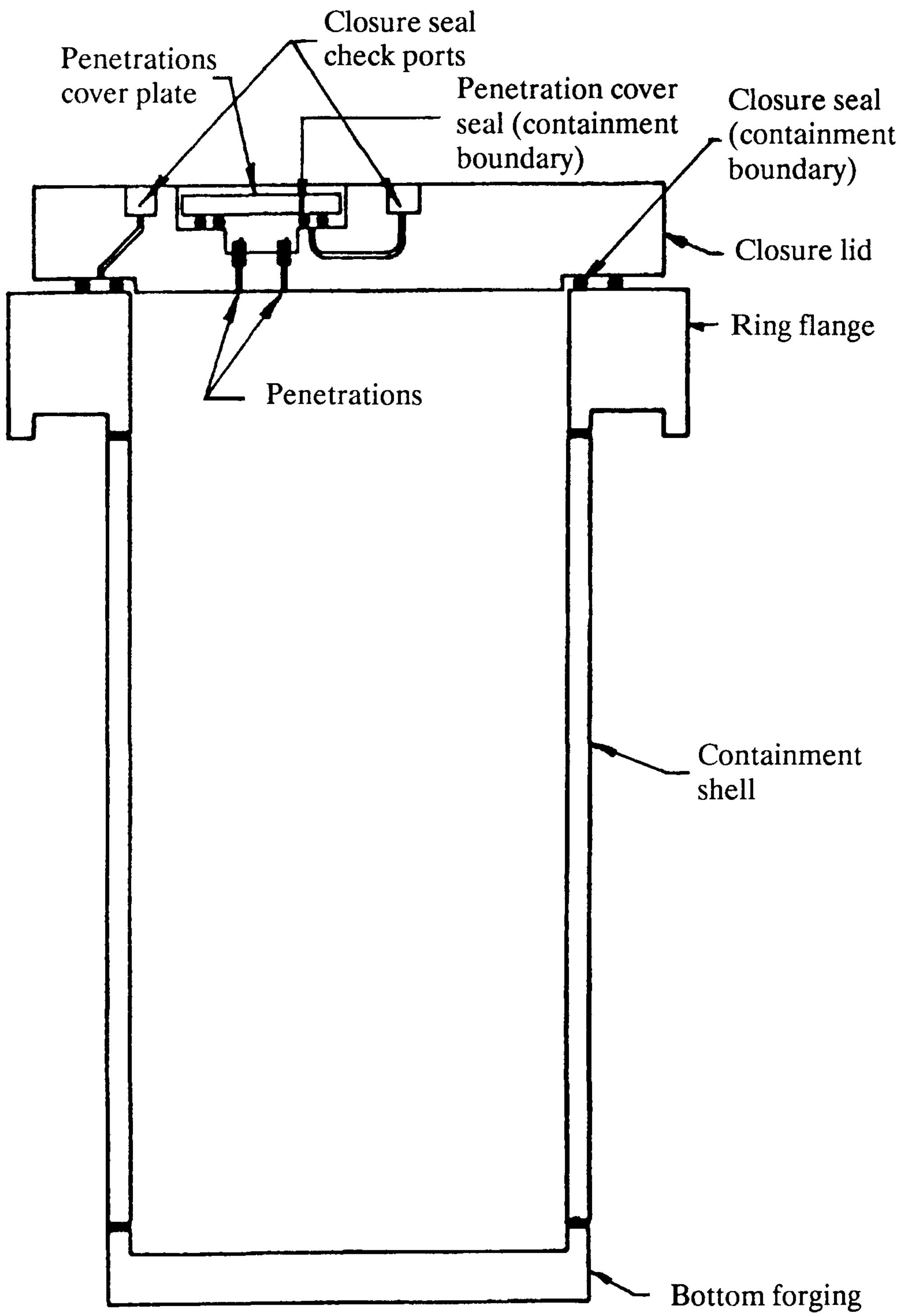
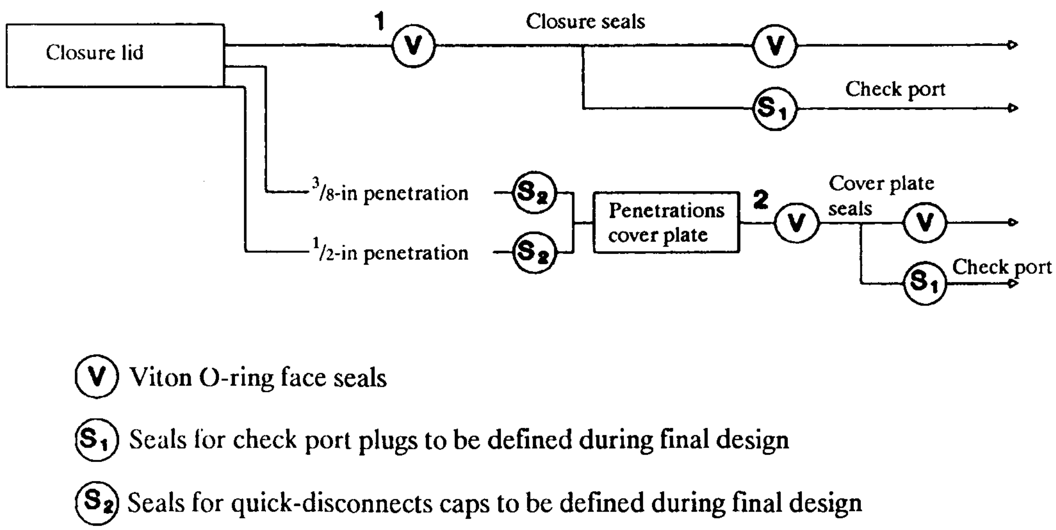


Figure 4-2

Physical Location of Containment Boundary Seals 1 and 2



5.0 SHIELDING EVALUATION

The BR-100 Cask is a multiple-use spent-fuel shipping container capable of handling both PWR and BWR fuel by utilizing specially designed baskets. The cask wall consists of concentric cylindrical steel, lead, and concrete layers to provide gamma and neutron shielding. The concrete contains boron for the reduction of thermal neutron flux and secondary gamma production and also contains an array of copper fins for decay heat conduction. The bottom of the BR-100 cask is composed of multiple layers of steel and one layer of lead. The top shield plug of the cask also has multiple layers of steel and a single layer of lead.

ORIGEN2[1] was used to generate gamma and neutron sources for input to QAD-CGGP[2] and ANISNBW[3]. Cask axial centerline dose rates were calculated by using QAD in conjunction with ANISN, but radial centerline dose rates were calculated with ANISN only (summary descriptions of these codes are in Sections 5.2 and 5.4). Shielding thicknesses were sized to ensure dose rates to satisfy design limits at locations specified by 10CFR71.

5.1 DISCUSSION AND RESULTS

Fuels to be transported in the BR-100 cask are pressurized water reactor (PWR) and boiling water reactor (BWR) fuel assemblies per the contract Statement-of-Work. The cask can accommodate 21 PWR assemblies or 52 BWR assemblies via change of the internal basket. The design basis parameters are given in Table 5-1, and the fuel characteristics are presented in Table 5-2. Fuel source parametric evaluation based on ORIGEN results show that for fuel with the specified design basis burnup, 3 wt % U-235 initial enrichment yields larger source terms than higher enrichments (about 10% more than 4.5 wt %). Since 3.0 wt % enrichment is both realistic for 35 Gwd/mtU burnups and leads to conservative shielding results, it was used in all BR-100 Cask baseline analytical shielding models.

The nuclear source characteristics of the design basis fuels (B&W 15 X 15 and G.E. 8 X 8) at the ten-year cooling time specified by DOE are given in Table 5-3. ORIGEN2 results show that the PWR design basis fuel produces the larger source terms and has the lower source density; therefore, it is used as the fuel for the limiting design parameters in the analysis of the BR-100 cask. An analysis with 52 BWR design basis fuel assemblies yielded dose rates of about 50% of those calculated with 21 PWR design basis fuel assemblies (see tables 5-4 and 5-5).

Lead and steel were chosen for gamma radiation shielding and were arranged to minimize cask weight without sacrificing their effectiveness. Lightweight borated concrete (supplemented with internal copper fins for thermal reasons) was chosen to moderate and absorb neutron radiation.

Figure 5-1 is a longitudinal cross-section of the BR-100 cask showing shielding materials and their thicknesses, and figures 5-2 and 5-3 show the fuel basket design.

The dose point locations considered are shown on Figure 5-4. The gamma and neutron dose rates calculated for each dose point shown on the figure are given in Table 5-4. From this table it may be seen that the maximum dose rate at the cask surface does not exceed the design limit of 200 mrem/hr at any location, nor does the dose rate exceed the 10CFR71 limit of 10 mrem/hr in any location 2 m from the personnel barrier of the cask. The personnel barrier was assumed to be 20.4 in from the cask surface in the radial direction and 25 in from the cask top and bottom in the axial directions (the thickness of the impact limiters).

All total dose rates presented in Table 5-4 include the neutrons and primary gammas originating from the fuel and secondary gammas resulting from neutron capture in the shielding materials. The dose rates from Co-59 activation in the intermediate grids of the fuel region were not included in the fuel mid-plane total dose rates, since the self-shielding in that region renders that contribution to be of little significance relative to the fuel sources. Total dose rates along the cask top and bottom axial centerlines and radially opposite the top and bottom end-fittings, however, do include the contributions of Co-60 due to activation in the stainless steel end fittings and the Inconel 718 end spacer grids.

Table 5-1
DESIGN-BASIS SPENT FUELS*

Fuel Type	PWR, Babcock & Wilcox 15 x15 3.0 wt % U-235 initial enrichment 35,000 MWd/mtU maximum burnup 10 years minimum decay time following reactor discharge
Fuel Form	Intact assemblies
Quantity	21 design basis fuel assemblies
Sources of Fuel	Commercial PWR reactors
Fuel Type	BWR, General Electric 8 x 8 3.0 wt % U-235 initial enrichment 30,000 MWd/mtU maximum burnup 10 years minimum decay time following reactor discharge
Fuel Form	Intact assemblies
Quantity	52 design basis fuel assemblies
Sources of Fuel	Commercial BWR reactors

*Developed from the cask contract Statement-of-Work.

Table 5-2
DESIGN-BASIS FUEL PARAMETERS*

	PWR	BWR
Assembly Array	B&W -15 x 15	G.E.-8 x 8
Assembly Weight, lb (Nominal)	1,515	587
Fuel Assembly Length, in	165.625	175.5
Active Fuel Length, in	143	138
Number Of Fuel Rods/Assembly	208	62
Fuel Rod Diameter, in	0.430	0.483
Cladding Material	Zircaloy-4	Zircaloy-2
Cladding Thickness, in	0.0265	0.032
Pellet Diameter, in	0.3686	0.410
Pellet Material	UO_2 (Sintered)	UO_2 (Sintered)
Pellet Theoretical Density, %	95	94.5
Max. Initial Enrichment, wt % U-235	3.0	3.0
Design Basis Burnup, MWd/mtU	35,000	30,000
Weight Of Uranium, kg/Assembly	465	176.8

*Values from ORNL/TM-9591/V1 & R1 and DOE/RW-0184, Vol. 3, Appendix 2A.

Table 5-3
NUCLEAR SOURCE PARAMETERS*

	21 PWR	52 BWR
Gamma Source (Fuel Region) (γ /s)	8.177 + 16	6.867 + 16
Neutron Source (Fuel Region) (n/s)	3.370 + 9	1.442 + 9
Top End Fitting (Co-60) (γ /cc/s)	1.204 + 9	Less than PWR
Hold-down Spring (Co-60) (γ /cc/s)	1.136 + 9	-------------
Top Grid Spacer and Skirt (Co-60) (γ /cc/s)	5.683 + 9	-------------
Bottom End Fitting (Co-60) (γ /cc/s)	9.244 + 8	Less than PWR
Bottom Grid Spacer & Skirt (Co-60) (γ /cc/s)	5.683 + 9	-------------

*Values derived by design-specific analyses.

Table 5-4
SUMMARY OF DOSE RATES FOR NORMAL OPERATING CONDITIONS
21 PWR Assemblies, 3.0 wt % Enrichment, 35,000 MWd/mtU, 10-yr Cooling

Location	Point	Dose Radiation Type	Dose Rate mrem/hr
Top surface cask, axial centerline	1	Neutron	4.7
		Gamma	49.5
		Total	54.2
Axial centerline at impact limiter top	2	Neutron	0.2
		Gamma	25.7
		Total	25.9
Axial centerline at 2 m from impact limiter	3	Neutron	0.1
		Gamma	8.8
		Total	8.9
Radial surface cask opposite upper end fitting	4	Neutron	7.1
		Gamma	112.9
		Total	120.0
Radial at personnel barrier opposite upper end fitting	5	Neutron	4.7
		Gamma	43.9
		Total	48.6
Radial at 2 m from personnel barrier opposite upper end fitting	6	Neutron	1.9
		Gamma	6.9
		Total	8.8
Radial surface cask fuel midplane	7	Neutron	15.2
		Gamma	20.9
		Total	36.1
Radial at personnel barrier, fuel midplane	8	Neutron	9.3
		Gamma	13.8
		Total	23.1
Radial at 2 m from personnel barrier, fuel midplane	9	Neutron	3.8
		Gamma	5.8
		Total	9.6

Table 5-4
SUMMARY OF DOSE RATES FOR NORMAL OPERATING CONDITIONS
21 PWR Assemblies, 3.0 wt % Enrichment, 35,000 MWd/mtU, 10-yr Cooling

Location	Point	Dose Radiation Type	Dose Rate mrem/hr
Radial surface cask opposite lower end fitting	10	Neutron	7.1
		Gamma	126.7
		Total	133.8
Radial at personnel barrier opposite lower end fitting	11	Neutron	4.7
		Gamma	25.4
		Total	30.1
Radial at 2 m from personnel barrier opposite end fitting	12	Neutron	1.9
		Gamma	6.7
		Total	8.6
Bottom surface cask axial centerline	13	Neutron	4.7
		Gamma	40.2
		Total	44.9
Bottom axial centerline at impact limiter top	14	Neutron	0.2
		Gamma	20.9
		Total	21.1
Bottom axial centerline at 2 m from impact limiter	15	Neutron	0.1
		Gamma	7.2
		Total	7.3

Table 5-5
SUMMARY OF DOSE RATES FOR NORMAL OPERATING CONDITIONS
52 BWR Assemblies, 3.0 wt % Enrichment, 30,000 MWd/mtU, 10-yr Cooling

Location	Radiation Type	Dose Rate mrem/hr
Radial surface cask fuel midplane	Neutron	10.5
	Gamma	8.8
	Total	19.3
Radial at personnel barrier fuel midplane	Neutron	6.1
	Gamma	5.5
	Total	11.6
Radial at 2 m from personnel barrier, fuel midplane	Neutron	2.6
	Gamma	2.4
	Total	5.0

Figure 5-1

BR-100 Cask

Longitudinal Schematic Shielding Materials

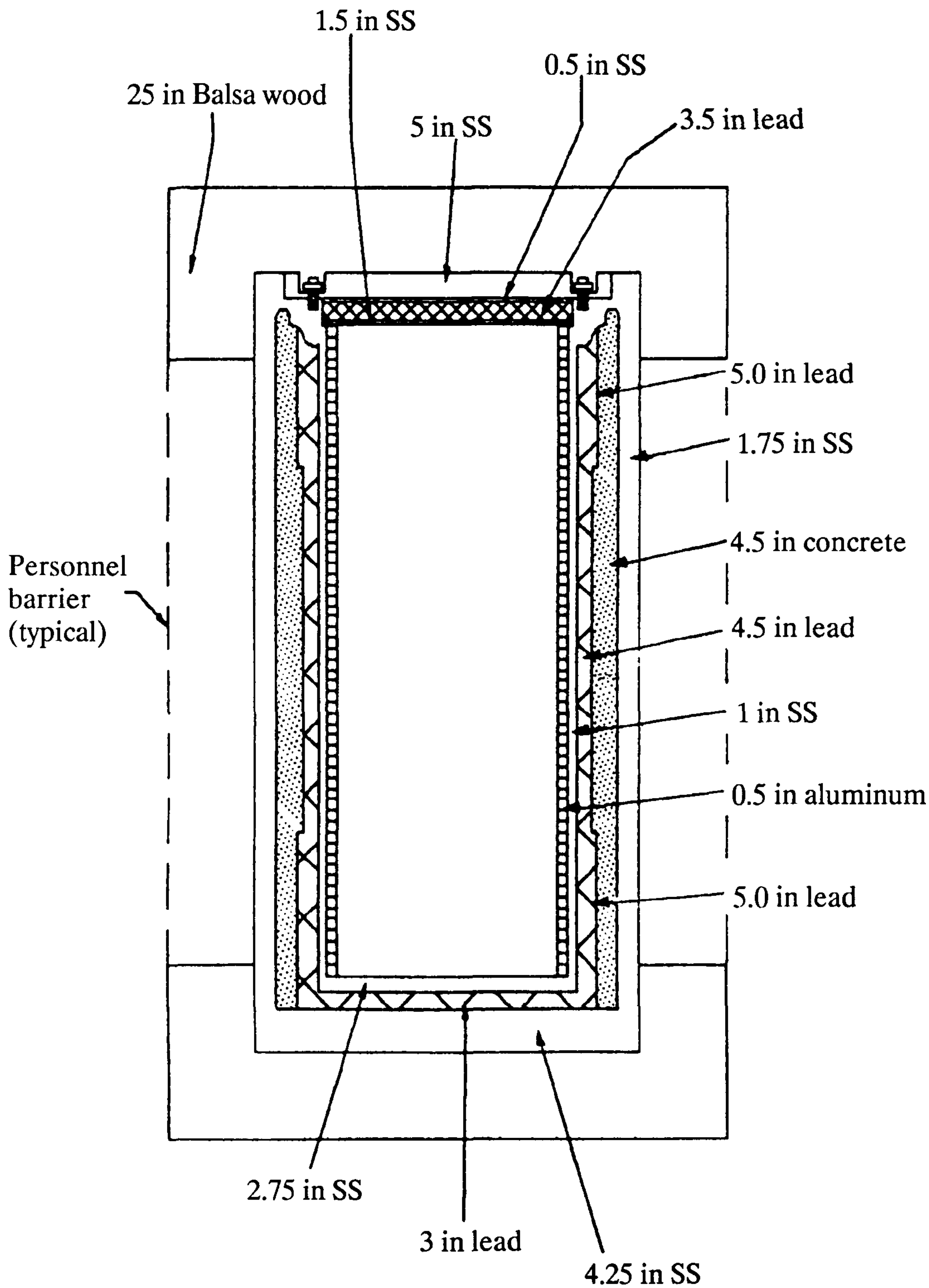


Figure 5-2
BR-100 PWR Basket and Cask Cross-Section

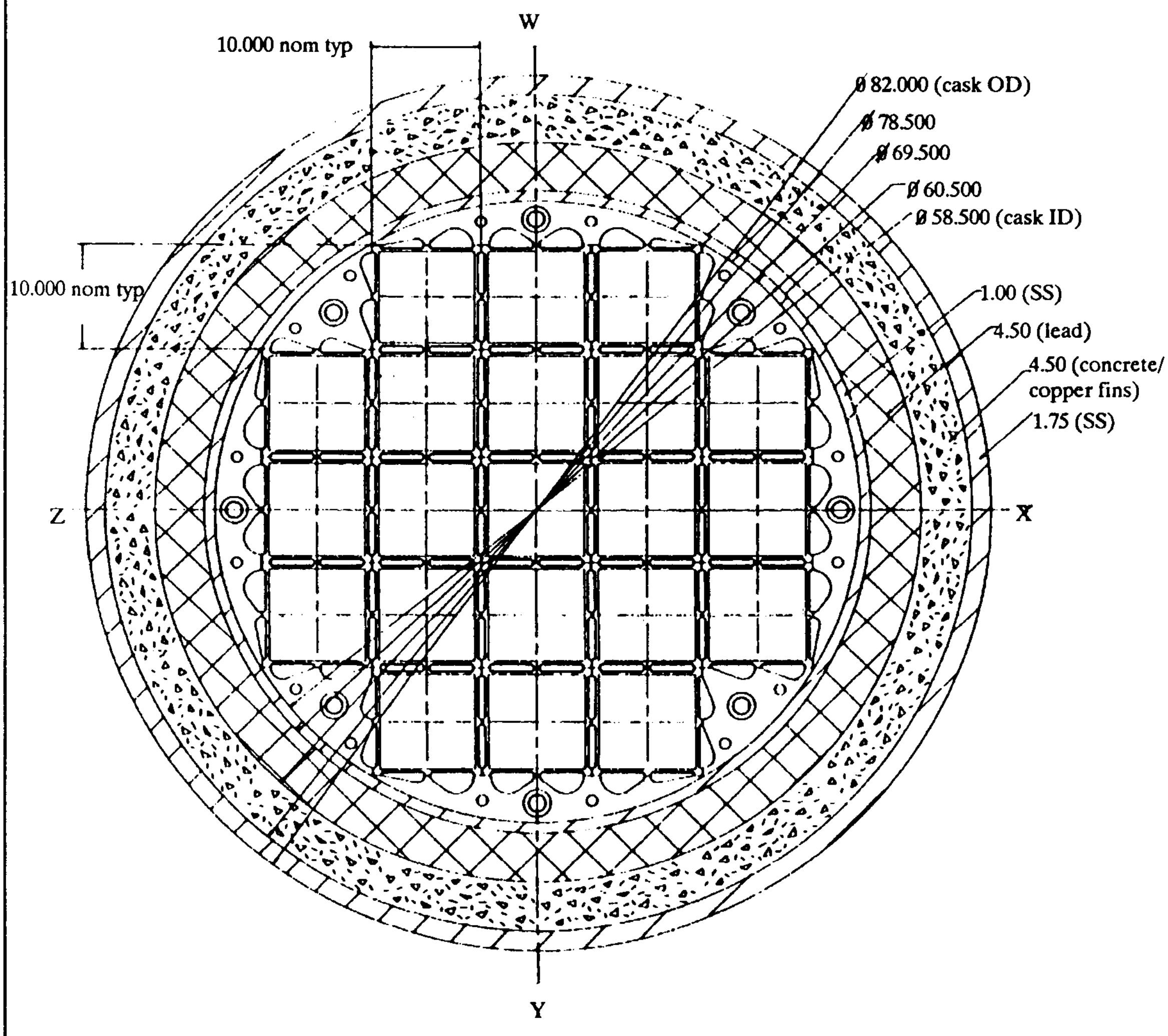


Figure 5-3

BR-100 PWR Fuel Cell Cross-Section

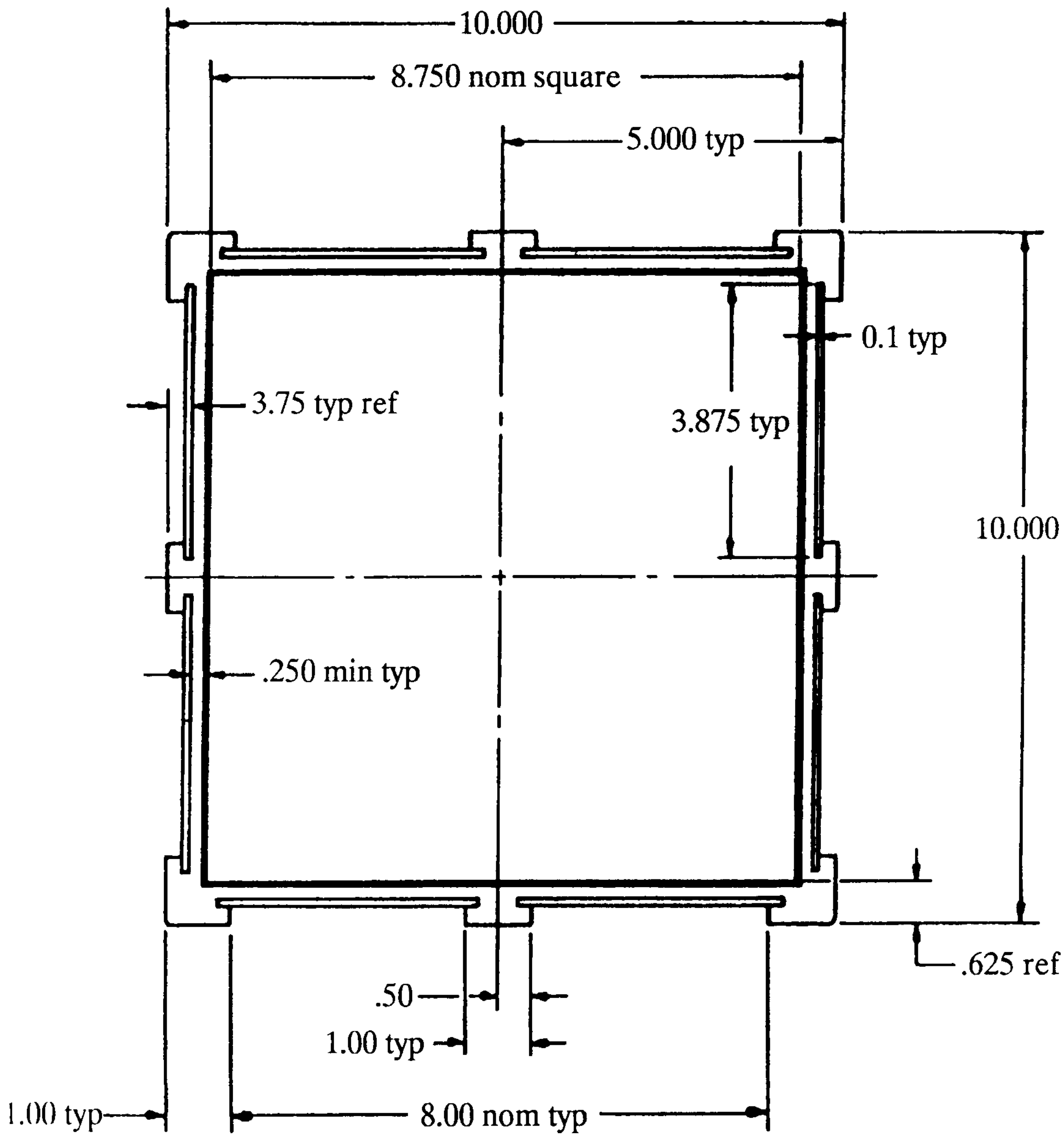
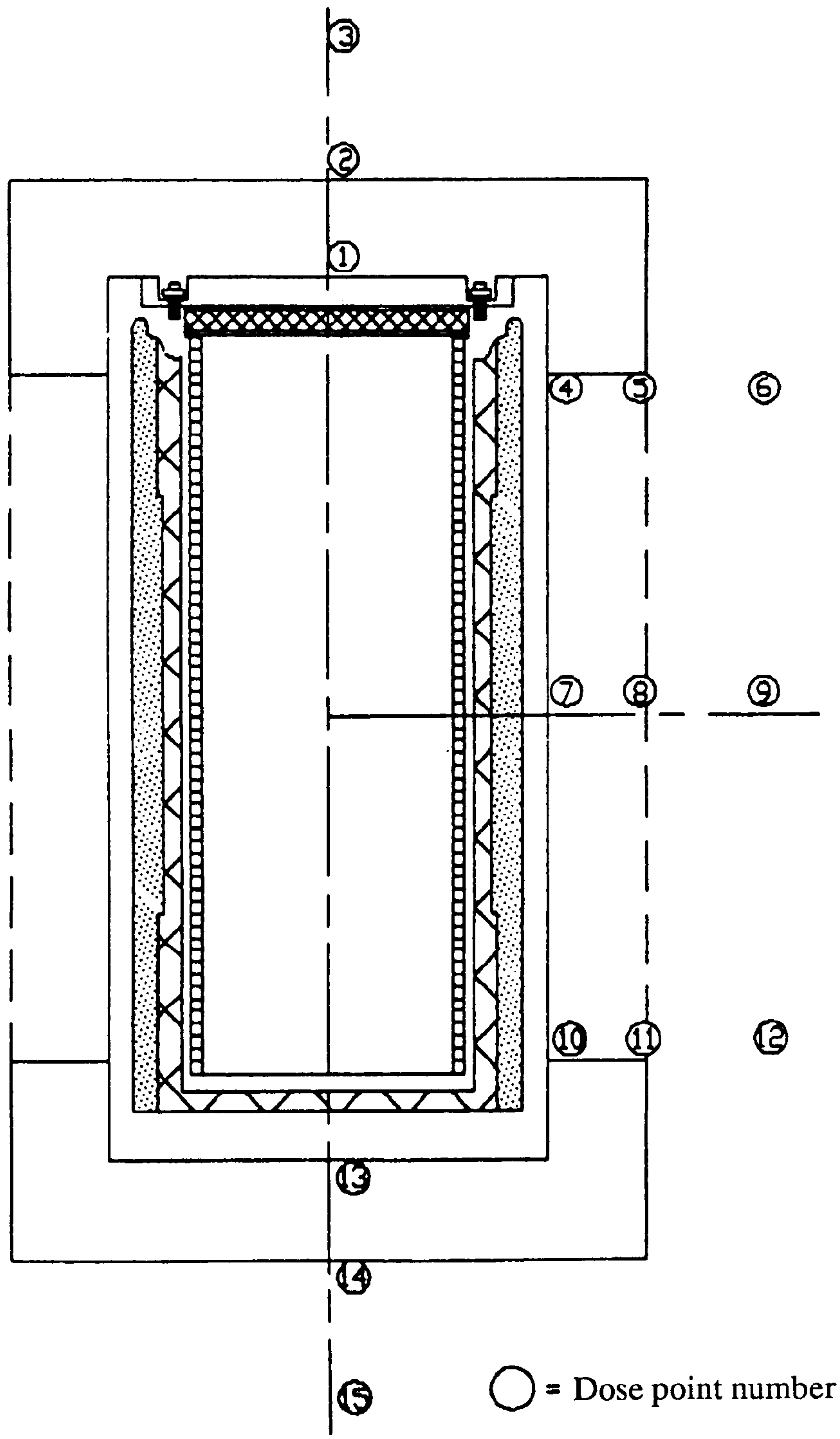


Figure 5-4

BR-100 Cask Dose Point Locations



5.2 GAMMA AND NEUTRON SOURCES

The radiation from the fuel assemblies originates from two basic sources, the active fuel region and the upper/lower structural regions. The source for the fuel region was obtained from ORIGEN2 calculations. It consists of neutron and gamma components from activation products, actinides, and fission products. The source for the structural regions is the gamma radiation from the decay of Co-60. A description of the processes used to generate these sources is provided below.

5.2.1 Fuel Rod Sources

ORIGEN2 was modeled to calculate the source for the fuel region of a typical PWR or BWR fuel assembly. The fuel region spans the active fuel height to include the fuel pellets and the cladding material. Spacer grids and instrument/guide tubes have been neglected. The PWR model was developed for a Westinghouse 17 x 17 (OFA) PWR fuel assembly with a basis of 1 kg of initial heavy metal. Thus, the source terms can be applied to PWR assemblies of different vendors merely by correction to the weight of the initial heavy metal. This is due to the similarity of component volume fractions of the various PWR fuel assemblies. For the BWR fuel assemblies, a model based upon the GE/ANF 8 x 8 fuel assembly was developed. In both cases, an enrichment of 3.0 wt % U-235 was chosen. This is the minimum enrichment required by the contract Statement-of-Work and, for a given burnup, will provide a bounding source for any higher enrichment. The ORIGEN case assumed a continuous irradiation at a constant power to the burnup desired: 35 GWd/mtU for PWR and 30 Gwd/mtU for BWR assemblies. The cross-sections used for the cases are the decay library, the UO2 Bremsstrahlung photon library, and the PWR-U 33 GWd/MTIHM or the BWR-U 27.5 GWd/MTIHM library. After the irradiation, the sources were allowed to decay ten years for the baseline condition.

ORIGEN2 provided a neutron and gamma source in terms of particles per kilogram per second. The 18 group ORIGEN2 gamma source is rebinned into the 20 group structure of the BUGLE-80 gamma cross sections. The neutron source is based upon the ORIGEN2 results for Cm-242, Cm-244, and Pu-238 for the (alpha,n) reaction and Cm-242, Cm-244, and Cm-246 for the spontaneous fission reaction. The spectra for these reactions were obtained from reference 4 and binned according to the structure of the 47-neutron group of BUGLE-80. The source is converted to particles per cc per second by applying the appropriate mass and volume parameters for the fuel assembly of interest. A factor of 1.25 is then applied to the source to account for the axial peaking factor of a fuel assembly (about 1.13) and subcritical multiplication. It is judged that the amount above 1.13 will provide sufficient margin to accommodate the subcritical multiplication. This will be explicitly considered in the final design. The PWR gamma source strengths are shown in Table 5-6 and the neutron source strengths are shown in Table 5-7. BWR gamma source strengths are shown in Table 5-8 and the neutron source strengths are shown in Table 5-9.

5.2.2 End-Fitting Region Sources

Source strengths for the stainless steel end-fittings and the Inconel 718 end spacer grids and skirts were calculated for Co-59 activation only. Other radionuclides present as activation products in those materials have short half-lives and decay relatively rapidly or emit low energy radiation that cannot penetrate the cask. Co-59 is present in quantities as high as 0.1 wt % in the end fittings and 1.0 wt % in the spacer grids. This activates to Co-60 with a 5.27 year half-life, emitting two gamma rays per decay with a mean energy of 1.25 MeV.

Because of the assumed mono-energetic decay of Co-60, hand calculations to determine source strengths in the components of interest are relatively simple, and this was the means used. Standard activation and decay equations were used with the average neutron flux in each activation region with a Maxwellian temperature correction applied to the Co-59 activation cross section. The region average flux was taken from thermal neutron flux profiles in the end fitting and spacer grid regions. The region average fluxes are given in Table 5-10. The component materials were assumed to be irradiated for five reactor cycles and were then allowed to decay for ten years. This approach is conservative since only a few fuel assemblies will ever be subjected to five full cycles at operating power. Source strengths were then homogenized for input into QAD-CGGP where discrete modelling of the Co-60 source region and shielding was performed. The homogenization factor represents the ratio of the material density in the component to the nominal density (see Table 5-10) of the material. Source region compositions and characteristics are shown in Table 5-10.

Since the PWR fuel assembly hardware is design limiting for Co-60 sources, no calculations were performed for the Co-60 dose rates for the BWR design fuel.

Table 5-6
PHOTON SOURCES FOR DESIGN-BASIS FUEL
21 PWR Assemblies with 35,000 MWd/mtU Burnup, 3.0 wt % Enrichment and 10-yr Cooling

Group	Upper Energy , MeV	Total Source, Photons/cc/s
1	14	2.093 - 1
2	10	1.046 - 1
3	8	1.366 + 0
4	7	1.366 + 0
5	6	1.185 + 1
6	5	1.185 + 1
7	4	1.202 + 3
8	3	1.461 + 5
9	2	6.544 + 6
10	1.5	5.448 + 8
11	1	3.680 + 8
12	0.8	1.840 + 8
13	0.7	2.614 + 9
14	0.6	3.979 + 9
15	0.4	3.564 + 8
16	0.2	5.414 + 8
17	0.1	7.299 + 8
18	0.06	1.417 + 9
19	0.03	7.971 + 8
20	0.02	3.686 + 9
TOTAL SOURCE		1.522 + 10

Table 5-7
NEUTRON SOURCES FOR DESIGN-BASIS FUEL
21 PWR Assemblies with 35,000 MWd/mtU Burnup, 3.0 wt % Enrichment and 10-yr Cooling

Group	Energy, MeV	n/cc/s
1	17.33-14.19	0.0
2	14.19-12.21	7.545 -2
3	12.21-10.00	6.493 -1
4	10.00- 8.60	1.003 + 0
5	8.60- 7.41	3.185 + 0
6	7.41- 6.07	9.626 + 0
7	6.07- 4.97	1.920 + 1
8	4.97- 3.69	5.021 + 1
9	3.68- 3.01	4.806 + 1
10	3.01- 2.73	2.530 + 1
11	2.73- 2.47	2.889 + 1
12	2.47- 2.37	1.241 + 1
13	2.37- 2.35	2.483 + 0
14	2.35- 2.23	1.448 + 1
15	2.23- 1.92	4.319 + 1
16	1.92- 1.65	4.198 + 1
17	1.65- 1.35	5.443 + 1
18	1.35- 1.00	7.255 + 1
19	1.00- 0.82	3.668 + 1
20	0.82- 0.74	1.753 + 1
21	0.74- 0.61	3.129 + 1
22	0.61- 0.50	2.507 + 1
23	0.50- 0.37	2.905 + 1
24	0.37- 0.30	1.508 + 1
25	0.30- 0.18	9.537 -3
26	0.18- 0.11	6.027 -3
27	0.11- 0.07	9.275 -4

Table 5-8
PHOTON SOURCES FOR DESIGN-BASIS FUEL
52 BWR Assemblies with 30,000 MWd/mtU Burnup, 3.0 wt % Enrichment and 10-yr Cooling

Group	Upper Energy , MeV	Total Source, Photons/cc/s
1	14	1.947 - 1
2	10	9.739 - 2
3	8	1.278 + 0
4	7	1.278 + 0
5	6	1.103 + 1
6	5	1.103 + 1
7	4	9.629 + 2
8	3	1.133 + 5
9	2	5.354 + 6
10	1.5	2.398 + 8
11	1	3.017 + 8
12	0.8	1.508 + 8
13	0.7	2.080 + 9
14	0.6	3.166 + 9
15	0.4	2.817 + 8
16	0.2	4.337 + 8
17	0.1	5.789 + 8
18	0.06	1.125 + 9
19	0.03	6.280 + 8
20	0.02	2.916 + 9
TOTAL SOURCE		1.191 + 10

Table 5-9
NEUTRON SOURCES FOR DESIGN-BASIS FUEL
52 BWR Assemblies with 30,000 MWd/mtU Burnup, 3.0 wt % Enrichment and 10-yr Cooling

Group	Energy, MeV	n/cc/s
1	17.33-14.19	0.0
2	14.19-12.21	7.006 -2
3	12.21-10.00	6.029 -1
4	10.00- 8.60	9.313 - 1
5	8.60- 7.41	2.956 + 0
6	7.41- 6.07	8.936 + 0
7	6.07- 4.97	1.783 + 1
8	4.97- 3.69	4.657 + 1
9	3.69- 3.01	4.443 + 1
10	3.01- 2.73	2.334 + 1
11	2.73- 2.47	2.668 + 1
12	2.47- 2.37	1.147 + 1
13	2.37- 2.35	2.295 + 0
14	2.35- 2.23	1.338 + 1
15	2.23- 1.92	3.993 + 1
16	1.92- 1.65	3.886 + 1
17	1.65- 1.35	5.044 + 1
18	1.35- 1.00	6.729 + 1
19	1.00- 0.82	3.404 + 1
20	0.82- 0.74	1.626 + 1
21	0.74- 0.61	2.905 + 1
22	0.61- 0.50	2.328 + 1
23	0.50- 0.37	2.696 + 1
24	0.37- 0.30	1.400 + 1
25	0.30- 0.18	8.034-3
26	0.18- 0.11	5.077 -3
27	0.11- 0.07	7.813 -4

5.3 MODEL SPECIFICATION

5.3.1 Description Of Radial And Axial Shielding Configuration

All shielding components of the BR-100 cask are solid materials that totally surround the spent fuel assemblies. Inside the cask cavity, an aluminum basket former fits the contour of the fuel cells (Figure 5-2). The minimum thickness of this former at the fuel assembly corner is about 1/2 in. Thus, a hollow cylinder of aluminum with that thickness was assumed in the analytical model with the remainder of the basket and cells mixed homogeneously with the fuel. This homogeneous mixture filled the source region occupying the interior volume of the hollow aluminum cylinder except for a 0.065-in layer of Cermet between the outer radius of the fuel and the inner radius of the aluminum. The Cermet layer represents the outermost layer that is present on the individual basket cells.

Figure 5-1 depicts the cask shielding configuration in both the radial and axial directions. In the radial direction, the 2.75 in of stainless steel in the cask inner and outer shell, coupled with 4.5 in of lead, provide effective gamma-ray shielding, while the 4.5 in of borated concrete provide neutron absorption and secondary gamma reduction. Radially, near the ends of the cask, the lead thickness is increased to 5 in and the concrete thickness is reduced to 4 in. The configuration was established to reduce the dose rates due to Co-60 gamma emission in the regions of the end fittings. Since neutron flux levels are lower at those elevations of the cask, the reduction of concrete thickness in those local regions presents no neutron dose rate problem.

The top of the cask is a steel/lead/steel configuration capped by a balsa-wood-cored impact limiter. The cumulative steel thickness is 7 inches, lead thickness is 3.5 in, and the balsa wood is 25 in thick.

The bottom of the cask also is a steel/lead/steel arrangement with a 7 in total steel thickness and 3 in of lead. It is also capped by a 25 in-thick Balsa wood impact limiter.

The dose points in the analytical model were located to satisfy the design requirements specified in 10CFR71. The locations of these dose points are depicted in Figure 5-4. Three dose points at each axial and radial location correspond to the cask surface, the Personnel Barrier (20.4 in from the cask surface radially and ends of the impact limiters axially), and two meters outside the Personnel Barrier.

ANISNBW with cylindrical geometry was used to calculate the radial centerline dose rates. The source model for ANISN had the design basis fuel homogenized with the basket material as described in the preceding paragraphs filling the inner cask cavity. A peaking factor of 1.13 max/avg was included in the source terms to account for the higher burnup at the fuel mid-plane (see Table 5-11). In addition, 12% was added to all dose rates calculated to account for subcritical multiplication of neutrons from the fuel in the dry cask. This was based on engineering judgment of the effect for the preliminary design. Verification of the magnitude of the subcritical multiplication will be performed in the final analyses.

Both QAD-CGGP and ANISNBW were used to determine the dose rates radially opposite the end fittings at the top and bottom of the cask. A cylindrical model in ANISN was used to calculate the neutron dose rate from the fuel while QAD with discrete geometry was used to calculate gamma dose rates from the fuel and the Co-60 in the homogenized end fittings and spacer grids. Since ANISN assumes an infinite-length source, the dose rates calculated for the cask midplane are essentially a factor of two greater than those at the top edge of the active fuel. Thus, source length correction factors of one-half were applied to the ANISN results to account for the fuel length being semi-infinite at the top and bottom sides of the cask.

The analytical models for the axial centerline dose rate calculations consisted of ANISNBW in slab geometry and QAD-CGGP in discrete geometry. Since the infinite slab source in ANISN overpredicts the dose rates, ANISN results were corrected for the finite source effect using QAD geometric factors.

5.3.2 Shield Regional Densities

Table 5-10 lists the compositions, densities, and number densities used for both the design basis PWR and BWR fuels and cask shielding materials. These values were used in the ANISN and QAD analytical models discussed in the preceding paragraphs. Density values were obtained from the Materials Handbook for BR-100 Rail/Barge Spent Fuel Cask (B&W Document 51-1174181-00) and the Handbook of Chemistry and Physics (Chemical Rubber Publishing Company). Data on Co-59 content in end fittings and spacer grids was obtained from relevant industry material specifications (primarily American Society For Testing and Materials, ASTM, standards) and is the maximum allowed in the manufacture of these components.

Table 5-10
SOURCE AND SHIELD MATERIAL COMPOSITIONS

	Element	Number Density	g/cc
PWR Fuel and Basket Region, ρ = 2.255 g/cc	U-235	1.1109-4	0.04334
	U-238	3.5466-3	1.4017
	O	7.3169-3	0.19438
	Zn	2.3203-3	0.35144
	Sn	2.4771-5	0.00488
	Fe	1.1323-5	0.00105
	Al	5.2954-3	0.2372
	N	1.9157-5	0.00045
	B-10	2.3427-4	0.00080
	B-11	9.7058-4	0.01397
	C	3.0131-4	0.00600
BWR Fuel and Basket Region, ρ = 2.571 g/cc	U-235	1.1071-4	0.04320
	U-238	3.5342-3	1.39680
	O	7.2896-3	0.19511
	Zn	2.5006-3	0.37875
	Sn	2.6697-5	0.00526
	Fe	9.0972-4	0.00084
	Al	1.1254-2	0.50411
	N	2.2840-5	0.00054
	B-10	2.3427-4	0.00080
	B-11	9.7058-4	0.0397
	C	3.0131-4	0.00600
Aluminum, ρ = 2.7 g/cc	Al	6.0244-2	2.7
Stainless Steel, 304L, ρ = 8.03 g/cc	C	1.409-4	0.00281
	Si	1.720-3	0.0802
	Ci	1.766-2	1.525
	Mn	1.759-3	0.1605
	Fe	5.842-2	5.417
	Ni	8.648-3	0.843

Table 5-10
SOURCE AND SHIELD MATERIAL COMPOSITIONS

	Element	Number Density	g/cc
Lead, ρ = 11.37 g/cc	Pb	3.2983-2	11.7
Air, ρ = 0.0012 g/cc	N	5.195-5	0.0012
B4C, ρ = 1.75 g/cc	B-10	1.4827-2	0.2466
	B-11	6.1429-2	1.1233
	C	1.9070-2	0.380
Cured Concrete (ρ = 1.90 g/cc) + 7.5% Cu (ρ = 8.89 g/cc), ρ = 2.4243 g/cc	H	4.7884-2	0.08021
	B-10	1.274-4	0.00229
	B-11	5.802-4	0.01041
	N	1.200-3	0.0279
	O	4.0899-2	1.08688
	Al	8.375-3	0.3752
	Ca	1.920-3	0.1278
	Fe	5.015-4	0.0465
	Cu	6.319-3	0.6667
Balsa Wood, ρ = 0.16 g/cc	C	3.567-3	0.071
	H	5.943-3	0.0099
	O	2.972-3	0.0789
SS Upper End Fitting + Inconel 718 Spring, ρ = 8.027 g/cc	VF SS in End Fitting = 0.241, Homo VF SS = 0.1420 VF 718 Spring = 0.0228, Homo Spring VF = 0.0134 ρ = SS = 1.1398 g/cc Homogenized ρ Inconel 718 = 0.1078 g/cc Homogenized Cobalt Content-SS = 0.1 wt % Cobalt Content-Inconel 718 = 1.0 wt % Weight SS End Fitting = 14 kg Weight-Inconel 718 Spring = 1.324 kg Region Average Thermal Neutron Flux - $2x10^{13}$ n/cm^2/s		

Continued...

Table 5-10
SOURCE AND SHIELD MATERIAL COMPOSITIONS

	Element	Number Density	g/cc
SS Lower End Fitting, ρ = 8.027 g/cc	VF SS in End Fitting = 0.200, Homo VF SS = 0.109 ρ SS = 0.8749 g/cc Homogenized Cobalt Content-SS = 0.1 wt % Weight-End Fitting = 8.17 kg Region Average Thermal Neutron Flux - $2x10^{13}$ n/cm^2/s		
End Spacer Grids, Inconel 718, ρ = 8.193 g/cc	VF Inconel 718 End Spacer Grid = 0.0335, Homo VF Inconel 718 = 0.01973 VF Zr Clad End Spacer Grid = 0.10307, Homo VF Zr Clad = 0.06073 ρ Inconel 718 = 0.16203 g/cc Homogenized ρ Zr Clad = 0.4008 g/cc Homogenized Cobalt Content-Inconel 718 End Spacer Grid = 1.0 w/o Cobalt Content-Zr Clad = Negligible Weight-End Spacer Grids = 1.36 kg Region Average Thermal Neutron Flux - $4x10^{13}$ n/cm^2/s		
Intermediate Spacer Grids, Inconel 718, ρ = 8.193 g/cc	VF Inconel 718 Intermediate Spacer Grid = 0.0511 ρ Inconel 718 Intermediate Spacer Grid = 0.4188 g/cc Cobalt Content-Inconel 718 Inter. Spacer Grid = 1.0 w/o Weight-Intermediate Spacer Grid = 0.75 kg		

5.4 SHIELDING EVALUATION

The two primary codes used in the shielding evaluation of the BR-100 rail/barge spent fuel cask were ANISNBW (Babcock & Wilcox version of ANISN-W) and QAD-CGGP.

ANISNBW is a one-dimensional discrete-ordinates-transport code that solves the Boltzmann transport equation for neutrons and/or gamma rays in slab, sphere, or cylindrical geometry. The sources may be fixed, fission, or a combination of the two. Cross-sections may be weighted using the space- and energy-dependent flux generated in solving the transport equation. ANISNBW is particularly suited to solve deep penetration problems in which angle-dependent spectra are calculated in detail due to variable dimension programming methods. The BUGLE-80 47n/20g group coupled neutron-gamma cross-section library is processed through GIP[5] to provide a working data library required as input to ANISNBW for dose rate calculations. Source input to ANISNBW was generated by ORIGEN2.

The QAD-CGGP code is a revised version of QAD-GP, which was developed at ORNL. In addition to the combinatorial geometry included in the CG version, the code contains the geometric progression (GP) fitting function. This five-parameter function is the only well-known function that can fit the buildup factor data within a few percents across the entire range of material and energy parameters. The code uses buildup factors based on Goldstein and Wilkins moments method calculations for gamma ray transport in an infinite, homogeneous medium. The buildup factor used for all shielding calculations for the BR-100 cask was for iron, which yields conservative results. QAD-CGGP is a three-dimensional point-kernel code that is widely used with good results for gamma ray dose rate calculations. Its value for neutron dose rate calculations where the moderator is absent, however, is questionable. Thus, the QAD neutron dose rates were not relied upon for BR-100 cask calculations. Source input for QAD used in modelling fuel radiation calculations was obtained from ORIGEN2 output. Sources used in QAD for Co-60 activation dose rates were derived by hand calculations using common activation and decay equations. A uniform average axial source distribution was input for the ANISN cylindrical model in the radial calculation, with a peaking factor of 1.13 applied at the fuel midplane to account for the actual fuel burnup distribution in the fuel assembly. This leads to slightly conservative results since the effect of the burnup in the axial directions is overestimated. The homogenized fuel area was extended over an inner cask radius to encompass the corners of fuel assemblies rather than the equivalent fuel cross-sectional area. This practice also leads to slight conservatism since the modelled density of the homogenized source region is less than that of the actual fuel and self-absorption is decreased.

Radially at the ends of the cask opposite the end fittings, the neutron dose rate was derived by reducing the ANISN fuel midplane values by a geometric factor to account for only one-half the fuel region. This is conservative since near the end extremities of the fuel burnup is lower and the source is also decreased as compared to fuel midplane values. The gamma ray dose rates from the fuel in these locations were calculated using QAD to model the homogenized fuel volume with the discrete shielding configuration. Added to the fuel gamma dose rate were the Co-60 gamma dose rates as calculated by discrete QAD modelling of the homogenized end-fitting region and the grid spacer and fuel skirt region.

Axially at the ends of the cask (top and bottom), the neutron dose rate was calculated using ANISN in a slab geometry. This neutron dose rate for the infinite slab geometry was then corrected by applying geometric correction factors as obtained from QAD for the actual source-shield configurations. Gamma ray dose rates at these locations were calculated by modelling the fuel, end fittings, and spacer grids in discrete QAD models. The flux-to-dose rate conversion factors for all QAD runs are found in the Radiological Health Handbook, and are tabulated in Table 5-12. The flux-to-dose conversion factors used in ANISN are based on the ANSI/ANS 6.1.1 (1977) Standard Values and are shown in tables 5-13 and 5-14.

In summary, reliable computer codes and methods have been used in the shielding calculations for the BR-100 cask. Realistic parameters have been supplied as input to the codes used with margin taken on the slightly conservative side in all cases. The dose rate at the 2-m location on the radial mid-plane is 9.6 mrem/hr, at the radial opposite the upper end fitting 8.8 mrem/hr, at the radial opposite the lower end-fitting 8.6 mrem/hr, at the top axial 8.9 mrem/hr, and at the bottom axial 7.3 mrem/hr. Hence, the dose rates are all within the limit of 10 mrem/hr as specified in 10CFR71.

Table 5-11
AXIAL SOURCE DISTRIBUTION

cm Above Bottom of Active Fuel	Relative Axial Source Strength
0.0	0.397
11.72	0.695
23.43	0.866
35.35	0.983
46.87	1.054
58.58	1.095
70.30	1.118
82.02	1.131
93.73	1.137
105.45	1.139
117.17	1.136
128.88	1.136
140.60	1.133
152.32	1.131
164.03	1.129
175.75	1.126
187.47	1.124
199.18	1.120
210.90	1.115
272.62	1.111
234.33	1.106
246.05	1.102
257.77	1.097
269.48	1.090
281.20	1.080
292.92	1.062
304.63	1.030
316.35	0.976
328.07	0.891
	Continued...

Table 5-11 (Continued)
AXIAL SOURCE DISTRIBUTION

cm Above Bottom of Active Fuel	Relative Axial Source Strength
339.78	0.763
351.50	0.592
363.22	0.330

Table 5-12
QAD GAMMA FLUX-TO-DOSE CONVERSION FACTORS

Mean Energy, MeV	Flux-to-Dose Rate, mrem/hr
1.50-2	1.25-3
2.50-2	4.0-4
3.75-2	2.0-4
5.75-2	1.25-4
8.50-2	1.33-4
0.125	1.78-4
0.225	4.00-4
0.375	7.14-4
0.575	1.11-3
0.850	1.54-3
1.25	2.17-3
1.75	2.86-3
2.25	3.45-3
2.75	4.00-3
3.50	4.54-3
5.00	5.88-3
7.00	7.14-3
11.00	1.00-2

Table 5-13
ANISN GAMMA -RAY DOSE CONVERSION FACTORS

Average Energy, MeV	Dose Conversion Factor, (rem/hr)/Flux
1.20000E+01	1.10197E-05
9.00000E+00	8.77164E-06
7.50000E+00	7.66257E-06
6.50000E+00	6.92649E-06
5.50000E+00	6.19049E-06
4.50000E+00	5.41358E-06
3.50000E+00	4.62198E-06
2.50000E+00	3.71397E-06
1.75000E+00	2.92697E-06
1.25000E+00	2.31552E-06
9.00000E-01	1.83255E-06
7.50000E-01	1.60381E-06
6.50000E-01	1.44170E-06
5.00000E-01	1.17228E-06
3.00000E-01	7.53169E-07
1.50000E-01	3.83460E-07
8.00000E-02	2.64933E-07
4.50000E-02	3.48724E-07
2.50000E-02	8.27235E-07
1.50000E-02	2.14817E-06

Table 5-14
ANISN NEUTRON DOSE CONVERSION FACTORS

Average Energy, MeV	Dose Conversion Factor, (rem/hr)/Flux
1.52279E+01	2.12595E-04
1.29850E+01	1.92715E-04
1.08413E+01	1.59897E-04
8.60710E+00	1.47056E-04
7.40820E+00	1.47056E-04
6.58903E+00	1.48674E-04
5.44964E+00	1.53866E-04
4.23225E+00	1.48038E-04
3.31867E+00	1.36953E-04
2.86287E+00	1.30589E-04
2.59565E+00	1.26507E-04
2.41464E+00	1.25243E-04
2.35550E+00	1.25418E-04
2.28736E+00	1.25623E-04
2.06968E+00	1.26328E-04
1.78161E+00	1.27390E-04
1.49740E+00	1.28637E-04
1.17098E+00	1.30426E-04
9.09907E-01	1.25469E-04
7.80876E-01	1.16069E-04
6.72598E-01	1.07601E-04
5.50780E-01	9.72325E-05
4.29479E-01	8.08194E-05
3.31582E-01	6.39791E-05
2.35618E-01	4.69679E-05
1.44242E-01	3.01733E-05
8.74861E-02	1.95532E-05
5.27979E-02	1.31891E-05
3.61672E-02	9.78376E-06
	Continued...

Table 5-14 (Continued)
ANISN NEUTRON DOSE CONVERSION FACTORS

Average Energy, MeV	Dose Conversion Factor, (rem/hr)/Flux
2.88276E-02	8.19629E-06
2.50982E-02	7.35221E-06
2.30025E-02	6.86530E-06
1.81809E-02	5.71630E-06
1.12265E-02	3.91041E-06
4.74103E-03	3.57877E-06
2.27490E-03	3.64572E-06
8.27098E-04	3.78553E-06
3.10270E-04	3.95962E-06
1.47691E-04	4.10469E-06
6.15995E-05	4.27255E-06
2.05153E-05	4.45537E-06
7.57852E-06	4.55832E-06
2.68428E-06	4.56838E-06
1.24843E-06	4.49212E-06
5.94338E-07	4.34230E-06
1.97337E-07	3.97557E-06
1.00000E-11	3.67484E-06

5.5 REFERENCES

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2. RISC-CCC-493, ORNL, July 1986, "QAD-OGGP - A Combined Geometry Version of QAD-P5A, A Point Kernel Code System for Neutron and Gamma-Ray Shielding Calculations Using the GP Buildup Factor."
3. Radiation Shielding Information Center, NPGD-TM-491, September 1987, "ANISNBW - A One-Dimensional Discrete Ordinates Transport Code, B&W Version of ANISN-W."
4. J. A. Bucholz, "Scoping Design Analysis For Optimized Shipping Casks containing 1-, 2-, 3-, 5-, or 10- Year-old PWR Spent Fuel," ORNL/CSD/TM/-149 TTC-0316, Jan. 1983
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6.0 CRITICALITY EVALUATION

6.1 DISCUSSION AND RESULTS

The BR-100 Cask is designed to hold 21 PWR or 52 BWR intact fuel assemblies with the basket configurations shown in figures 6-1 and 6-2. Criticality control for these configurations is maintained by a combination of geometry, fixed poison, and burnup credit. The PWR fuel cell (21 such cells constitute the PWR basket) supports the fuel assemblies in a regular array with a 10-in pitch. A significant criticality feature of this cell is the space provided between adjacent cells. Two 0.1-in B_4C Cermet poison plates are positioned on either face of the space (see Section 1.2.1.3 for a description of the Cermet). With this arrangement, a 0.55-in water gap is provided between the plates during the flooded accident condition to increase their effectiveness. However, the combination of the geometry and fixed poison alone are not sufficient for criticality control in the PWR basket. A fuel assembly burnup credit of 18 GWd/mtU is also required to satisfy the criticality criterion requiring a k_{eff} less than 0.95. For the BWR basket, the criticality criterion can be met with the fixed poison plates positioned between the fuel cells but with neither a water gap nor burnup credit required. The PWR basket will accommodate between 10 and 15 consolidated fuel canisters due to the 100-ton hook weight limit; with this reduced payload, it is judged that a checkerboard loading would make burnup credit unnecessary for criticality control.

A detailed model of the radial dimensions of the PWR fuel assembly cask was prepared. This model was used in KENO-IV[1] analyses of the cask under normal, dry conditions, and for a flooded accident condition. The analytical model was based upon: 1) uranium oxide fuel enriched to 4.5 wt % U-235 exposed to a burnup of 16 GWd/mtU, 2) intact Westinghouse 17x17 fuel assembly parameters without assembly structural materials, 3) a homogenous fuel region represented by spatially self-shielded cross sections with U-238 resonance self-shielded, 4) nominal basket and cask radial dimensions, 5) infinite axial dimension, and 6) an infinite array of water-filled casks for the flooded accident condition. For the nominal dry, single cask a maximum k_{eff} of 0.367 was obtained for fresh fuel. For the flooded case, the maximum k_{eff} with burnup credit was calculated as 0.932. A similar explicit geometry case was generated for the BWR cask configuration. As noted, neither the water gap nor burnup credit was required. For the flooded case, the maximum k_{eff} with fresh BWR fuel was found to be 0.865. No case was executed with consolidated fuel canisters placed in the PWR basket arrangement. Based upon the hook weight constraint, the cask will be limited to a maximum of 15 fuel canisters. The reduced number of canisters allows use of a checkerboard configuration, with special inserts if necessary. This arrangement will effectively increase the water gap between canisters and should remove the need for burnup credit to meet the criticality criterion.

The analyses for the preliminary design indicate that the PWR basket will meet the criticality criterion with allowance for burnup credit. Analyses for the BWR configuration show it will satisfy the criterion without using burnup credit. Engineering judgment indicates that burnup credit will not be needed for loading consolidated canisters into a checkerboard-configured PWR basket. However, there is a lacuna in the analyses that must be filled for the final design. Future cask analyses will consider fabrication tolerances, off-center fuel assembly placements, accident deformations, and axial details for the three basic contents/basket arrangements. In addition, studies on axial burnup effects will be required. The results of these analyses/studies will ensure conformance with the criticality criterion for all cask loadings and conditions.

Figure 6-1
BR-100 PWR Basket and Cask Cross-Section

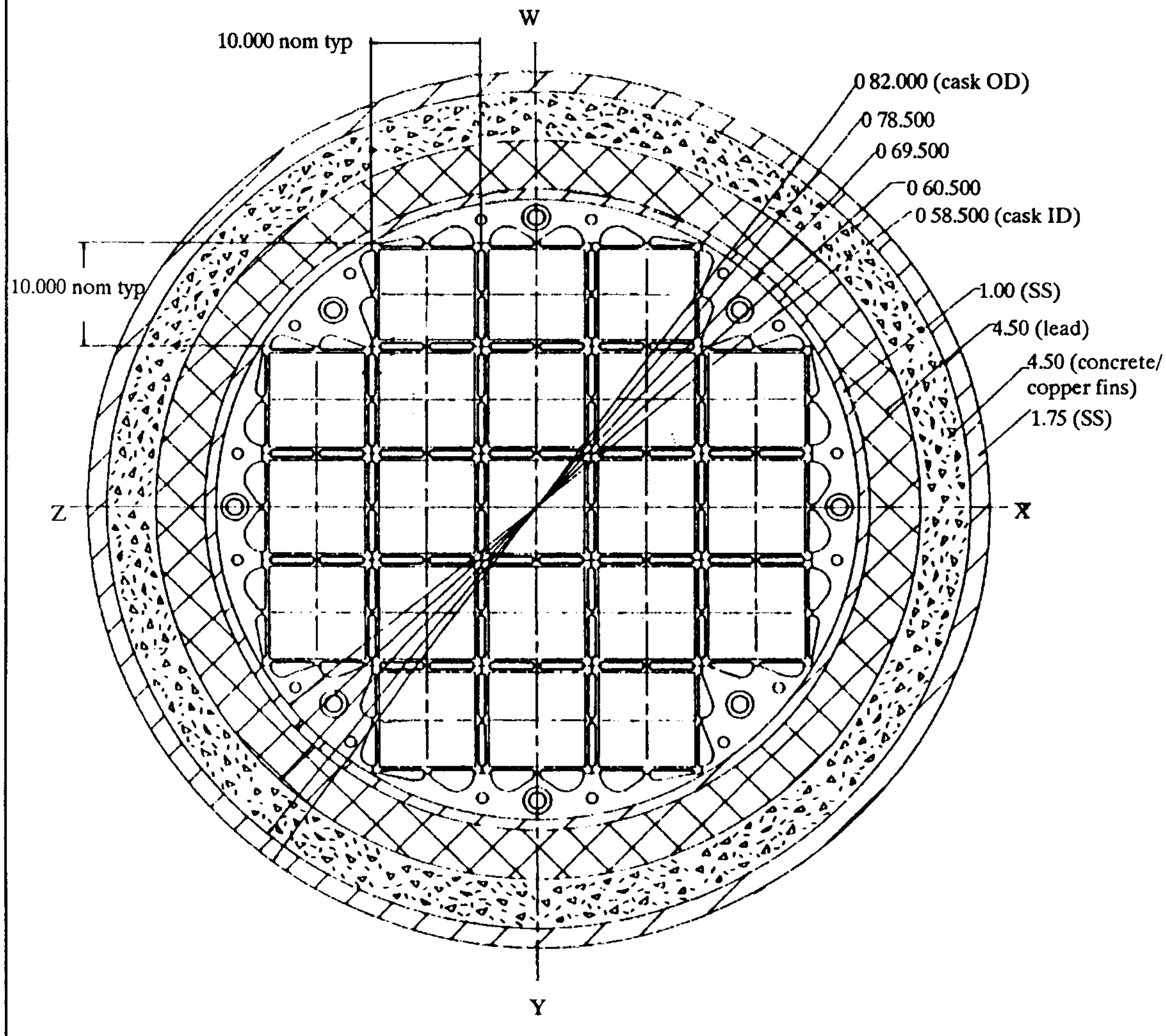
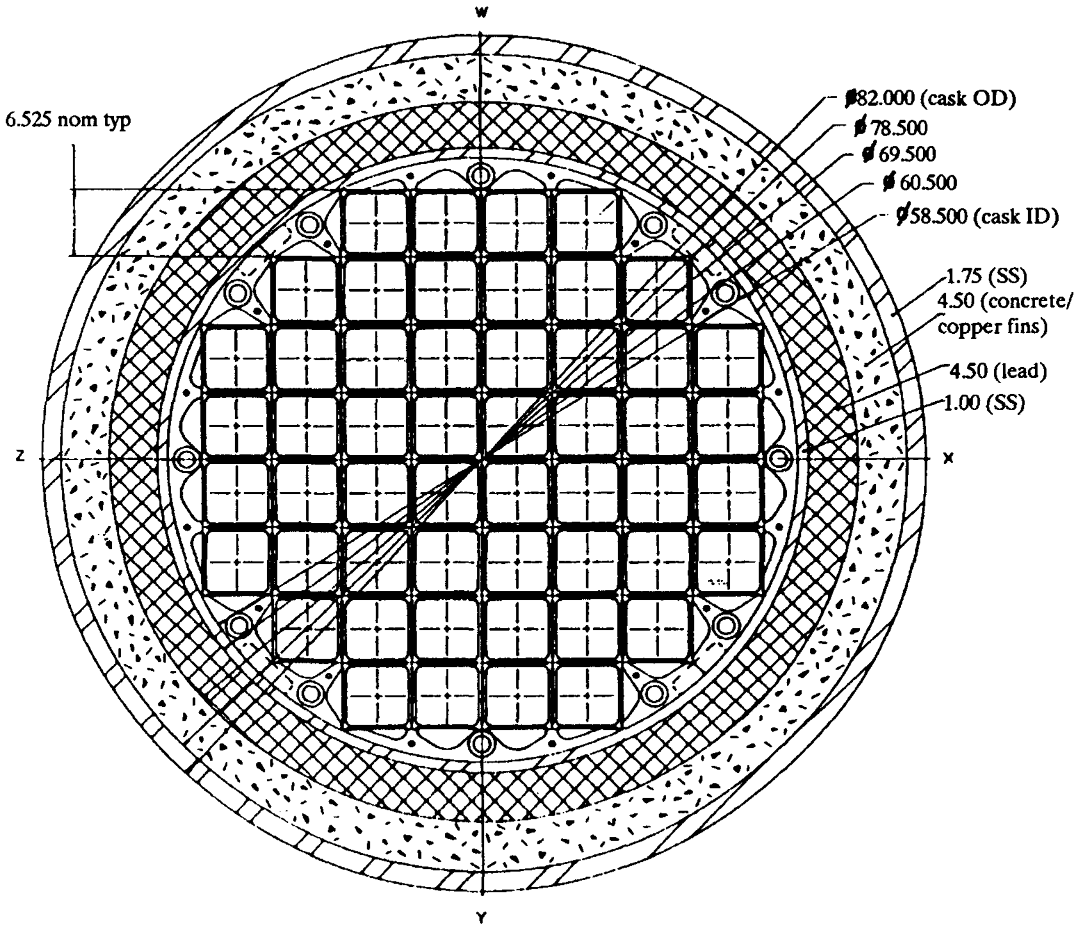


Figure 6-2

BR-100 BWR Basket and Cask Cross-Section



6.2 PACKAGE FUEL LOADING

The BR-100 cask was designed to transport 21 PWR or 52 BWR fuel assemblies. Up to 15 consolidated fuel canisters can be transported in the PWR basket configuration; the exact number depends on the consolidation ratio and the canister weight. The characteristics of the three fuel types are provided in Table 6-1.

For the PWR analysis, the Westinghouse 17 x 17 fuel assembly was found to represent the most reactive configuration by infinite pin cell calculations using the NULIF[2] code. It was used in the analysis to bound all other PWR fuel assemblies that could be placed in the cask. For PWR fuel assemblies, a minimum average burnup of 18 GWd/mtU is required to satisfy the criticality criterion. For the analysis, an average burnup of 16 GWd/mtU was used to cover axial burnup effects. The ORIGEN2 code[3] was used to generate the burnup isotopics for PWR fuel with an initial U-235 enrichment of 4.5 wt % with a minimum decay period of ten years. Table 6-2 presents the isotopes and their respective number densities within a fuel rod. These data were used as the basis for the PWR analyses with burnup credit. Table 6-2 includes two gaseous isotopes, Xe-135 and Kr-85, and the potentially volatile isotopes Cs-133 and Cs-135. The current model did not include the release fraction of these isotopes from the fuel pellets. While the majority of these isotopes will remain entrained in the pellet, this slight non-conservatism is acknowledged. The release rates will be factored into the final design analysis but should cause an increase in k_{eff} less than 0.005.

For the BWR fuel assembly analyses, the ANF 8 x 8 JP-4,5 fuel assembly was assumed to represent a bounding assembly. A fresh assembly without gadolinium was modeled. No axial or radial zone loading was included so that an average enrichment of 4.5 wt % U-235 was assumed for the assembly. Table 6-3 lists the heterogeneous fuel number densities. As mentioned, the gadolinium poison that is contained in essentially all BWR fuel assemblies for this enrichment is ignored in the analyses. Thus, there is some inherent conservatism in the model.

The consolidated fuel canisters are assumed to have an external square dimension equivalent to that of a PWR fuel assembly. Based upon hook weight constraints and the consolidation ratio, about 10 to 15 canisters can be accommodated in the cask. With the use of a checkerboard loading pattern, it is expected that burnup credit will not be required to satisfy the criticality criterion for consolidated fuel canisters.

Table 6-1
FUEL CHARACTERISTICS

Parameter	PWR	BWR	Consolidated
Assembly rod array	17 x 17	8 x 8	1.3-2:1 ratio
Active fuel length, in	144	138	144
Fuel rods/assembly	264	62	343-528
Fuel rod diameter, in	0.36	0.483	0.36
Cladding material	Zirc-4	Zirc-2	Zirc-4
Cladding thickness, in	0.0225	0.032	0.0225
Pellet diameter, in	0.3088	0.41	0.3088
Fuel cell pitch, in	0.496	0.641	Variable
Pellet material	UO_2 (Sintered)	UO_2 (Sintered)	UO_2 (Sintered)
Maximum initial enrichment, wt % U-235	4.5	4.5	4.5
Design basis burnup, GWd/mtU	35	30	35
Initial uranium weight, kg/assembly	423.2	176.8	550-846

Table 6-2
BURNUP ISOTOPICS FOR 16 GWd/mtU TEN-YEAR DECAYED PWR FUEL

Isotope	Fuel Rod Number Density, Atoms/barn-cm
U-235	7.2304-4[a]
U-238	2.1764-2
U-234	6.7619-6
U-236	5.7834-5
NP-237	2.2236-6
PU-238	1.7133-7
PU-239	7.6051-5
PU-240	1.3217-5
PU-241	2.7398-6
PU-242	3.5567-8
O-16	4.4974-2
SM-149	9.8861-8
RH-103	1.0474-5
ND-143	1.6360-5
XE-131	8.6424-6
GD-155	7.0734-8
SM-151	3.4821-7
CS-133	2.0403-5
TC-99	1.8309-5
SM-152	1.8882-6
SM-147	5.1201-6
ND-145	1.1581-5
EU-153	8.9807-7
MO-95	1.9139-5
SM-150	3.4609-6
RU-101	1.6290-5
AG-109	6.9021-7
KR-83	1.4943-6
PR-141	1.8058-5
	Continued...

Table 6-2
BURNUP ISOTOPICS FOR 16 GWd/mtU TEN-YEAR DECAYED PWR FUEL

Isotope	Fuel Rod Number Density, Atoms/barn-cm
CS-135	6.8351-6
LA-139	1.9809-5

[a] Read as 7.2304×10^{-4}

Table 6-3
FUEL ROD NUMBER DENSITIES FOR BWR FUEL

U-235	1.0131-3
U-238	2.1229-2
O-16	4.4484-2

6.3 MODEL SPECIFICATION

For the preliminary design, a detailed model was developed for both the PWR and BWR basket configurations. These are described in this section. For consolidated fuel, no explicit calculations have been made; however, a brief description of the planned model is provided.

6.3.1 Description of Calculational Model

The normal operation of the cask includes either underwater loading in a storage pool or shipment in a dry condition. The hypothetical accident condition includes the addition of pure, unborated water to the cask. The accident condition provides the most reactive configuration. Thus, all limiting analyses are performed with water in the basket region. In addition, the basic model assumes an infinite array of water-filled casks in an air medium.

6.3.1.1. PWR KENO-IV Model

The analysis of the BR-100 utilized the generalized geometry option of the KENO-IV code to generate the basic geometry model of the cask. This option enables a very detailed description of the actual geometry that requires only minor assumptions. Figure 6-1 provides a cross-sectional view of the BR-100 shipping cask. The evident radial quarter-cask symmetry allows an analytical model consisting of an explicit description of only one quarter of the cask in the radial direction. Reflective boundary conditions on the inner faces of the cask produce the other quadrants. The current model assumes an infinite axial dimension; however, future models will provide explicit axial detail. The fuel cell model is nearly identical to the actual cell arrangement (see Figure 6-3). The only two assumptions are: 1) complete contact between the Cermet plate and the walls of the fuel cell; i.e., no gaps included for plate insertion, and 2) increasing the rib of the extruded aluminum cell from the minimum 0.25 in to 0.275 in. The latter assumption was made to model the minimum 0.5-in water gap between Cermet plates rather than the nominal 0.55-in gap. Figure 6-4 provides a sketch of the fuel cell model. (Note: It is not to scale. The Cermet plate thickness has been increased for clarity.) Comparison of this figure with Figure 6-3 shows the close agreement between the model and the actual fuel cell. The total model of the fuel basket region is constructed of quarter, half, and complete sections of this basic fuel cell unit. The basket former region, i.e. the support area between the fuel cell array and the cask body, was modelled with a minor simplification. The "tear-drop" water holes adjacent to the fuel cells (see Figure 6-1) were modelled as half-ellipses with a cross-section area equivalent to that for the respective "tear-drop" region. Figure 6-5 illustrates the former region along the diagonals of the fuel cell region as well as the model of the cask body. Note that the holes for the tie rods and the tie rods were neglected, so this model should be conservative in that water is removed from the system. The fuel assembly is modelled as a homogeneous mixture of uranium pellets, cladding, and water. The cross-sectional area of a Westinghouse 17 x 17 assembly represents the region over which the fuel rods, guide tubes, and instrument tubes are homogenized. The homogeneous number densities of the 16 GWd/mtU burned fuel are provided in Section 6.3.2.1. The current model assumes that the only result of the accident is the introduction of water at 50°F into the fuel region. However, the minimum gap of 0.5 in is expected to survive the accident. The homogenized region was assumed to be centered in the fuel cell for the preliminary analyses.

This model is the basic one used for the preliminary analyses of the PWR basket configuration. Future models will either evaluate or include tolerances, off-center fuel assembly placement, and maximum deformations due to the hypothetical accident.

6.3.1.2 BWR KENO-IV Model

The evaluation of the k_{eff} of the BWR configuration also utilized a generalized geometry model of the cask. Quarter-cask symmetry in the radial dimension (see Figure 6-2) was assumed with an infinite axial dimension. Figure 6-6 depicts the actual fuel cell, while Figure 6-7 provides a sketch of the KENO-IV model. The primary assumption was squaring off the dovetail slot for the Cermet plates. The BWR fuel assembly was modeled as a homogeneous mixture of fuel pellets, cladding, tie rods, and water. Since the spacer grids and channel were neglected, this assumption should be conservative. As with the PWR former region, the "tear-drops" in the BWR former region (see Figure 6-2) were approximated by half-ellipses. The complete KENO-IV model of the cask was composed of 13 fuel cells surrounded by the former region and cask body. The region outside of the cask was assumed to be filled with air. Reflective boundary conditions on the inner surfaces expanded the model to that of the full cask. Reflective boundary conditions were also used on the exterior of the cask body. This provides an infinite array of water filled casks immersed in air.

Future analyses will provide axial detail, including the blanket regions above and below the active fuel region. These analyses will determine the effects of fabrication tolerances, off-center fuel assembly placement, and actual deformations due to the hypothetical accident.

6.3.1.3 Consolidated Fuel Model

Future analyses will include a model of the consolidated canister in the PWR shipping cask model. A optimized fuel model of the rods in the canister will be developed to provide the most reactive configuration for the canister. The homogeneous fuel model, placed inside the canister structure, will be inserted in the PWR KENO-IV model based on projected loading arrangements. The type of analyses performed for the intact PWR and BWR fuel assemblies will be repeated for the loadings with consolidated canisters. Various checkerboard loading schemes will be examined to determine which provides the least reactive system. The initial analysis will assume fresh fuel is placed in the canisters. A checkerboard loading scheme is expected to be found that will produce a cask k_{eff} with this assumption. If the reactivity criterion cannot be met with fresh fuel, burnup credit will be examined.

6.3.2 Package Regional Densities

The densities used in the criticality analyses are:

Material	Density, g/cc
UO_2	
PWR	10.31
BWR	9.98
Zircalloy	6.56
H_2O	1.00
SS-304	8.03
Iron	5.444
Chromium	1.526
Nickel	0.803
Manganese	0.1606
Silicon	0.0803
Nitrogen	0.0080
Others	0.008
Lead	11.34
Aluminum	2.71
Robatel Concrete	1.52
Oxygen	0.9008
Aluminum	0.3903
Calcium	0.1304
Iron	0.0423
Hydrogen	0.0378
Boron	0.0106
Others (neglected)	0.0106
Copper	8.94
Cermet	2.60

6.3.2.1 PWR Fuel Region

Fuel rod number densities for the flooded condition for 4.5 wt % fresh fuel are listed below:

Material	Density, atoms/barn-cm
UO_2	
U-235	1.0458-3
U-238	2.1914-2
O-16	4.5919-2
Zirc-2	
Zr	4.2568-2
Sn	4.6593-4
Fe	1.4856-4
Cr	7.5982-5
Water	
H	6.6854-2
O	3.3427-2

Homogeneous number densities for the fuel assembly in the flooded condition with 16 GWd/mtU burnup are listed in Table 6-4.

Table 6-4
PWR 16 GWd/mtU HOMOGENEOUS NUMBER DENSITIES

Material	Density, atoms/barn-cm
U-235	2.0106-4[a]
U-238	6.0520-3
U-234	1.8803-6
U-236	1.6082-5
NP-237	6.1833-7
PU-238	4.7643-8
PU-239	2.1148-5
PU-240	3.6753-6
PU-241	7.6188-7
PU-242	9.8903-9
SM-149	2.7491-8
RH-103	2.9125-6
ND-143	4.5494-6
XE-131	2.4032-6
GD-155	1.9669-8
SM-151	9.6830-8
CS-133	5.6735-6
TC-99	5.0912-6
SM-152	5.2505-7
SM-147	1.4238-6
ND-145	3.2203-6
EU-153	2.4973-7
MO-95	5.3220-6
SM-150	9.6240-7
RU-101	4.5298-6
AG-109	1.9193-7
KR-83	4.1552-7
PR-141	5.0216-6
CS-135	1.9007-6
	Continued...

Table 6-4 (Continued) PWR 16 GWd/mtU HOMOGENEOUS NUMBER DENSITIES	
Material	**Density, atoms/barn-cm**
LA-139	5.5084-6
Zr	4.1151-3
Sn	4.0381-5
Fe	1.2875-5
Cr	6.5850-6
H	4.1045-2
O	3.3029-2

[a]Read as 2.0106 x 10^{-4}

6.3.2.2 BWR Fuel Region

Fuel rod number densities for the flooded condition for 4.5 wt % fresh fuel are:

Material	Density, atoms/barn-cm
UO_2	
U-235	1.0131-3
U-238	2.1229-2
O-16	4.4484-2
Zirc-2	
Zr	4.2568-2
Sn	4.6593-4
Fe	1.4856-4
Cr	7.5982-5
Water	
H	6.6854-2
O	3.3427-2

Homogeneous number densities for the fuel assembly in the flooded condition for 4.5 wt % fresh fuel are listed below:

Material	Density, atoms/barn-cm
U-235	3.1536-4
U-238	6.6082-3
Zr	5.2489-3
Sn	5.7456-5
Fe	1.8318-5

Material	Density, atoms/barn-cm
Cr	9.3692-6
H	3.6876-2
O	3.2285-2

6.3.2.3 Consolidated Region

The number densities for the consolidated canisters will be determined at a later date. They will be based upon the optimum moderation of rods in the canister. No burnup credit is expected to be required; thus, fresh fuel parameters will be used with an enrichment of 4.5 wt % U-235.

Figure 6-3
BR-100 PWR Fuel Cell

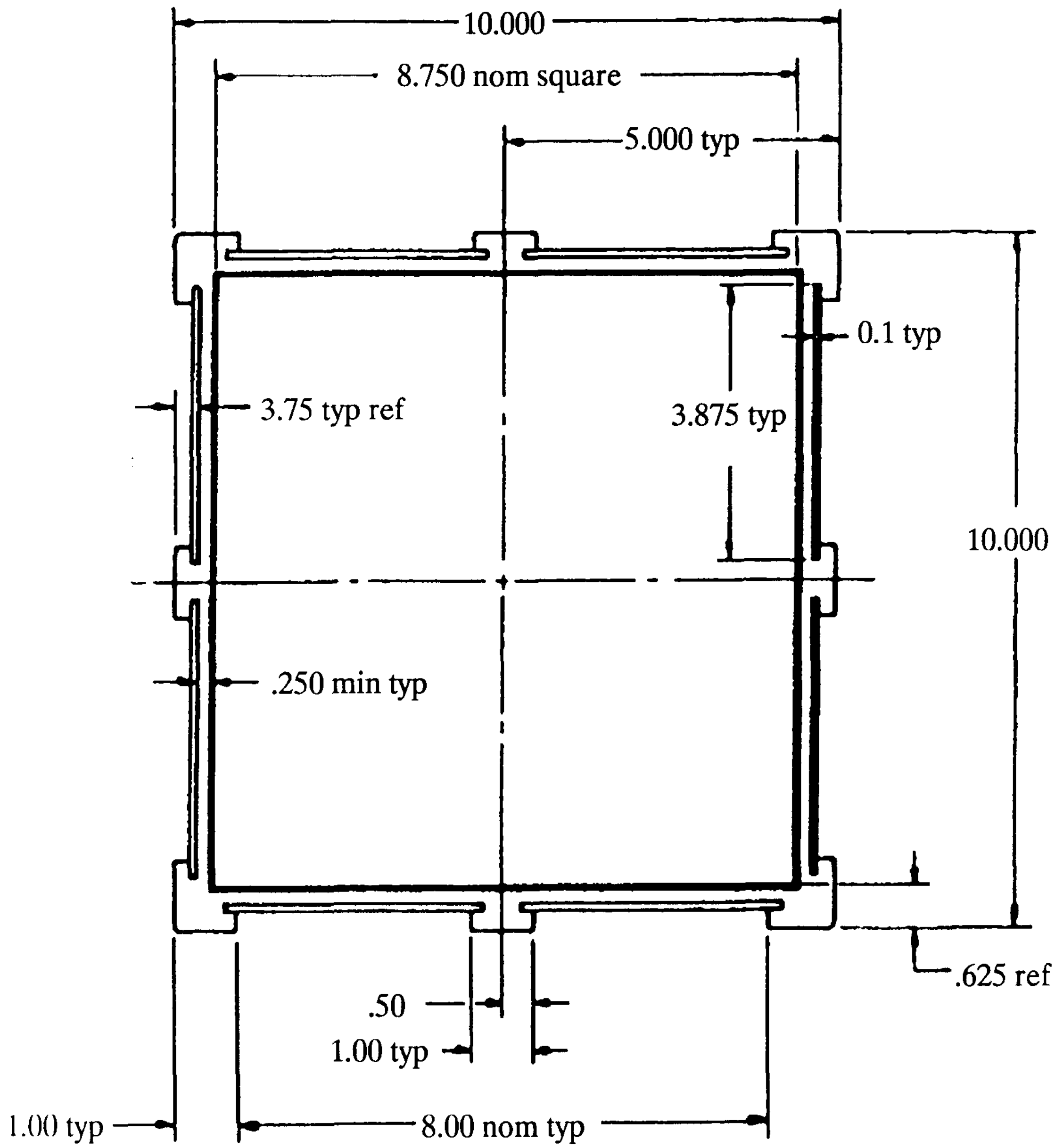


Figure 6-4
PWR Fuel Cell Model

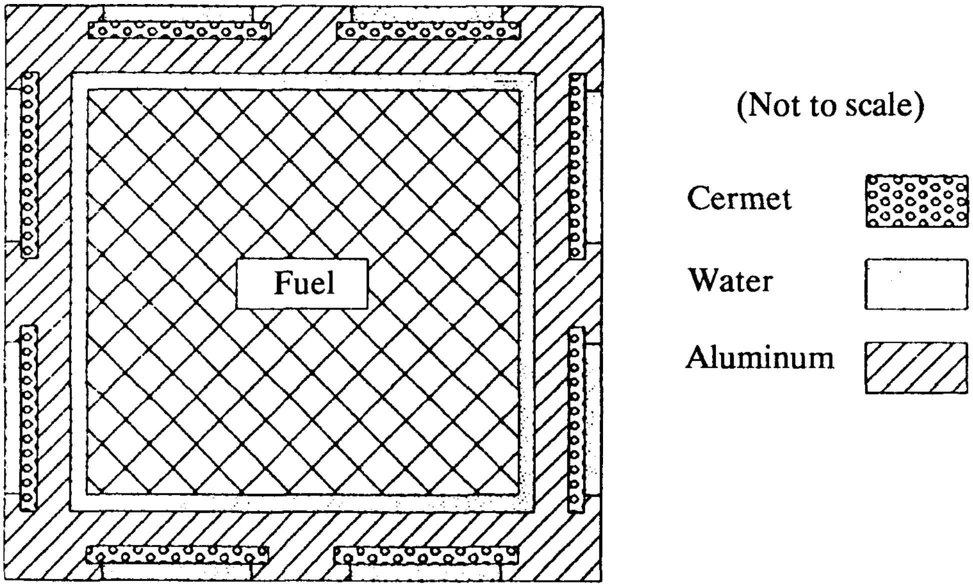


Figure 6-5
Ellipsoidal Approximation in Former Region

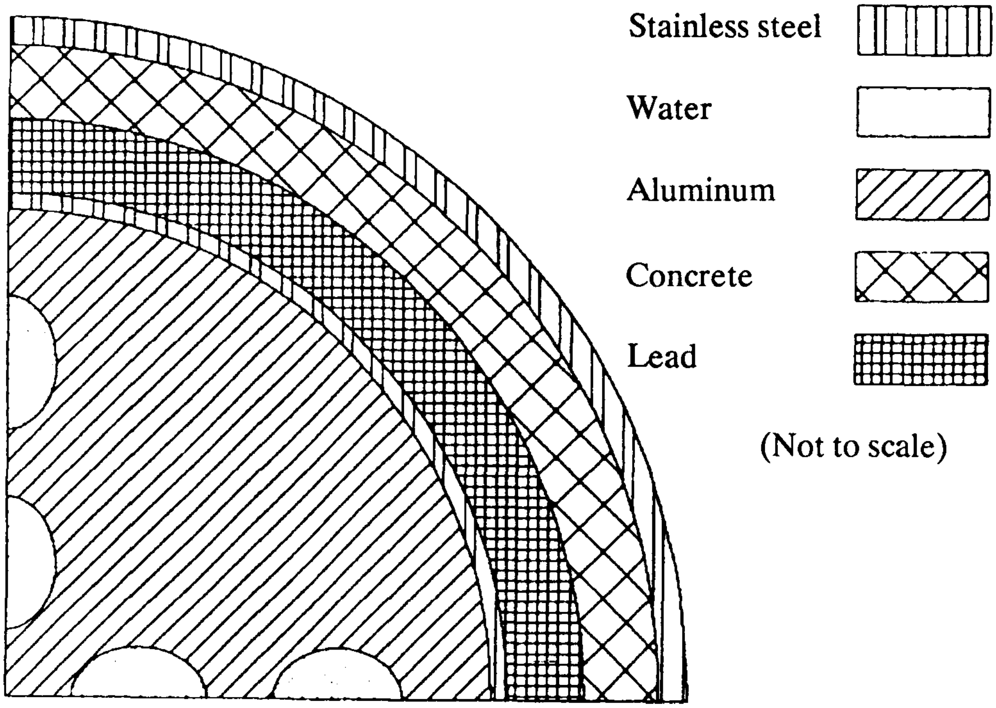


Figure 6-6
BWR Fuel Cell

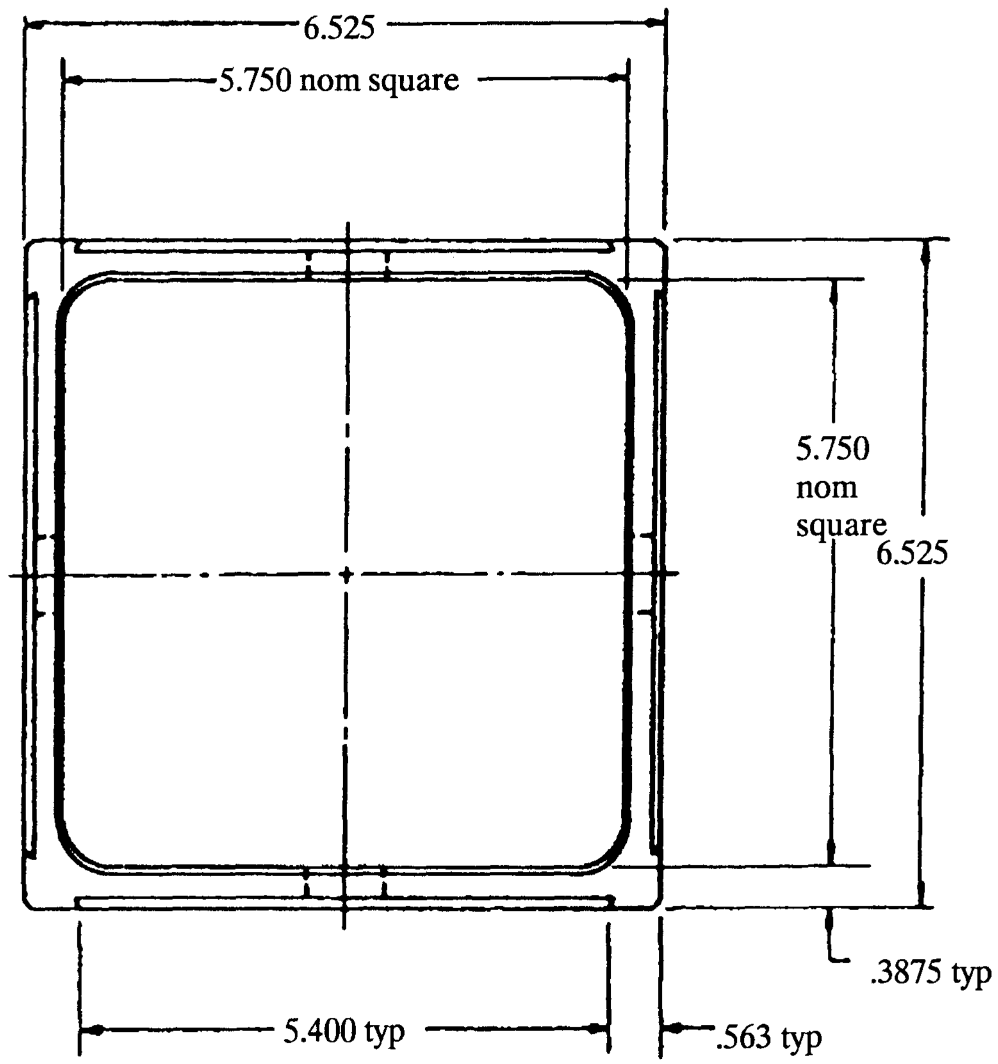
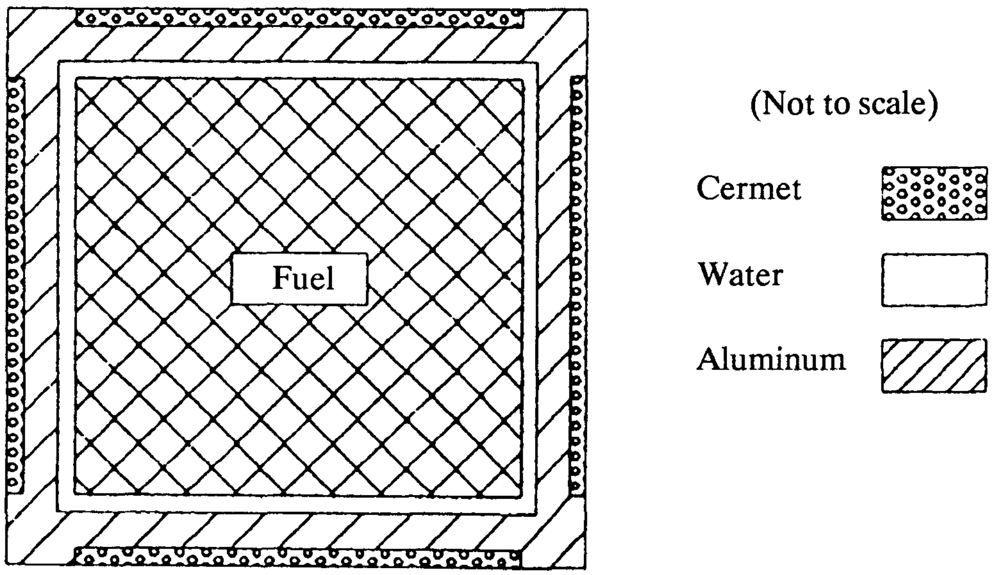


Figure 6-7

BWR Fuel Cell Model



6.4 CRITICALITY CALCULATIONS

This section describes the criticality analyses and evaluations performed for the BR-100 shipping cask. Based upon the results discussed below, the BR-100 will satisfy the criticality safety criterion for the flooded accident condition. Additional studies are planned to factor accident deformations and fabrication tolerances into the analysis.

6.4.1 Calculational Method

The criticality analyses are performed using subsets of the AMPX/KENO-IV system of computer codes. This system, or derivatives of it, are commonly used for criticality analyses of spent fuel casks. The 123-group XSDRN cross section set[4] was used for the analyses. The cross sections were processed with NITAWL[5] and with XSDRNPM[6]. Selected input data for NITAWL, as well as some optimization studies, were prepared with the NULIF[2] code. The criticality analyses utilizing the processed cross-sections were made with the KENO-IV[1] code. As discussed in Section 6.5, this system has been extensively benchmarked. The availability and results of the benchmark documentation were the primary basis for choosing this system for the analysis.

The fuel parameters tabulated in Table 6-1 provided the basis for generating the cross-section. Based upon the pitch of the fuel-rod unit-cell model, the NULIF code generated a cell Dancoff factor. This, plus effective moderator cross-sections, provided the requisite input for the resonance self-shielding by NITAWL. The cell model (i.e., fuel pellet, cladding, and water) was employed in XSDRNPM to generate spatially-weighted homogeneous cross sections.

KENO-IV was then used to determine the k_{eff} for the PWR and the BWR cask configuration under the flooded condition. Burnup isotopics for the PWR analysis were obtained from the ORIGEN2[3] code. This analysis used the explicit radial model discussed in Section 6.3.1.1. The BWR configuration with fresh fuel was analyzed with the infinite quarter-assembly model described in Section 6.3.1.2.

No KENO-IV analysis was performed for the consolidated fuel canisters. However, these canisters are expected to satisfy the 0.95 of criticality criterion when placed in appropriate locations in the PWR cask. Due to the hook weight constraint on the cask, only 10 to 15 canisters (for consolidation ratios of 2:1 to 1.3:1, respectively) can be loaded in the cask. With spacers restricting the canisters to selected locations in the cask, the effective water gap between fuel cells can approach that necessary to satisfy the criticality criterion without using burnup credit.

6.4.2 Fuel Loading Optimization

At the beginning of this analysis, a series of cases were executed with the NULIF code to determine the most reactive PWR fuel assembly. These cases examined the reactivity of the design basis PWR fuel assemblies that are to be transported in the cask. The NULIF cases modeled an infinite array of pin cells for each assembly assuming an enrichment of 4.5 wt % U-235. The results from this study indicated that the most reactive assembly was the Westinghouse 17x17 OFA. Based upon these results, this assembly was used for the PWR cask analysis to bound any other assembly to be placed in the cask.

As indicated above, it was determined that burnup credit would be required for the PWR configuration. The design baseline minimum burnup is 18 GWd/mtU, which represents an average burnup for the assembly. At the center location, the actual burnup will be larger than this amount, and near the ends the burnup will be reduced. Based upon B&W Fuel Company's experience, an estimated average burnup of 16 GWd/mtU was chosen to bound the effects caused by the axial burnup extremes over the length of the fuel assembly. Isotopics for this burnup were obtained from ORIGEN2. Future analyses will be made to verify this estimate. The analyses will examine the effects of the axial burnup profile using KENO-IV with the fuel assembly modeled axially as a multiregion fuel zone. This will provide a relationship between an average burnup and a minimum effective burnup that will bound the effects of the axial distribution.

For BWR fuel, the 8 x 8 ANF/GE JP-4,5 fuel assembly was assumed to be representative of the design basis BWR fuel assemblies. Due to a lack of information on the BWR assemblies, primarily those of GE design, a study equivalent to that for the PWR assemblies is yet to be made. In an effort to bound the BWR assemblies, an optimization study on this BWR fuel assembly was performed. The study used the NULIF code to determine the optimum moderation of the fuel rods as a function of pitch. It was found that increasing the pitch so that an 8 x 8 array of fuel pin cells would just fit within the basket cell would provide optimum moderation of the assembly. The resulting pitch was 0.715 in; the standard pitch is 0.641 in. The parameters for this arrangement were used to generate weighted cross-sections for a KENO-IV case. This optimally moderated fuel is judged to bound other BWR assemblies. This hypothesis will be demonstrated in future analyses.

6.4.3 Criticality Results

Based upon the models and methods described previously, KENO-IV calculations were performed for the PWR and BWR basket configurations. The results from these calculations are provided in Table 6-5. The k_{max} is defined as follows:

$$k_{max} = k_{eff} + 0.0103 + [(2 \times sigma)^2 + (2 \times 0.0049)^2],$$

where:

k_{eff} = KENO-IV calculated value,
sigma = uncertainty associated with that value,
0.0103 = the KENO-IV bias (Section 6.5),
0.0049 = the KENO-IV bias uncertainty (Section 6.5).

Table 6-5
KENO-IV RESULTS AND CASK k_{max}

Cask Basket	Condition	K_{eff}	K_{max}
PWR	Air filled, fresh fuel	0.3466	0.3673
PWR	Flooded, burnup credit	0.9114	0.9321
BWR	Flooded, Standard pitch	0.8404	0.8651
BWR	Flooded, optimum pitch	0.9183	0.9394

These results indicate that the BR-100 shipping cask can transport 21 PWR fuel assemblies with a minimum assembly burnup of 18 GWd/mtU or 52 BWR fuel assemblies without burnup credit with a k_{max} less than 0.95. Since these calculations, and thus results considered an infinite array of casks, the casks can be classified as a Fissile Class I package. Based upon the discussion of consolidated fuel canisters, between 10 and 15 canisters could be accommodated in the cask with the same classification.

6.5 KENO-IV BENCHMARK EXPERIMENTS

The KENO-IV bias was estimated from a comparison of KENO-IV results with those of 21 critical experiments, as documented in Reference 7. The primary conclusion resulting from the comparison is the functional relationship between the bias and the spacing between assemblies. A discussion of the comparison, the functional relationship, and the applicability of the relationship is provided in this section.

6.5.1 Data Base

A brief review of published data available to benchmark the KENO-IV code indicated that the data in Reference 7 was the most applicable for storage or shipping cask analyses. This reference describes a series of critical experiments on fuel storage racks and KENO-IV[1] results modeling the experimental configurations. The critical experiments consisted of low-enriched UO_2 (2.459 wt %) fuel rods arranged in a water-moderated lattice to simulate lighter-water-reactor (LWR) fuel assemblies. Twenty-one configurations were constructed to simulate a variety of close-packed storage arrangements. The spacings between assemblies ranged from 0 in to 2.576 in with and without interspersed absorber materials. The absorber materials included stainless steel plates, B_4C rods, and borated aluminum plates. The KENO-IV code was used to model these critical configurations with a rod-by-rod representation of the fuel assemblies with explicit models of the material placed between assemblies. The cross-sections for these cases were prepared by NITAWL[5] utilizing the 123 group XSDRN[4] cross-section set. All pertinent data for each critical configuration are documented in Reference 7 to permit the use of these data for validating calculational methods according to ANSI Standard N16.9-1975 (Ref. 8). Table 6-6 contains the results both for the critical measurement and the KENO-IV calculations.

6.5.2 KENO-IV Bias Determination

The database above provides the information necessary to benchmark the KENO-IV code system. The system includes the KENO-IV code, the NITAWL code, and the 123-group cross-section set. From calculations originally benchmarked with CDC mainframe computers, an estimate of the bias of this calculational system is obtained.

A review of the data in Table 6-6 indicates no direct correlation between the KENO-IV-to-measured differences and the type of material placed between the moderated assemblies. The only obvious correlation is between the differences and the spacing between assemblies. Table 6-7 illustrates the trend. This table lists the average KENO-IV-to-measured differences for core configurations 1 through 21 for each spacing. The difference for cores with only water-moderated assemblies is also given. An average bias independent of the spacing is also given for these core configurations and the water cases.

The bias used for the shipping cask was originally obtained from the values for the water-moderated assemblies. This method was chosen to provide a consistent set of conditions for the range of spacings of the experiments, and the overall bias appeared slightly larger for these cores. However, the use of the configuration with stainless steel and/or borated plates between the assemblies is a more realistic representation of the cask. A second-degree polynomial was fit through these points to provide the following relationship between the bias and the spacing X:

$$\text{bias} = 0.0069 - 0.01299172X + 0.001607448X^2$$

The spacing for the assemblies in a cask based on nominal dimensions used in the current design is in the range of at least 1.57 in. Using the equation above for this spacing results in a bias of -0.0095. The one-sigma uncertainty for this bias will be about the same as the average of the water cases, or ±0.0047. The bias calculated in this manner is appropriate for the KENO-IV calculations, with approximately 20,000 neutron histories performed on the B&W Control Data Corporation (CDC) mainframe computer.

The original KENO-IV bias analysis previously discussed could not be directly used since the calculations for the BR-100 analysis were not performed on the B&W CDC mainframe computer as were the original benchmark calculations. The calculations in this report were performed on a Data General MV/4000 and a Data General DS7540 Workstation. Additionally, the KENO-IV code that was converted for use on the Data General machines was an IBM version that contains a different random number generator. Therefore, a series of cases recalculating the limiting core configurations contained in Table 6-6 had to be over the different range of spacings using exactly the same number of neutrons per generation and the total number of generations as in the original analysis. These calculations considered not only water cores but also those that contained steel and poison plates between assemblies since these cases were the most limiting. Additionally, it was desired to perform calculations on the Data General computers with approximately 160,000 neutron histories to reduce the calculated uncertainty and to ensure a normal distribution of calculated eigenvalues. The limiting critical core configurations were therefore run a second time with 160,000 neutron histories.

Table 6-6
MEASURED VERSUS CALCULATED VALUES OF k_{eff}

Spacing between ass'ys, in	Core	Material between ass'ys	KENO-IV (CDC) $k_{eff} \pm U_{nc}$ [a]	Measured $k_{eff} \pm U_{nc}$ [a]	KENO-IV Measured±Unc[a]
None	I	H_2O	0.998 ±0.006	1.0002 ±0.0005	-0.002 ±0.006
	II	H_2O	1.007 ±0.004	1.0001±0.0005	+0.007±0.004
0.644	III	H_20	0.999 ±0.004	1.0000±0.0006	-0.001±0.004
	IV	84 B_4C pins	1.004 ±0.007	0.9999±0.0006	+0.004±0.007
	XI	SS plate	1.015±0.004	1.0000±0.0006	+0.015±0.004
	XIII	1.6B/A1 plate[b]	1.008±0.005	1.0000±0.0010	+0.008±0.005
	XIV	1.3B/A1 plate	1.003 ±0.004	1.0001±0.0010	+0.003±0.004
	XV	0.41B/A1 plate	0.995±0.005	0.9998±0.0016	-0.005±0.005
	XVII	0.24B/A1 plate	0.993±0.005	1.0000±0.0010	-0.007±0.005
	XIX	0.1B/A1 plate	0.991±0.004	1.0002±0.0010	-0.009±0.004
1.288	V	64 B_4C	1.005±0.005	1.0000±0.0007	+0.005±0.005
	VI	64 B_4C pins	0.998±0.004	1.0097±0.0012	-0.012±0.004
	XII	SS Plate	0.991±0.005	1.0000±0.0007	-0.009±0.005
	XVI	0.41B/A1 plate	0.990 ±0.005	1.0001 ±0.0019	-0.010 ±0.005
	XVIII	0.24B/A1 plate	1.005 ±0.005	1.0002 ±0.0011	+0.005 ±0.005
	XX	0.1B/A1 plate	0.997 ±0.005	1.0003 ±0.0011	-0.003 ±0.005
1.932	VII	34 B_4C pins	0.994 ±0.005	0.9998 ±0.0009	-0.006 ±0.005
	VIII	34 B_4C pins	1.003 ±0.005	1.0083 ±0.0012	-0.005 ±0.005
	X	H_2O	0.988 ±0.004	1.0001 ±0.0009	-0.012 ±0.004
	XXI	0.1B/A1 plate	0.981 ±0.004	0.9997 ±0.0015	-0.019 ±0.004
2.576	IX	H_2O	0.987 ±0.005	1.0030 ±0.0009	-0.016 ±0.005

[a]All uncertainties are 1 sigma.

[b]1.6 is the average weight percent of boron in the borated aluminum plate.

Table 6-7
AVERAGE KENO-IV-TO-MEASURED DIFFERENCES[a]

Spacing, in	Cores 1-21 Average (KENO-IV - Experimental) + Unc[b]	Water Cores (KENO-IV - Experimental) + Unc[b]
0.00	+0.0025 ±0.0051	+0.0025 ±0.0051
0.644	+0.0010 ±0.0049	-0.0010 ±0.0040
1.288	-0.0040 ±0.0050	----
1.932	-0.0105 ±0.0047	-0.0120 ±0.0040
2.576	-0.0160 ±0.0050	-0.0160 ±0.0050
Core 1-21 avg.	-0.0033 ±0.0048	-0.0048 ±0.0047

[a]All calculations were performed on the CDC mainframe computer.
[b]Unc = $((Uncj)^2/k)^{1/2}$, where k is the number of calculated KENO-IV values. All uncertainties are 1 sigma.

Table 6-8
COMPARISON OF KENO-IV CALCULATIONS WITH MEASURED DATA

Spacing Between Ass'ys., In	Core	Material between ass'ys.	KENO-IV on DG k_{eff}±Unc [a]	KENO-IV on CDC k_{eff}±Unc [a]	Measured±Unc[b]
None	I	H_20	1.009±0.006	0.998±0.006	1.0002±0.0005
0.644	XIX	0.1B/Al plate[b]	1.003±0.004	0.991±0.004	1.0002±0.0010
1.288	XVI	0.41B/Al plate	0.989±0.005	0.990±0.0051	0.0001±0.0019
1.932	XXI	0.1B/Al plate	0.991±0.004	0.981±0.004	0.9997±0.0015
2.576	IX	H_2O	0.988±0.005	0.987±0.005	1.0030±0.0009

[a]All uncertainties are 1 sigma.
[b]0.1 is the average weight percent of boron in the borated aluminum plate.

Shown in Table 6-8 is a list of the critical core configurations originally performed on the CDC mainframe computer. The simplest experimental configuration consisted of a 15-in cylindrical "core" with a water reflector. This configuration represents essentially an isolated critical one. For this configuration, original KENO-IV calculations overpredicted the measured k_{eff} on the average by +0.0025 delta k (see Table 6-7). Comparisons for configurations with spacings between assemblies ranging from 0.644 in to 1.288 in showed an average KENO-IV deviation of +0.001 to -0.004 delta k, respectively. For experimental configurations with spacings between 1.932 in and 2.576 in, the average deviations were -0.0105 and -0.0160 with the maximum delta k underprediction of -0.019 occurring in this range for Core XXI. The primary trend exhibited from the comparison was an increasing negative bias as the spacing increased.

Table 6-9
DATA GENERAL KENO-IV-TO-MEASURED DIFFERENCES

Spacing, in	Core	KENO-IV on DG (KENO-IV-Meas) + Unc[a]	KENO-IV on CDC (KENO-IV-Meas) + Unc[a]
0.0	I	+0.009±0.006	-0.002±0.006
0.644	XIX	+0.003 ±0.004	-0.009±0.004
1.288	XVI	-0.011 ±0.005	-0.010 ±0.005
1.932	XXI	-0.009 ±0.004	-0.019 ±0.004
2.576	IX	-0.012 ±0.005	-0.013 ±0.005

[a]Unc = $((Unc_k)^2 + (Unc_m)2)^{1/2}$, where Unc_k is the KENO-IV uncertainty and Unc_m is the measured uncertainty. All uncertainties are 1 sigma and rounded to three decimal places.

Table 6-10
KENO-IV-TO-MEASURED DIFFERENCES WITH 160,000 HISTORIES

Spacing, in	Core	KENO-IV on DG (KENO-IV-Meas) + Unc[a]	KENO-IV on DG (160K) (KENO-IV-Meas) + Unc[a]
0.0	I	+0.009±0.006	+0.005±0.002
0.644	XIX	+0.003 ±0.004	-0.004±0.002
1.288	XVI	-0.011 ±0.005	-0.010 ±0.002
1.932	XXI	-0.009 ±0.004	-0.010 ±0.002
2.576	IX	-0.012 ±0.005	-0.010±0.002

[a]Unc = $((Unc_k)^2 + (Unc_m)2)^{1/2}$, where Unc_k is the KENO-IV uncertainty and Unc_m is the measured uncertainty. All uncertainties are 1 sigma and rounded to three decimal places.

From Table 6-6, the limiting core configurations that were identified as a function of spacing were cores I, XIX, XVI, XXI, and IX. These critical cores were recalculated on the Data General computer exactly as in the original analyses. When comparisons were made to the measured data using KENO-IV on the Data General computer with 17,000 to 28,000 neutron histories, results indicated an overprediction of k_{eff} for spacings between 0 and 0.644 in. For spacings between 0.644 in and 2.576 in, there was an underprediction of k_{eff} with the maximum bias occurring between 2 in and 2.6 in. Shown in Table 6-8 is a comparison of the limiting critical core configurations calculated with KENO-IV using both computer code versions on the respective CDC and Data General computers. Shown in Table 6-9 is a comparison of KENO-IV and measured differences in critical k_{eff} for the different computer systems. These results indicate greater continuity of the bias with spacing on the Data General computer and a less severe bias for spacings in the range of 0 in to 0.644 in and for the limiting critical core configuration XXI. These calculations were repeated for 160,000 neutron histories, and a comparison of the differences between Data General results and measured data with different numbers of histories is shown in Table 6-10.

To develop the KENO-IV bias for the Data General Computer for cases with 17,000 to 28,000 neutron histories, a second order polynomial was fit through the limiting points as a function of assembly spacing, X, as follows:

$$\text{bias} = 0.00978 - 0.0165344X + 0.0023991X^2$$

For the cask, the assembly-to-assembly spacing within a rack resulted in a bias of -0.0103 ±0.0049. Calculations in Table 6-10 with 160,000 or more neutron histories determine the bias as -0.010 ±0.0017 over spacings ranging from 1.288 in to 2.576 in. These calculations also indicate that the bias approaches an asymptotic value with increased spacings. The quoted uncertainties on the previously quoted biases are one-sigma. When a one-sided upper tolerance factor is considered (representing a 95/95 confidence level) and when the critical configuration measurement error is included, the resultant bias is -0.010 ± 0.00367 for KENO-IV calculations based on 160,132 neutron histories.

6.6 REFERENCES

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7.0 OPERATING PROCEDURES

This section discusses the operability aspects of the BR-100 Cask System. We intend to do so by reviewing the different operating procedure requirements specified in Subpart G to 10CFR71, and by describing the approach we will take during the Final Design to ensure compliance with those requirements as well as with ALARA considerations. Handling and turnaround time estimates are discussed as well.

Only highlights of generic procedures are given in the following sections. Small differences in procedures will occur from one reactor site to another, mainly in the handling process due to the different site layouts and the available equipment. Detailed Handling Procedures will be developed during the Final Design Phase to cover these different situations. For example: 1) handling in the horizontal position, 2) handling in the vertical position, and 3) transfer from the railcar to an on-site carriage. In general, BWFC recommends the use of one main procedure developed for a specific site rather than several small ones. With that strategy, there is less chance that a series of steps will be performed at the wrong time, out of sequence, or even deleted. These procedures should be prepared and approved by cognizant personnel at shipping and receiving sites (Utilities and DOE/Service Contractor) based on a general set of procedures BWFC will provide for the use of the BR-100 Cask System. This set of procedures will be classified as follows:

1. Cask Receipt and Preliminary Transfers - inspection, survey, etc.; unloading from railcar, intermediate transfer to on-site carriage (if necessary) and transfer to pool area.
2. Cask Fuel Loading - preparation (including any routine maintenance to be performed at this point), lowering into the pool, loading of fuel, installation of the shield plug/fixture plate, dewatering, any tests to be performed before lifting, and cask removal from the pool.
3. Cask Preparation for Shipment - decontamination, maintenance (as required), fixture plate removal, lid installation, drying, backfilling, testing, surveying, documentation, reloading on railcar, and final inspections.

A similar set of procedures will be prepared for the repository and MRS when the interface equipment is defined.

7.1 PROCEDURES FOR LOADING THE PACKAGE

7.1.1 Initial Status

The cask is assumed to be on the railcar (or on-site carriage) in the working area of the pool crane. Further assumptions are that the preliminary inspections have been conducted: Documentation checked, visual inspection performed, contamination inspection conducted, etc. The approved fuel loading plan is available. This plan should be prepared by the service contractor in close cooperation with the utility. According to this fuel loading plan, a set of stand-offs should be available. Several options are possible: The stand-offs can be put in place in the cask cavity at the Repository or MRS before shipment of the empty cask, or the cask service contractor can provide a separate set of stand-offs with the cask with the utility having the responsibility of putting them in place before loading the fuel.

7.1.2 Preparation of the Cask

7.1.2.1 Moving the Cask to the Preparation Area

a. Remove the personnel barrier.

b. Remove the bolts of the impact limiters.

c. Remove the impact limiters. (They slide on a trolley and are stored on the railcar.)

d. Remove the two U-bolts blocking the front of the cask on the skid and the two saddle braces blocking the rear trunnions.

e. Lower the lifting yoke and engage the front/upper trunnions in their seating in the arms of the yoke.

f. Lift the cask. While the cask is rotating on its rear trunnions, move the railcar or the crane to keep the crane cables vertical.

g. Transfer the cask to the preparation area. (The railcar can be removed from the unloading area.)

h. Remove the lifting yoke.

7.1.2.2 Cask Preparations Before Immersion

a. Connect the vent port to the off-gas system and vent the cavity.

b. Remove the 32 closure bolts.

c. Install the lifting lugs on the lid.

d. Remove and store the lid.

e. Install the seal-surface protective ring.

f. Install the fixture plate on the shield plug and install vent/drain lines to the assembly.

g. Remove and store the shield plug/fixture plate.
h. According to the approved fuel loading plan and to the height of the elements, install or ensure the proper stand-offs and check the length of the compartments.
i. Fill up the cask cavity with water.

7.1.3 Immersion and Loading of the Cask

a. Lower and engage the lifting yoke with the front/upper trunnions.
b. Lift the cask and transfer it to the pool.
c. Lower the cask into the pool.
d. Remove the lifting yoke.
e. Load the fuel elements according to the appropriate loading plan and proper fuel handling procedures.

7.1.4 Cask Draining and Removal from Pool

a. Verify fuel assembly identification numbers to confirm proper location.
b. Install the shield plug/fixture plate. Activate the fixture plate lock mechanism.
c. Remove the shield plug/fixture plate lifting tool.
d. Pressurize cask cavity to 3 atm with nitrogen or dry air.
e. When bubbles start to come out of the main drain pressure relief valve or when there is a sudden increase in the gas flow rate, stop gas pressurization.
f. Lower and engage the lifting yoke with the front/upper trunnions.
g. Lift the cask.
h. While cask is being lifted above the pool, decontaminate with water spray and wipe down the pressure and drain lines.
i. Move to poolside; place the cask in the preparation area and remove the yoke.
j. Wipe down cask surfaces.
k. Verify that radiation levels and surface contamination are within specified limits.
l. Perform additional decontamination as necessary.

7.1.5 Preparation for Shipment

a. Pressurize to 3 atm with nitrogen or dry air through the vent draining water from the 1/2-in line.
b. After draining is complete, cap the vent line.
c. Connect the vacuum drying equipment to 2 in drain line.
d. Pump down to a vacuum of about 5 mbars in the cavity.

e. Continue vacuum drying until the pressure is steady inside the cavity.
f. Disconnect the vacuum pump and fill the cavity with helium.
g. Remove the fixture plate.
h. Remove the protective ring.
i. Check the seal surfaces; clean and dry them if necessary.
j. Install the closure lid. Gaskets have been replaced in the meantime.
k. Install lid bolts according to the installation diagram and torque (to be supplied during final design).
l. Connect the vacuum pump to the vent port and pressurize the cavity to 0.5-0.7 atm helium.
m. Install the sampling/drain cover plate.
n. Perform leak tightness test of the spaces between gaskets (lid and sampling). Install plugs over check ports.
o. Install the lifting yoke.
p. Lift the cask and move it above the skid.
q. Lower the cask until the rear trunnions are in their seat on the skid.
r. Install loosely the saddle braces on the trunnions.
s. Rotate the cask to the horizontal position while moving the railcar or the crane to keep the cables near vertical.
t. When the front part of the cask settles in its saddle, remove the lifting yoke.
u. Lock the front of the cask with the U-bolts and block the rear saddle braces.
v. Perform the final radiation and Quality Control Check.
w. Install the impact limiters and the personnel barrier.

7.2 PROCEDURES FOR UNLOADING THE PACKAGE

In this procedure, we assume that the repository or MRS is equipped with dry unloading facilities. We also assume that the unloading facility includes an unloading cell equipped with an interface seal ring and a sliding/elevating table to support the cask in the vertical position. Of course, the final procedures will be written to reflect the actual conditions for handling the cask and unloading the fuel elements.

7.2.1 Initial Status

The cask is on its skid on the railcar in the unloading facility. The preliminary inspections have been performed: Documentation, visual inspection, and surface contamination survey.

7.2.2 Preparation of the Cask

7.2.2.1 Rotating the Cask to the Vertical Position in the Preparation Area

a. Remove the personnel barrier.
b. Remove the bolts of the impact limiters.
c. Remove the impact limiters. (They slide on a trolley and are stored on the railcar.)
d. Remove the two U-bolts blocking the front of the cask on the skid and the two saddle braces blocking the rear trunnions.
e. Lower and engage the lifting yoke with the front/upper trunnions.
f. Rotate the cask to vertical. While the cask is rotating on its rear trunnions, move the railcar or the crane to keep the crane cables vertical.
g. Transfer the cask to the preparation area and place it on the elevating table. (The railcar can be removed from this area.)
h. Remove the lifting yoke.

7.2.2.2 Sampling and Cooling Down

a. Remove the cover plate of the sampling ports.
b. Take a gas sample from the cask cavity.
c. Check for fission products. If fission products are found, refer to the proper procedure.
d. Connect the sampling port to the vent line.
e. Restore atmospheric pressure inside the cavity.
f. Connect the nitrogen or dry air inlet to the 1/2-in drain port.
g. Ensure a gas flow within the cavity until the temperature (of the cavity or of the gas at the outlet) is below 120^{o}F.

h. Disconnect the gas inlet and vent pipes.

7.2.3 Unloading

a. Using the elevating table, move the cask under the unloading cell.

b. Lift the table until the cask is sealed against the cell opening (tightness is ensured by the seal ring). Pressure inside the cell should be lower than in the preparation area.

c. With the pneumatic tool, unbolt the lid.

d. Remove the lid, decontaminate and inspect it.

e. Install the protective ring.

f. Remove the shield plug, decontaminate and inspect it.

g. Unload the fuel assemblies.

Note: All other operations are described in the next section.

7.3 PREPARATION OF AN EMPTY PACKAGE FOR TRANSPORTATION

As mentioned above, the final procedures cannot be prepared until the facilities available at a repository or a MRS are well known. We shall assume for the purposes of this document that the unloading cell is also used for the cask decontamination and preparation for the next shipment.

7.3.1 Initial Status

The empty cask is in place on the elevating table against the unloading cell. The lid and the shield plug have been removed during unloading operations, and they have been decontaminated and inspected. The protective ring is in place.

7.3.2 Decontamination, Draining, and Drying

a. Survey cask cavity.
b. Decontaminate as required.
c. Install the shield plug/fixture plate.
d. Connect the draining system to the fixture plate.
e. Open drain lines.
f. Pressurize to 3 atm with nitrogen or dry air.
g. When no more water comes out of the main drain (2 in), or when there is a sudden increase in the gas flow rate, close the main drain.
h. When no more water comes out of the second drain (1/2 in), or when there is a sudden increase in the gas flow rate, close the second drain, close the fill line, and vent cask pressure to 1 atm.
i. Disconnect the drains and fill pipes.
j. Connect the vacuum drying equipment to the 2-in drain.
k. Pump down to about 5 mbars in the cavity.
l. Continue pumping until the pressure is steady inside cavity.
m. Disconnect the vacuum pump and fill the cavity with nitrogen.
n. Remove the fixture plate.
o. Remove the protective ring.
p. Check the seal surfaces, and clean and dry them if necessary.
q. Install the closure lid.
r. Install lid bolts according to the installation diagram and torque (to be supplied during final design).
s. Connect the vacuum pump to the vent port and pressurize the cavity to 0.9 atm nitrogen.

7.3.3 Removal from the Cell and Preparation for Shipment

a. Lower the elevating table.
b. Move the table and cask to the preparation area.
c. Install the sampling/drain cover plate.
d. Perform leaktightness test of the spaces between gaskets (lid and sampling).
e. Install the lifting yoke.
f. Lift the cask and move it above the skid.
g. Lower the cask until the rear trunnions are in their seat on the skid.
h. Install loosely the saddle braces on the rear trunnions.
i. Rotate the cask to horizontal while moving the railcar or the crane to keep the cables vertical.
j. When the front part of the cask settles in its saddle, remove the lifting yoke.
k. Lock the front of the cask with the U-bolts and block the rear saddle braces.
l. Perform the final radiation and Quality Control Check.
m. Install the impact limiters and the personnel barrier.

7.4 APPENDIX

7.4.1 Description of the Closure Lid System

The closure lid system is an innovative feature of the BR-100. As shown in Figure 7-1, it includes :

- o the lid,
- o shield plug, and
- o 32 closure bolts.

The lid itself includes a vent line (3⁄8 in) and a drain line (1⁄2 in). These lines are used for sampling, cooling down, and pressurizing the cavity. Each line is fitted with a quick disconnect. The quick disconnects are located under a common cover plate. The tightness of the cover plate is ensured by two O-rings and checked through a test port. The tightness of the lid is ensured by two O-rings and is also checked through a test port. Drawings 1192007 (BR-100 Cask Closure Lid Assembly) and 1192011 (BR-100 Cask Closure Lid Sections) show the principle of these components. The lid also includes an attachment and keys which will be defined during the final design phase.

The shield plug includes a vent line ((3⁄8 in), a drain line (1⁄2 in), and a quick draining line (2 in). All these lines are made of stainless steel pipes, "S-shaped" to prevent any radiation streaming. The shield plug performs only a shielding function and therefore has no gasket.

The closure bolts are fully described in Section II-2.4.2.

The draining lines are connected to the bottom of the cask through two pipes located in a former of the basket. Tightness of these lines is required to perform the dewatering operations. Two seals are provided: a) between the lid and the shield plug (1⁄2-in drain) and b) between the shield plug and the upper grid of the basket (1⁄2-in and 2-in drains). Figure 7-2 shows the seal arrangements. Between the lid and the shield plug, an intermediate flange equipped with two O-rings ensure tightness. Between the shield plug and the basket, a system including a bellows, a spring and a metallic gasket is used. The metallic gasket is used because of the radiation level at that location. These parts are designed to be easily replaced during normal maintenance and to provide flexibility for the alignment requirements of the lid, shield plug and basket.

<u>Alignment of the closure lid system</u>

As indicated on the preliminary drawings, alignment devices are not yet designed. However the following principles will be used:

- o The basket is aligned with the cask body by a key between the upper flange of the cask and the upper grid of the basket,

- o The shield plug is aligned with the cask body (and therefore with the basket) by the same key, and
- o The lid is aligned with the cask body by two guiding pins.

This alignment will ensure the proper function of the vent and drain lines.

Special tooling

Two special tools are used in conjunction with the closure lid system during operations: The protective ring and the fixture plate. These tools, shown on Figure 7-3 are shown in Figure 7-3 in place on the BR-100.

The protective ring will be designed to protect the seal surface of the cask as soon as the lid is removed. Furthermore, it will be equipped with two seals, one on each side of the bolt holes to prevent the pool water from entering the bolt holes. This will reduce the contamination of the front part of the cask. The protective ring will be bolted to the cask with three bolts using the bolt holes of the closure lid. The protective ring will be also aligned with the cask using the same alignment device as the lid. A locking mechanism (such as pneumatic jacks) will be used to maintain the fixture plate (and also the shield plug).

The fixture plate is a unique feature designed to reduce the turnaround time and personnel exposure to radiation. It will be bolted to the shield plug when the lid is removed and the protective ring is in place. The fixture plate will be equipped with all the necessary equipment (automated valves, fittings, etc.) to perform the draining operations. A seal will ensure the tightness between the fixture plate and the protective ring. This tightness is needed to perform the draining operations. The fixture plate will be aligned with the protective ring. It will be used to handle the shield plug during the loading and unloading operations.

Sequence of operations: (this is not a procedure)

Opening of the Cask: (the cask is empty)

- o removal of the lid,
- o installation of the protective ring,
- o installation of the fixture plate,

(all other operations are done remotely)

- o filling of the cavity with water,
- o transfer to the pool,
- o removal of the shield plug.

Closing and draining of the cask: (after loading)

- o installation of the shield plug (with the fixture plate),
- o locking of the fixture plate on the protective ring,
- o draining of the cavity by pressurizing. The tightness is ensured by the seals between the cask and the protective ring, and between the protective ring and the fixture plate.
- o transfer to the preparation area,
- o final draining of the cavity,
- o vacuum drying,

(all preceding operations are done remotely)

- o removal of the fixture plate,
- o removal of the protective ring,
- o installation of the lid.

7.4.2 Discussion

The major objective during the Preliminary Design phase has been to design a cask system that is safe and economical. One of the most important goals was to minimize the Total Transportation Life Cycle Cost (TTLCC) by reducing handling and turn-around times at both the utilities' sites and other facilities (repository or MRS). The BR-100 Cask system includes proven technologies (such as multiwall body, lead shielding, and stainless steel shells) as well as new technologies (Kevlar-reinforced impact limiters and extruded aluminum fuel cells).

Operability is enhanced by the following features of the BR-100 Cask System:

- o Simplified cask, impact limiter, and skid tie-down fasteners--impact limiters are removed by means of a trolley on the railcar to minimize handling operations and floor space requirements.
- o A two-piece closure system, which allows the removal and installation of the outer lid out of the pool.
- o Location of the vent and drain lines at the top of the cask facilitating their connection.
- o A fixture plate, which can be connected to the draining system during the fuel loading operations thereby saving time.
- o Hard anodization of the aluminum basket, which provides a smooth surface to minimize decontamination time and wear.
- o No outer cooling system, such as copper fins (which requires the use of a skirt before immersion in a pool).

- o A smooth, stainless-steel outer shell coated with an easily decontaminated paint.

The B&W approach for the final design includes the following considerations:

1. Confirmation of the validity of some features by an extensive testing program.
2. Development of a quick-release mechanism for the impact limiters.
3. Preparation of detailed Reactor Site Operating Procedures for the loading operations in close cooperation with Duke Power.
4. Development of specialized tooling to facilitate the operations at the utility sites.
5. Preparation of detailed unloading procedures in close cooperation with repository and/or MRS personnel.

7.4.3 Handling and Turnaround Times

Table 7-1 gives estimates for handling times at a reactor site for the BR-100 in its PWR configuration, based on the Operating Procedure described in Section 7.1. These estimates assume that there is no equipment failure during the operations, and that all equipment and manpower are available when needed. The size of the handling crew will depend on the particular operation being performed. The average size is estimated at three to four people, but this may vary from two to seven depending on the work in progress. At the reactor sites, the operations will be supervised by the utility. DOE or its contractor should supply a specialist in charge of the cask operations who will also conduct certain maintenance/inspections tasks.

Table 7-1
HANDLING TIME FOR LOADING THE BR-100 (PWR) AT A REACTOR SITE

Procedure Step	Description	Duration, hr	Manhours, hr
7.1.1	Initial Status	1.0	4.0
7.1.2	Preparation of the cask	1.5	5.0
7.1.3	Immersion and loading of the cask	10.0	32.4
7.1.4	Cask draining and removal from the pool	2.2	7.65
7.1.5	Cask preparations for shipment	3.3	12.45
Total for Loading on Site		18.0	61.5

Note: Many of the above tasks include administrative and health/physics control. We assume that the utilities will provide the adequate personnel to perform these tasks in a reasonable time.

Several steps can be taken to achieve an 18-hr turnaround. For example, a full set of spare parts for the cask should be available at the site. In addition, the Operating Procedures will include "call-points," i.e., procedure steps wherein the personnel required for an upcoming task are called ahead of time so that they will be ready to work when required.Major time savings can also be achieved through proper preparation activities at the sites. A detail of assumptions made to achieve an 18-hr turnaround time at reactor site is given in Section 7.4.4.

The handling and turnaround times for unloading at the repository or MRS are difficult to estimate due to the lack of detailed information about these facilities. However, a reasonable assumption is that the turnaround time at these facilities will be less than the 18 hours required at a reactor site. The repository/MRS facilities will be dedicated to the unloading of casks, and their personnel will be working on a more-or-less routine basis. In addition, there is the advantage of standardization and automation of some of the equipment. Thus, a goal of 12 hr for repository/MRS turnaround seems reasonable.

7.4.4 Assumptions Regarding Site Handling Preparation

Although not directly related to the Operating Procedures of the BR-100 Cask System itself, the following assumptions have been made in order to reduce as far as possible the turnaround time at reactor site.

1. Cask shipments should be scheduled so that there is a (relatively) continuous series of shipments from a particular reactor site. If at all possible, these back-to-back shipments should continue until the site's "quota" has been removed. This will prevent the site personnel from having to "relearn" operating procedures and will result in a higher cask utilization.
2. Each site scheduled for near-term shipments should be sent a preliminary information package for their review. Key site personnel could be trained at the Cask Maintenance Facility prior to start of the campaign.
3. Once a schedule has been agreed to by the utility/site, a team of DOE/contractor cask personnel should visit the site well in advance of the first shipment. This visit would include the following steps:
   a. A general presentation to all affected site personnel. The purpose of this would be to make the site people fully aware of the program objectives, special regulations, cask characteristics, interface requirements, etc.
   b. A tour of the reactor fuel pool (or other storage area). The purpose here is to determine critical building dimensions (heights, clearances, headroom, etc.), crane capabilities and load limits, fuel handling bridge dimensions, available floor area, air/water/electricity locations and capacities, and other important cask/site interfaces.
   c. A discussion of site personnel requirements, including crane operators, fuel handlers, Health Physics, shipping personnel, and decontamination assistance. The main site contacts should also be established for each of the interface requirements. A major point of discussion should be the need for close coordination and efficient operation, not only to hold down operating costs but to minimize the impact on normal site operations as well.
4. Cognizant DOE/contractor cask representatives should remain in close contact with site personnel during the ensuing preparation phase to resolve any interface questions. This phase would also include assistance with detailed preparations such as the following:
   a. Converting cask handling procedures into site-specific format where necessary.
   b. Setting up dedicated work areas to support cask operations; these would include a smear survey station, a storage area for tools and spare parts, a storage/work area for decontamination of tools and materials, nitrogen gas supply tanks, etc.
   c. Providing assistance and information regarding expected radiation levels, radiation work permits, shipping document requirements, site Technical Specification limitations, etc.

5. Within a few months of the first expected shipment, the actual DOE/contractor crew involved with the shipments should visit the site for a dry run of the entire operation. If at all feasible, this dry run should be carried out with an actual (perhaps prototype or model) cask. The practice run will enable the crew to identify any need for additional personnel, better communication links, procedure revisions, etc. At this time, the DOE/contractor cask personnel could also take any necessary Health Physics/security training required by the site.

7.4.5 Quality Assurance Considerations

Special attention will be given to the quality assurance aspects of the cask operations. A QA Plan for operating the cask will be established to address the following considerations:

- o Training and qualifications of the personnel involved in loading and unloading operations.
- o Preparation and approval of the "dedicated" operating procedures.
- o Preparation and approval of the "Loading Plans."
- o Calibration of the testing equipment used.
- o Management of shipping records.

Figure 7-1
Closure Lid System

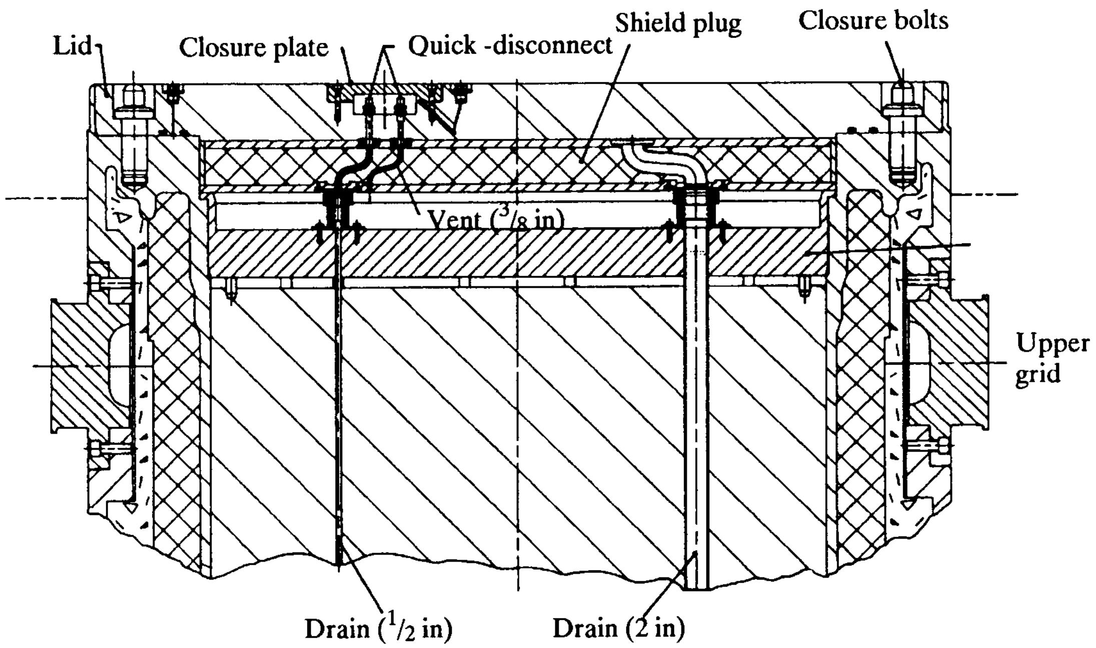


Figure 7-2
Vent and Drain Line Seal Arrangement

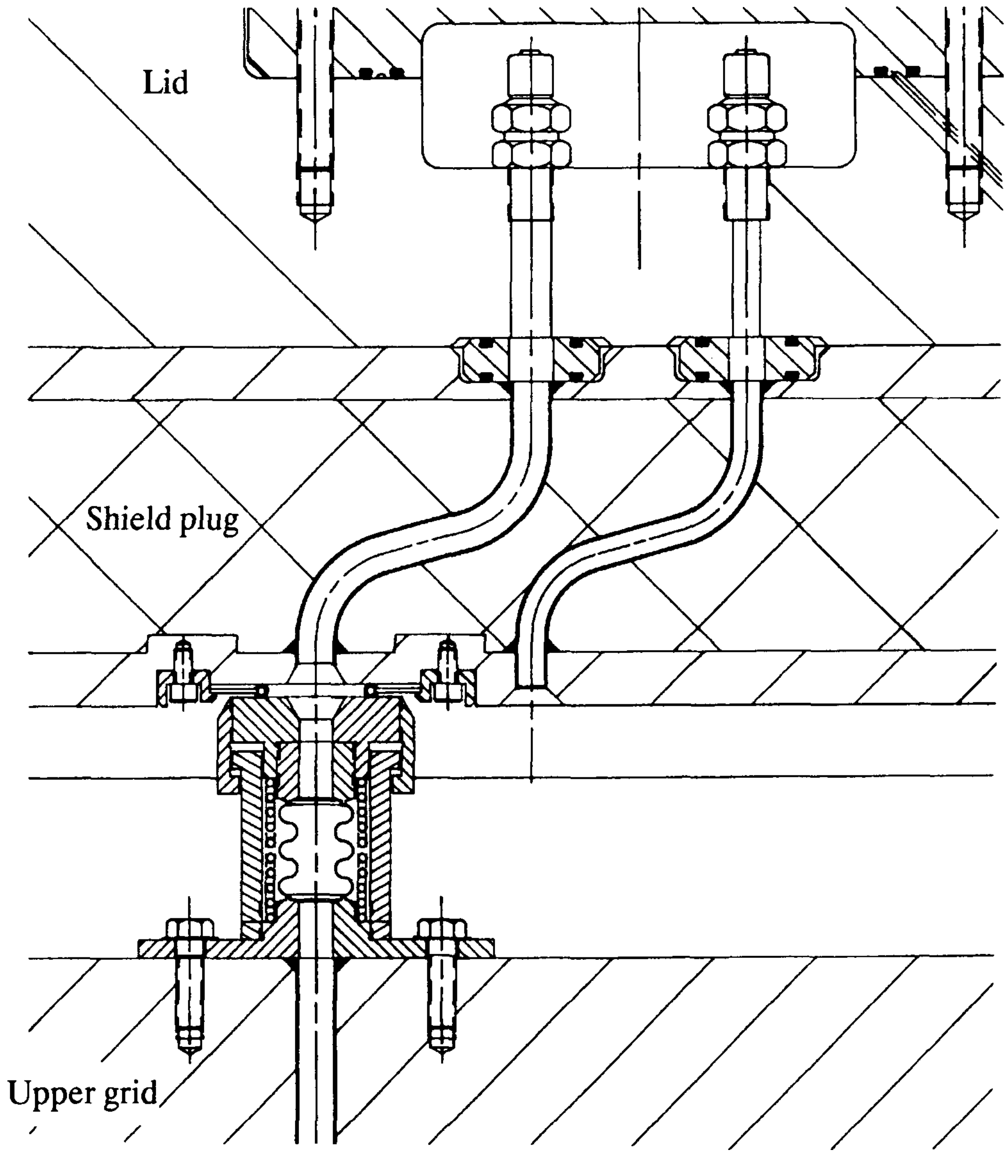
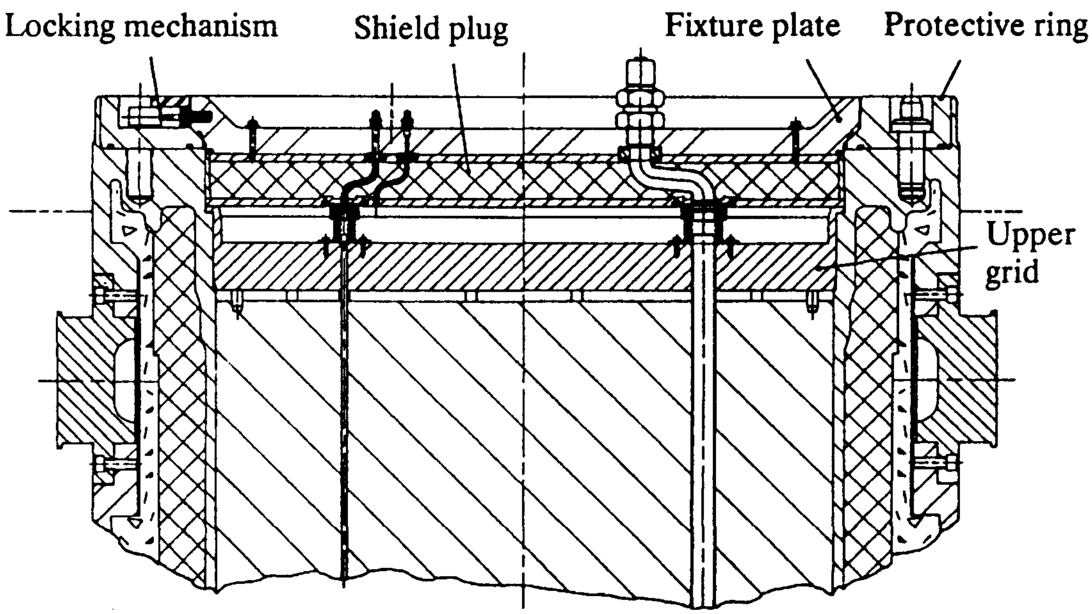


Figure 7-3

Closure Lid Features



8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

This section discusses the different types of acceptance tests BWFC will perform on the BR-100 Cask system as well as describes the philosophy of the maintenance program. This will be done by reviewing the different kinds of acceptance tests proposed and the major maintenance operations, all in compliance with Subpart G of 10CFR71. Specific acceptance test procedures and maintenance procedures will be defined during the final design phase and will be updated during the tests performed on the BR-100 prototypes.

8.1 ACCEPTANCE TESTS

This section describes the tests to be performed on the BR-100 Cask system before the first use of the package.

8.1.1 Visual Inspection

A visual inspection of all components of the cask will be performed. This inspection includes the following items:

- o basket,
- o cask body,
- o shield plug,
- o lid and its bolts,
- o cover plate and its bolts,
- o impact limiters and their bolts,
- o seals and seal surfaces, and
- o trunnions.

The visual examination is intended to look for cracks, pinholes, or other defects that could significantly reduce the effectiveness of the packaging. The basic acceptance criteria will assure compliance with requirements of the drawings and/or applicable specifications. Visual inspection will also determine the presence and proper location of the regulatory DOT and NRC markings. Most of the final visual inspections (performed as acceptance tests) will be supported by inspections performed during fabrication. A comprehensive Quality Inspection and Test Plan will be prepared first for the quarter-scale model and then for the prototypes. This plan will include visual examinations at all necessary steps; i.e., before the related part is no longer accessible. For example:

- o visual inspection of the neutron absorber plates on the fuel cells before assembly into the basket and
- o inspection of the copper fins before the concrete pouring.

8.1.2 Structural and Pressure Tests

8.1.2.1 Structural Test of the Handling Devices

Trunnions

In accordance with ANSI N14.6-1986 Section 7.3.1, a load of 600,000 lb (three times the weight) will be applied to each pair of trunnions. The load will be applied twice and maintained for 10 min each time. Measurements will be taken on the trunnions and on the cask surface close to the trunnion attachment (see Figure 8-1). Any permanent deformation greater than $5x10^{-4}$ in will be recorded. In addition, a dye-penetrant test of the welds between the outer shell and the trunnion attachment will be performed before and after the test. The images should be the same.

Lifting Ears of Impact Limiter

The same kind of test will be performed on the impact limiter lifting ears; i.e., applying twice the weight of the impact limiter to the ears. The acceptance criteria will be determined later on according to the kind of material (Kevlar or steel) used in the final design of this equipment.

8.1.2.2 Pressure Test of the Cavity

This test is a hydraulic one. The cask cavity will be filled with water and then pressurized to 150% of the maximum normal operating pressure; i.e., 150 psi. No leakage will be allowed. Following this, the cavity will be sealed under pressure for 24 hr. Pressure and temperature inside the cavity will be recorded. No pressure drop will be allowed.

8.1.3 Leak Tests

Leak tests of the cavity (containment vessel) will be performed in several steps. The cavity is defined by the following:

- o cavity (bottom, inner shell, upper flange),
- o lid,
- o penetrations in the lid (quick connections), and
- o closure plate.

The lid and the closure plate are equipped with two seals, and a port is provided to check the tightness of the space between the seals.

The pressure-rise method of testing is used. The Sensitivity of the Pressure Rise (SPR) depends on 1) the total volume tested (cavity + connections), Vt; 2) the minimal pressure rise measurable, Δ Pm; and 3) the elapsed time between the initial and the final measurement, T.

$$SPR = (Vt \times \Delta Pm) / T$$

The minimum time of the test, Tm, is defined as the time necessary to detect a leak equivalent to the required sensitivity, SPR_0.

$$Tm = (Vt \times \Delta Pm) / SPR_0$$

The actual sensitivity of the measurement, SPR_1, is thus better than the required sensitivity SPR_0 since the duration of test T_1 is greater than Tm.

$$SPR_1 = (Vt \times \Delta Pm) / T_1$$

The pressure gauges and the minimum time of the test will be chosen in such a way that the sensitivity of the measurement is less than or equal to half the permissible leak rate.

To ensure the success of these final tests, the cavity and the closure components will be leak tested at the different stages of their fabrication in order to detect leaks when they are easy to repair, such as before and after the lead pour. The Quality Inspection and Test Plan will reflect this complete set of tests.

In addition to the leak test of the containment vessel, other leak tests will be performed on the following BR-100 components:

- o shield plug,
- o concrete enclosure, and
- o impact limiters.

Depending on which piece of equipment is being tested and the stage of fabrication, these leak tests can be performed by pressure rise or by helium methods, whichever is the most suitable.

8.1.4 Component Tests

8.1.4.1 Valves, Rupture Discs, and Fluid Transport Devices

The only equipment of this kind used on the BR-100 are the two quick-disconnect fittings mounted on the lid. These connections, which are used for the vent (3/8 in) and drain (1/2 in) lines, are in a cavity in the lid and covered by a closure plate equipped with two O-rings. Although not strictly part of the containment vessel, each connection will be subjected to the same testing program as the containment vessel, including a pressure test (50% higher than the Maximum Normal Operation Pressure), a leak test, and an operational test.

8.1.4.2 Gaskets

Gaskets will be selected after a comprehensive qualification program simulating the most adverse conditions. The manufacturer will have a quality-assurance program that ensures that acceptance testing of a given gasketing device is equivalent to acceptance testing of all gaskets supplied and identified by that manufacturer as that model of gasket.

8.1.4.3 Miscellaneous

In addition to the tests described in this section, BWFC will perform a complete set of operational tests to ensure the proper working of the BR-100 Cask system. This set of tests will include the mounting and removal of all removable parts (impact limiters, lid, shield plug, basket, quick-disconnect fittings, trunnions, etc.), the handling of the cask, the loading/unloading of a dummy fuel assembly in each cell, weight measurement, and measurements of the draining and drying times.

8.1.5 Shielding Integrity Tests

These tests will be conducted by positioning a gamma (or neutron) source inside the cavity and measuring the dose rate on the outer surface of the shielding. To be able to repair any defect, preliminary tests will performed immediately after the lead pouring and then again after the concrete pouring. If the dose rate in one area is much greater than another, a radiographic examination will be performed. The defect, if any, can be repaired at this stage of the fabrication.

8.1.6 Thermal Acceptance Tests

8.1.6.1 Discussion of Test Setup

The Thermal Acceptance Test will be conducted to demonstrate that the thermal performance of the BR-100 Cask under normal operating conditions agrees with the results of the thermal analyses. During the final design phase, detailed analyses will be performed to determine the behavior of the cask when fully loaded; i.e., temperature rise versus time. These analyses will also determine the best location for thermocouples, the test equipment to be used, the sensitivity of the measurements and the acceptance criteria. To reproduce the normal operating conditions, 21 heating elements (one in each cell) will be mounted in the fuel basket. The heating elements will be placed on a support representing the volume of a fuel assembly. All connections will be made through a special lid so that an inert atmosphere can be maintained inside the cask. Since the front impact limiter cannot be installed (due to the electrical connections), the front face will be insulated to simulate the insulation effects of the impact limiter. The equipment will be able to maintain a constant electrical power even if there are variations in the voltage. The pressure will be measured in the cavity, in the concrete enclosure, and in the impact limiter. During the equilibrium phase, the ambient temperature will be maintained as steady as possible (within 3^oC).

8.1.6.2 Test Procedure

The test procedure will be developed in two stages. During the final design phase, a general procedure will be prepared. This procedure will address all the topics that are to be taken into consideration for the thermal tests. A suggested format for such a procedure is as follows:

1. Purpose
2. Applicable documents
3. General conditions
4. Personnel qualifications
5. Calibration of test equipment
6. Test conditions
7. Specific conditions
   - 7.1 Electrical power
   - 7.2 Cask position
   - 7.3 Pressures
   - 7.4 Duration of test
8. Acceptance criteria
9. Testing equipment specifications
10. Test and test report form

During the prototype fabrication, a second procedure will be established. The purpose of this procedure is to:

- o list the actual equipment that will be used,
- o describe the electrical connections, and
- o describe step by step the preparation for the test and the test itself.

The content of this second procedure will be in full compliance with the requirements of the first one.

8.1.6.3 Acceptance Criteria

The acceptance criteria of the thermal test will be established during the final design phase.

8.2 MAINTENANCE PROGRAM

This section describes the BR-100 cask maintenance program as currently envisioned. The maintenance program is divided into two parts, routine maintenance (those activities that are performed once each shipment cycle) and periodic maintenance.

During the preliminary design phase, cask maintenance was found to have an important influence on life-cycle costs. Therefore, one of the major objectives during the final cask design phase will be to minimize maintenance requirements as long as such design features do not compromise the overriding objective of safety. Providing all maintenance details at this point in the program is not feasible. For the preliminary overview presented in this report, a typical maintenance program is described with the realization that many additional details will have to be provided for the final program. Another major task will be the implementation of a quality-assurance plan to cover the safety-related maintenance items, which will include provisions for instrumentation calibration schedules, acceptance criteria, and documentation requirements.

Routine maintenance will consist of relatively simple tasks to be performed during, and for the most part concurrent with, the reactor-site cask-loading operations. The specific items to be addressed during routine maintenance will be identified during the final cask design phase. A number of key components (such as bolts, threads, O-rings, seal grooves, valves, disconnects, and trunnion surfaces) will be inspected during (or just before) each cask-loading operation and will be replaced or refurbished as necessary. These routine activities will be incorporated into the cask Operating Procedures (discussed in Section 7 of this Package) and will not be discussed further here. The only components that are expected to be replaced on a routine basis (before each loaded shipment) are the lid seals.

The remainder of Section 8.2 will address the periodic maintenance program. The major portion of the program will be conducted on an annual basis, assuming that the cask is being operated at a normal-use rate. If the cask remains idle for a significant period, there will be a stipulation for the annual maintenance to be performed following a specific number of shipments and/or prior to its next shipment depending on the idle time. In addition to the annual maintenance tasks, there will be additional tests and inspections to be conducted at somewhat longer intervals.

For the purposes of discussion, the basic cask assembly is defined to include the cask body itself and the main closure lid. Major subsystems also discussed are as follows:

1. shield plug and its auxiliary components,
2. cask lifting yoke assembly,
3. fuel basket assembly,

4. impact limiters, and
5. railcar skid.

8.2.1 Cask Structural and Pressure Tests

The structural design criteria imposed on the BR-100 cask, along with stringent acceptance criteria after manufacture, will be sufficient to ensure cask integrity over the anticipated lifetime under normal operating conditions. Thus, no specific structural tests, other than yearly load tests of the trunnions, will be required on the cask body. However, if cask damage occurs, a detailed test program will be formulated to ensure that the cask retains, or has been returned to, its original structural integrity before returning it to service.

8.2.1.1 Cask Pressure Test

The maximum anticipated internal cask pressure during normal operation is 100 psia. The cask has been designed to withstand an internal pressure of 150 psia. The cask will undergo a hydraulic pressure test to 150 psia at five-year intervals.

8.2.1.2 Trunnion Tests

A structural test (see Section 8.1.2.1) will be conducted annually on each of the cask lifting trunnions. In addition, the trunnion bolts will be UT-inspected annually, and the trunnion mounting plate welds will be inspected using dye-penetrant techniques.

8.2.2 Leak Tests

Annual leak tests will be conducted on the cask as outlined below.

The integrity of the cask concrete enclosure will be checked by testing each fusible plug. This can be done either by the pressure rise method or by a helium leak test.

The cask closure system will also be helium leak checked by pressurizing the cask cavity and checking for leakage around the lid sealing surface and the drain/vent line seals.

8.2.3 Subsystems Maintenance

8.2.3.1 Shield Plug and Auxiliary Components

The shield plug and its associated parts (fixture plate and protective ring) are primarily operational-type components and not directly related to the cask structure. Their sealing integrity will be checked during each loading operation. During the annual maintenance period, the sealing surfaces will be inspected in greater detail, and the critical areas resurfaced as needed. The quick-disconnect fittings will also be inspected and replaced as necessary.

8.2.3.2 Lifting Yoke Assembly

The annual maintenance will be done according to the recommendations of the ANSI N14.6-1986 standard, Section 6.3.1. The lifting yoke assembly will be subjected to either of the following:

1. A test load equal to three times the maximum service load, including visual examination of critical areas, or
2. In cases where surface cleanliness and conditions permit, a dimensional testing, a visual examination, and a nondestructive testing of major load-carrying welds and critical areas.

8.2.3.3 Fuel Basket Assembly

The design of the fuel basket assembly is such that annual maintenance will be minimal. However, periodic checks will be performed on a schedule to be determined. (It is also possible that the maintenance can be performed off-line by substituting a spare basket assembly.) The periodic inspection will include straightness tests, bolting checks, visual examination of wear, corrosion, and integrity of the Cermet poison plates.

8.2.3.4 Impact Limiters

Annual leak testing of the impact limiters will be conducted to check sealing integrity as well as to determine moisture content. In addition, the impact limiter bolts will be inspected.

8.2.3.5 Cask Railcar Skid

Annual maintenance on the skid will concentrate on the trunnion cradle surfaces and the stirrup/bolt assemblies.

8.2.4 Cask Valves, Rupture Discs, and Gaskets On Containment Vessel

These items will all be inspected during each cask-loading operation. Periodic maintenance will involve replacement of components on a schedule to be determined during the final design phase.

8.2.5 Shielding

Gamma shielding characteristics of the cask are not expected to change during the life of the cask.

8.2.6 Thermal Testing

The cask thermal characteristics will be checked in five-year intervals. The decay heat of irradiated fuel assemblies may be used if the total is 5 kW or greater.

8.2.7 Miscellaneous

Certain additional inspection and testing operations will be performed during periodic maintenance. Most of these are not safety-related but will be checked to ensure more efficient operability of the cask. Such tests will be determined during the final design phase. For instance, the cask outside-surface inspection is one of these miscellaneous items. The condition of the cask outside-surface paint will have an important effect on site decontamination operations as well as on the thermal properties (emissivity). Thus, the surface must be kept clean, smooth, and free of pits, scratches, etc. Each maintenance period will include a 100% surface inspection and repair where needed.

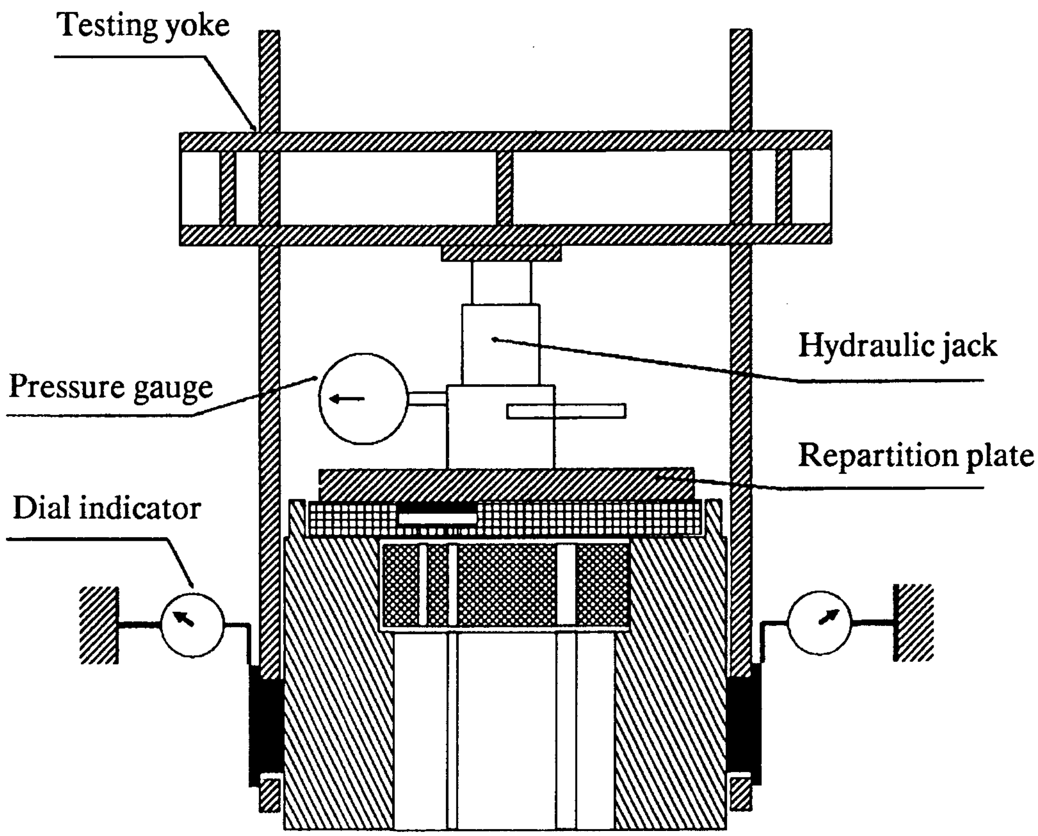
8.2.8 Discussion

Maintenance costs are an important part of the Total Transportation Life Cycle Cost (TTLCC). A sensitivity study performed early in the project showed that maintenance-cost impact on TTLCC could range about ±3%. Thus an important criterion during the preliminary design phase was to develop a cask with maintenance requirements that are as low as possible. The BR-100 has been designed to reduce these requirements to the lowest extent possible, and this effort will be pursued throughout the final design phase.

The major features of the BR-100 Cask that minimize the maintenance costs (materials and manhours) are described below:

- The hard anodizing of the fuel cells enhances the wear and corrosion resistance thus minimizing decontamination operations and the need for refurbishing.
- The removable fuel basket is easy to dismantle and allows a 100% visual inspection of the Cermet plates and their replacement, if necessary. The basket design also allows a partial replacement of one or more individual fuel cells thus minimizing the cost of maintenance as compared to a completely new basket.
- Cask sealing surfaces are protected during loading and unloading operations by the protective ring thus minimizing the chances of scratches and the need for repairs.
- Elastomer gaskets will be replaced on a routine basis during the loading of the cask without affecting the turnaround time.
- The outer cask surface, which is covered with an epoxy coating, is very easy to decontaminate and has strong chemical and thermal resistance. The maintenance of such a coating is easy to perform and not expensive.
- The use of moving parts has been reduced to the lowest extent possible. Only two quick-disconnect fittings (located in the lid) are used on the BR-100 Cask. These connections can be easily replaced during loading or unloading operations.

Figure 8-1
Structural Test of Trunnions



1.0 CHECKLIST CRITERIA FOR THE REVIEW AND EVALUATION OF THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: Dominic J Sanlatte DATE: Feb. 90

CHECKLIST ITEMS	Y/N
A. DOE REQUIREMENTS: (SOW par. 4.4.1) Does the Preliminary Design Report (PDR) include the following information?	
1. Thermal and hydraulic data	Y II-2-3
2. Criticality data	Y II-2-6
3. Shielding data	Y II-2-5
4. Mechanical data	Y II-2-2
5. Calculations	Y (results of calc)
6. Handling and turnaround time estimates, estimates of capacity	Y II-2-7
7. Maintainability, reliability, operability estimates	Y II-2-8
8. Production cost estimates	Y III-5
9. Technical certification issues	Y III-6
10. Technical issues requiring experimental verification, including test results	Y III-7
11. Safety/QA issues	Y III-2
12. Preliminary drawings (11 x 17 in.)	Y V
13. Design Review Meeting minutes	Y III-4
14. Design Review Resolution Document	Y III-4&VI-5
B. DOE REQUIREMENTS (SOW par. 4.10) Does the PDR include the following trade-off studies and evaluations?	
1. Allowance of fuel burnup credit for criticality evaluations	Y Section IV
2. Reduction of the allowable 2-m dose rate from 10 to 2 mrem/hr	Y Section IV
3. Transportation of fuel aged 5 yr after discharge design basis (10-yr-old) fuel	Y Section IV
4. Transportation of high burnup fuel	Y Section IV
5. Transportation of consolidated fuel assuming consolidation ratios ranging from 1.2:1 to 2.0:1	Y Section IV
6. The effects of nonstandard and failed fuel and nonfuel-bearing materials on cask payloads	Y Section IV

CHECKLIST CRITERIA
FOR THE REVIEW AND EVALUATION OF
THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: DJS DATE: Feb 90

CHECKLIST ITEMS	Y/N	
7. Five increments of fuel burnup within range of 30,000 to 60,000 MWd/mtU for PWR and five increments within range of 25,000 to 50,000 MWd/mtU for BWR	Y	Section IV
8. Five increments of burnup within the range of 5,000 to 35,000 MWd/mtU. The lower burnup range assessment will consider the higher enrichment for lower burnup values	Y	
C. OTHER EVALUATIONS Does the PDR include the evaluations and scoping analyses performed to support key design decisions?		
1. In criticality	Y	II-6
2. In shielding	Y	II-5
3. In selection of materials	Y	II-2
4. Others		N/A
D. PDR FORMAT (Regulatory Guide 7.9) Check that the PDR follows the Table of Contents of the Regulation Guide 7.9 and that each of the following sections are addressed, even if some of them are to be completely addressed during a later phase (final design or SARP preparation).		
1. General Information	Y	
1.1 Introduction		OK
1.2 Package description		OK
1.2.1 Packaging		OK
1.2.2 Operational Features		OK
1.2.3 Contents of Packaging		OK
1.3 Appendix		OK
2. Structural Evaluation	Y	
2.1 Structural Design		OK
2.1.1 Discussion		OK
2.1.2 Design Criteria		OK

CHECKLIST CRITERIA
FOR THE REVIEW AND EVALUATION OF
THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: DJS DATE: FEB 90

CHECKLIST ITEMS	Y/N
2.2 Weights and Centers of Gravity	Y
2.3 Mechanical Properties of Materials	Y
2.4 General Standards for All Packages	Y
2.4.1 Chemical and Galvanic Reactions	
2.4.2 Positive Closure	OK
2.4.3 Lifting Devices	OK
2.4.4 Tiedown Devices	OK
2.5 Standards for Type B and Large Quantity Packaging	Y
2.5.1 Load Resistance	OK
2.5.2 External Pressure	OK
2.6 Normal Conditions of Transport	Y
2.6.1 Heat	OK
2.6.2 Cold	OK
2.6.3 Pressure	OK
2.6.4 Vibration	OK
2.6.5 Water Spray	OK
2.6.6 Free Drop	OK
2.6.7 Corner Drop	OK
2.6.8 Penetration	OK
2.6.9 Compression	OK
2.7 Hypothetical Accident Conditions	Y
2.7.1 Free Drop	OK
2.7.2 Puncture	OK
2.7.3 Thermal	OK
2.7.4 Water Immersion	OK
2.7.5 Summary of Damage	OK

CHECKLIST CRITERIA
FOR THE REVIEW AND EVALUATION OF
THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: DJS DATE: Feb. 90

CHECKLIST ITEMS	Y/N
2.8 Special Form	Y
2.8.1 Description	N/A
2.8.2 Free Drop	N/A
2.8.3 Percussion	N/A
2.8.4 Heating	N/A
2.8.5 Immersion	N/A
2.8.6 Summary	N/A
2.9 Fuel Rods	Y
2.10 Appendix	Y
3. Thermal Evaluation	Y
3.1 Discussion	Y
3.2 Summary of Thermal Properties of Materials	Y
3.3 Technical Specifications of Components	Y
3.4 Thermal Evaluation for Normal Conditions of Transport	Y
3.4.1 Thermal Model	OK
3.4.2 Maximum Temperatures	OK
3.4.3 Minimum Temperatures	OK
3.4.4 Maximum Internal Pressure	OK
3.4.5 Maximum Thermal Stresses	OK
3.4.6 Evaluation of Package Performance for Normal Conditions of Transport	OK
3.5 Hypothetical Accident Thermal Evaluation	Y
3.5.1 Thermal Model	OK
3.5.2 Package Conditions and Environment	OK
3.5.3 Package Temperature	OK
3.5.4 Maximum Internal Pressures	OK

CHECKLIST CRITERIA
FOR THE REVIEW AND EVALUATION OF
THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: DJS DATE: Feb. 90

CHECKLIST ITEMS	Y/N
3.5.5 Maximum Thermal Stresses	OK
3.5.6 Evaluation of Package Performance for the Hypothetical Accident Thermal Conditions	OK
3.6 Appendix	Y
4. Containment	Y
4.1 Containment Boundary	Y
4.1.1 Containment Vessel	OK
4.1.2 Containment Penetrations	OK
4.1.3 Seals and Welds	OK
4.1.4 Closure	OK
4.2 Requirements for Normal Conditions of Transport	Y
4.2.1 Release of Radioactive Material	OK
4.2.2 Pressurization of Containment Vessel	OK
4.2.3 Coolant Contamination	OK
4.2.4 Coolant Loss	OK
4.3 Containment Requirements for the Hypothetical Accident Conditions	Y
4.3.1 Fission Gas Products	OK
4.3.2 Release of Contents	OK
4.4 Appendix	No
5. Shielding Evaluation	Y
5.1 Discussion and Results	Y
5.2 Source Specification	Y

CHECKLIST CRITERIA
FOR THE REVIEW AND EVALUATION OF
THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: SJS DATE: Feb. 90

CHECKLIST ITEMS	Y/N
5.2.1 Gamma Source	Fuel rod sources
5.2.2 Neutron Source	End fitting sources
5.3 Model Specification	Y
5.3.1 Description of the Radial and Axial Shielding Configuration	OK
5.3.2 Shield Regional Densities	OK
5.4 Shielding Evaluation	Y
5.5 Appendix	Y (References)
6. Criticality Evaluation	Y
6.1 Discussion and Results	Y
6.2 Package Fuel Loading	Y
6.3 Model Specification	Y
6.3.1 Description of Calculational Model	OK
6.3.2 Package Regional Densities	OK
6.4 Criticality Calculation	Y
6.4.1 Calculational or Experimental Method	OK
6.4.2 Fuel Loading or Other Contents Loading Optimization	OK
6.4.3 Criticality Results	OK
6.5 Critical Benchmark Experiment	Y
6.5.1 Benchmark Experiments and Applicability	Database
6.5.2 Details of the Benchmark Calculations	Bias determination
6.5.3 Results of the Benchmark Calculations	OK
6.6 Appendix	Y

CHECKLIST CRITERIA
FOR THE REVIEW AND EVALUATION OF
THE PRELIMINARY DESIGN REPORT OF THE BR-100

REVIEW MADE BY: SJTS DATE: Feb 90

CHECKLIST ITEMS	Y/N
7. Operating Procedures	Y
7.1 Procedures for Loading the Package	Y
7.2 Procedures for Unloading the Package	Y
7.3 Preparation of an Empty Package for Transport	Y
7.4 Appendix	Y
8. Acceptance Tests And Maintenance Program	Y
8.1 Acceptance Tests	Y
8.1.1 Visual Inspection	OK
8.1.2 Structural and Pressure Tests	OK
8.1.3 Leak Tests	OK
8.1.4 Components Tests	OK
8.1.5 Tests for Shielding Integrity	OK
8.1.6 Thermal Acceptance Tests	OK
8.2 Maintenance Program	Y
8.2.1 Structural and Pressure Tests	OK
8.2.1 Leak Tests	OK
8.2.3 Subsystems Maintenance	OK
8.2.4 Valves, Rupture Discs, and Gaskets on Containment Vessel	OK
8.2.5 Shielding	OK
8.2.6 Thermal	OK
8.2.7 Miscellaneous	OK
E. <u>QUALITY ASSURANCE REQUIREMENTS</u>	
Does the PDP describe the system used on the BR-100 Project?	Y III-2

2.0 QUALITY ASSURANCE

B&W Fuel Company (BWFC) operates its Office of Spent Fuel & Waste Technology Services through a Quality Assurance Manual created to address the unique requirements of DOE's (OCRWM) Program by applying B&W's years of leadership in commercial- and defense-related quality assurance activities. The BWFC Quality Assurance Program, as described in that Manual, has been approved by the NRC (Docket Number 71-0506, Rev. 2). The BWFC Quality Assurance Program (QAP) complies with ANSI/ASME NQA-1 (1986), DOE/RW-0032 (10-85), DOE OSTS Directive DOE/RW--103 (10-86), Appendix B to 10CFR50, 10CFR71, 10CFR72, and 10CFR60. The QAP is in accordance with NRC-approved Topical Report BAW-10096A. B&W operates several facilities under ASME N-stamp approval for Section III activities, including BWFC.

The BR-100 project is conducted under the requirements of the BWFC QAP, which was approved by DOE-Idaho without comment on January 4,1989. An internal audit was performed to ensure complete implementation, and EG&G-Idaho has also performed a QA Survey/Audit of Project Operations. The internal audit had no significant findings, with only minor procedural issues identified for revision. The EG&G survey had complete agreement with the internal audit and had no findings. The issues identified by the internal audit were successfully resolved and a schedule agreed to for their implementation.

The BWFC QAP will be used for the remaining phases of the BR-100 Project. There are currently no safety/quality assurance issues for this project.

The work described in this preliminary design package was conducted in accordance with the provisions of the BWFC QAP and its implementing procedures. Highlights of QAP implementation are as follows:

- o Baseline design drawings and specifications were produced as specified in the BWFC design and document control procedures. They were independently reviewed by qualified individuals to assure their technical accuracy and released, distributed, and filed in accordance with the BWFC records-management system.

- o The structural, thermal, shielding, and criticality evaluations were conducted and documented in accordance with the BWFC procedures for calculations. These evaluations were independently reviewed by qualified reviewers to assure the appropriateness of methods used and their technical accuracy. They were released, distributed, and filed as specified by the BWFC records-management system.

- o Computer software used in the performance of the above evaluations was processed in accordance with the BWFC software control and calculation procedures. Where appropriate, the software was certified for use in accordance with these procedures.

- o The trade-off studies were performed under the provisions of BWFC engineering procedures. These studies were independently reviewed by qualified personnel to assure that all contractual requirements and technical considerations were adequately addressed. They were released, distributed, and filed in accordance with the BWFC records-management system.

- o Engineering test requirements documents were prepared as specified in the engineering test plan and in accordance with the requirements of the BWFC design verification and test control procedures. These documents were independently reviewed by qualified individuals to ensure that these accuracies reflected the test requirements and were released, distributed, and filed as required by the BWFC records-management system.

- o Procurement documents for safety-related engineering test items and test services were processed as specified in the BWFC procurement document control procedures. These documents were reviewed by BWFC QA to assure the inclusion of appropriate quality-assurance requirements. The orders for safety-related engineering test items and services were placed with BWFC QA-approved suppliers, as specified in the BWFC procedures for the control of purchased items and services. The procurement documents were released, distributed, and filed in accordance with the BWFC records-management system.

- o A preaward survey of the cask model fabrication subcontractor (Robatel) was conducted by BWFC QA as specified in the BWFC procedures for the control of purchased items and services and supplier audits. This survey resulted in Robatel being approved for order placements with restrictions on material procurement and subsequent fabrication pending the completion and implementation of certain quality-assurance plans and procedures. Due to commercial restraints imposed by DOE, the order with Robatel for the quarter-scale cask has not yet been placed. The audit documentation was released, distributed, and filed as specified by the BWFC records-management system.

- o As previously discussed in this section, an internal audit of the BR-100 project was conducted by BWFC QA. This audit was performed and documented in accordance with the BWFC procedure for internal audits. The audit documentation was released, distributed, and filed as provided for in the BWFC records-management system. Periods of internal audits will be performed throughout the life of the BR-100 project.

- o A preliminary Design Review Board (DRB) was convened to review the BR-100 Cask system preliminary design as presented in this package. This DRB was conducted and documented as specified in the BWFC design review procedure. The DRB members consisted of the Advisory Review Board members (See Section III.4) and other B&W employees selected for their expertise in thermal-hydraulic analysis, materials and structural analysis, hot cell work, cask handling operation, and quality assurance. This DRB concluded that the BR-100 cask system preliminary design was excellent and that it was capable of meeting all DOE and NRC requirements. The DRB did have a number of comments directed toward design improvements and enhancements to be considered during the final design phase. The DRB documentation was released, distributed, and filed in accordance with the BWFC records-management system. A final DRB will be conducted at the completion of the final design work.

3.0 PROJECT MANAGEMENT

In order to describe, control, and manage the project, a set of documents was issued before the start of the design phase. The general purpose of these documents, which are described in the following sections, was to assure the proper, orderly, and efficient administration of the BR-100 project, including but not limited to the administration of technical, financial, scheduling, quality assurance, NRC certification, fabrication, testing, and liaison aspects of the contract. The documents constituting the project management documentation are described in this section. They are the Project Management Plan (PMP), the Quality Assurance Plan (QAP), the Configuration Management Plan (CMP), and the Management Control System (MCS). Other documents were developed during the preliminary design phase to support the project management task but do not describe the functioning of the project.

3.1 PROJECT MANAGEMENT PLAN

The PMP is the road map of all project management activity. The primary objective of the PMP is to set forth the plans, organization, and systems for the successful completion of this contract according to the requirements of the DOE PMP (DOE-ID 10154). The major sections of B&W's PMP are described below.

Section 1. Summary
Provides a summary of the contract and an overview of the PMP content, purpose, and scope and identifies project participants.

Section 2. Objectives and Performance Criteria
Details the objectives established for this contract. These objectives are the bases for definitions of the performance criteria.

Section 3. Project Organization and Responsibilities
Identifies the divisions of B&W involved in this project as well as the main subcontractors, responsibilities, relationships, and interfaces that are required to achieve the objectives set forth in this plan.

Section 4. Work Plan
Establishes the work plan through logic diagrams, Work Breakdown Structure (WBS), and the project baseline.

Section 5. Systems Engineering
Presents the approach for using systems engineering in planning, conducting, and managing the technical work of this project.

Section 6. Project Management Control System
Describes the Management Control System (MCS). The primary goal of the project MCS is to ensure planning and execution of the project in a manner that is technically sound, timely, cost-effective, and quality- and safety-conscious. All planning is identified and correlated to the Uniform Contractor Reporting WBS.

Section 7. Quality Assurance
Establishes the Quality Assurance (QA) policy for the project.

Section 8. Implementation Plans
Describes the approach to be used in design and analysis, testing, certification, manufacturing, and subcontracting.

Section 9. Institutional Interactions
Describes the interactions with federal, state, and local governments, affected indian tribes, electric utilities, and other interested groups.

3.2 QUALITY ASSURANCE PLAN

The primary objective of B&W's QAP is to set forth the plans, organization, and systems for the successful completion of the contract according to the requirements of the DOE QMP (DOE/ID-10178). This QAP implements the BWFC quality assurance program for Spent Fuel & High Level Waste Services (56-1168014-01) which has been approved by the NRC (Docket #71-0506). This QAP is consistent with the following applicable documents: 10CFR71, DOE 5700.6b, DOE/RW-0032, DOE/RW-0103, DOE/OSTS QA Plan for Transportation Cask Systems Development Program, NRC Regulation Guide 7.10, ANSI/ASME NQA-1, and DOE/ID CSDP QMP-10178.

3.3 CONFIGURATION MANAGEMENT PLAN

This document describes how Babcock & Wilcox (B&W), through B&W Fuel Company (BWFC), implements a configuration management program in response to the requirements of the Statement of Work (SOW) for DOE-ID's Cask System Development Program (CSDP). Those requirements are outlined in DOE 4700.1. The major sections of this CMP are described below.

4.0 DESIGN REVIEWS

4.1 B&W DESIGN REVIEWS

B&W procedures require a formal review of any safety-related product at the preliminary design stage and again at the final design stage. In addition to those reviews, which are fully documented and comprehensive, the BR-100 project has quarterly reviews by an Advisory Review Board (ARB) that was selected to provide both technical and managerial oversight. The five members of the ARB are: Chairman, Dr. Hassan Hassan, Senior Technical Consultant for BWFC; David M. Frech, Senior Engineer with Duke Power Company; Michel Robatel, Chief Executive Officer of Robatel SA; Herbert Feinroth, President of Gamma Engineering; and Dr. William Harris, Chairman of the Transportation Technology Center for Texas A&M University. The B&W Design Review Board (DRB) consists of the ARB members supplemented by: Dr. Hubert Davis, Manager of B&W's Lynchburg Research Center; Charles A. Armontrout, Senior QA Engineer; Alvin D. McKim, Manager, Structural Analysis; and Dr. John MacAllister, Senior Thermal Analyst. Resumes of the ARB and DRB members are given in Appendix VI-1.

The first ARB meeting was held on February 1, 1989 and the second was on May 1, 1989. The third ARB meeting was combined with the formal (internal) B&W Preliminary Design Review and was held on September 28 and 29. Recommendations from the three meetings are given in Section 4.1.1 and actions taken by the project team in response to those recommendations are listed in Section 4.1.2.

4.1.1 Recommendations

The February 1 meeting of the ARB resulted in the following technical recommendations to the BR-100 project team:

1. Perform adequate sensitivity studies to ensure an optimum combination of capacity, turnaround time, fabrication costs, and development costs. These factors drive life-cycle cost.
2. Thoroughly investigate the proposed use of aluminum as a basket material; limit vibration and fatigue stresses.
3. Incorporate features where possible to enhance postaccident handling.
4. Design the dewatering system to minimize flow blockage.
5. Incorporate a railcar designer/fabricator into the design effort.

6. Pursue the use of burnup credit to increase capacity.
7. Adopt a fuel cavity that realistically accepts all PWR and BWR fuel.
8. Incorporate, if possible, the ability to transport (PWR) control components or (BWR) channels within host fuel assemblies.

The May 3 meeting of the ARB had these technical recommendations:

9. Investigate the feasibility of using a unit-basket construction instead of a basket requiring some fixturing inside the cask body.
10. Incorporate testing where needed to ensure proper reliability.
11. Incorporate a span on test temperatures to allow as much flexibility as possible in design use.
12. Review calculational techniques and assumptions to ensure that realistic, but not overly conservative, methods are being used.

The September 28/29 ARB/DRB meeting had these design-related recommendations:

13. Review closure bolt head-to-shank transition to see if a compound radius would reduce stress; also investigate rolled threads instead of machined.
14. Document the basis for selection of 250°F temperature limit for normal operation of the borated concrete.
15. Perform testing to define material limits as well as predicted behavior of the new Cermet material.
16. Investigate the use of a removable skid that contributes structural strength to the railcar (this could help provide a sturdy transporter while minimizing weight).
17. Obtain component weight feedback from review of fabrication drawings and establish a matrix to track crane-hook and gross-vehicle weights.
18. Define shielding conservatisms in terms of weight reduction potential; can crane hook weight credit be obtained for BR-100 in-pool dewatering.
19. Develop realistic fabrication and QA procedures for the Kevlar casings on the impact limiters.
20. Ensure compliance with NUREG 0612 with current strategy on lifting equipment.
21. Incorporate more automation into the cask handling equipment.
22. Put chamfer or radius on bottom edge of shield plug to aid remote insertion into cask.
23. Investigate the effective lifetime of proposed paint coating on the outside of the cask.

24. Investigate the use of threaded inserts in the cask body for closure-lid and impact-limiter fasteners. This could prevent galling and associated problems.

4.1.2 Item Resolution

The following actions were taken in response to the recommendations above:

1. Thorough sensitivity studies were made of neutron absorber materials and flux traps to minimize cell pitch and maximize capacity. Studies were also made of shielding materials, basket construction, dewatering techniques, and fastener designs. The results of those studies were incorporated into the BR-100 design.
2. The use of aluminum was judged by the project team to be acceptable if the following design rules were used: No welding on the fuel cells or any component required for criticality control, no operating temperatures over 350°F, hard anodize for enhanced corrosion and wear resistance, and use ASME-grade material for structural applications. A thorough analysis will be performed using the Association of American Railroad values for vibration input to ensure fatigue margins.
3. In response to this recommendation, the BR-100 was fitted with four trunnion locations on the bottom end; two will be fitted with blanks but will be available if needed. It was noted that the borated concrete neutron shield will not lose significant effectiveness, even after accidents more severe than required by regulation, thereby ensuring a post-accident dose rate much below federal limits.
4. The BR-100 uses a dewatering system that initially drains through a large 2-in-diameter pipe and fitting. Final dewatering is through a 1/2-in line and fitting. Care was taken to minimize obstructions in the drain paths.
5. A railcar design/operations consultant, Victor Nelson of Nelson Associates, was contracted to help evaluate design proposals and provide an overcheck on vendor performance.
6. The use of burnup credit was evaluated as part of a required trade-off study (see Section IV-1). The benefit of using burnup credit was evaluated and found to be worth the additional licensing effort.
7. BWFC reviewed its design of the Three Mile Island Unit 2 (TMI-2) defueling canister and the design of other storage racks and shipping casks and decided on the following criteria: 8.72-in minimum square with a 12.306-in minimum diagonal for PWRs, 5.72-in minimum square with a 7.675-in minimum diagonal for BWRs.

8. BWFC designed the BR-100 fuel cavities to be structurally and dimensionally compatible with control component or channel payloads.
9. BWFC reviewed peak basket temperatures with the unit basket, which allows a maximum gap of 0.050 in to the inner cavity wall and the "spread" basket, which forced good conduction paths all around the basket. The unit basket was found to cause peak temperatures only about 10°F higher if a helium fill gas was used. The expected margin in aluminum temperatures allowed the less complex, faster changeout, unit basket to be incorporated into the baseline design.
10. Various aluminum, Cermet, coating, and seal reliability tests have been incorporated into the proposed BR-100 test program (Section VI-2) per NRC and ARB recommendations.
11. The span of material and component test temperatures has been checked to ensure overlap of expected performance with allowance for margin.
12. BWFC techniques and assumptions for structural, shielding, and criticality analyses have been reviewed by us against known benchmarks. EG&G has also had the shielding methods of all cask vendors checked by independent reviewers; BWFC's methods were found to be appropriate.
13. The changes suggested will be reviewed early in Phase 2
14. Robatel has performed tests and has rationale to support the 250°F normal operation. This information will be documented in a B&W calculation by December 1, 1989.
15. Scoping tests now in progress will determine the feasibility of Cermet for the proposed application. If the material appears feasible, a more rigorous testing program in Phase 2 will determine the parameters requested.
16. This concept is promising and will be investigated in Phase 2.
17. This will be done in Phase 2.
18. Weight/dose-rate trade-offs will be investigated in Phase 2 at the ends of the cask. Although DOE has indicated that the BR-100 may not take credit for the water physically removed by an operation designed to be routine, the resulting conservatism with respect to the BR-100's crane hook weight (about 10,000 lb) is significant.
19. This is an integral goal of the impact limiter development program. Procedures will be available about midway through Phase 2.
20. Current BR-100 strategy is to design the handling equipment lifting arms and cask trunnions with a safety factor of 10 to ultimate strength. This would allow a two-point lift of the cask and lead to easier and quicker turnaround times. Compatibility with cranes that are not single-failure proof is achieved by having the spreader bar provide access to two crane hooks (as well as one

hook when that hook meets standards). Confirmation of the feasibility of this strategy will be accomplished through contracts with relevant utility personnel.

21. The cask handling equipment will be redesigned early in Phase 2 to incorporate lifting arm actuators, proximity sensors, and other features to improve remote operation.
22. This feature will be incorporated at the start of Phase 2.
23. A literature search and experience profile will be performed by completed early in Phase 2 to document the performance and expected lifetime of the proposed coating. A test program will be proposed in Phase 2 if results of the survey are not conclusive.
24. The use of threaded inserts will be investigated early in Phase 2.

4.2 DOE TECHNICAL REVIEW GROUP DESIGN REVIEW

The Department of Energy, through its support contractor, EG&G-Idaho, assembled an eleven-member panel of technical specialists to review the BR-100 preliminary design. Appendix 5 presents the report from this Technical Review Group (TRG) and lists all comments from each member. Each comment has been assigned an identifying number. B&W's response to each comment is keyed to the appropriate comment identifier.

5.0 PRODUCTION COST ESTIMATE AND SCHEDULE

5.1 SUMMARY

Fabrication costs and schedules have been determined for quantities of 10, 25, and 50 casks. These estimates are based both on the updated data from B&W's original cask proposal R&D 86-206 and from new estimates for those parts of the cask that have been significantly changed. Prices are in 1989 dollars and include a G&A and profit that B&W considers appropriate for cost-plus-fixed-fee contracts. The prices include:

- o The cask body (with its shield plug, lid, bolts, and gaskets),
- o The PWR or BWR basket,
- o Two impact limiters,
- o All inspections and acceptance tests, and
- o Project management.

For a BR-100 cask in its PWR version, the price varies from $1,725,000 to $1,515,000, while the schedule varies from 42 months for 10 units to 122 months for 50 units. This production schedule is based on the use of only one facility. The schedule assumes 1) that the design, development, and certification of the BR-100 and fabrication of two prototypes have been completed before the purchase order and 2) either all units are ordered together or cumulative orders are placed with sufficient lead time that material orders can be made and manufacturing setups retained for continuous fabrication. Significantly faster delivery of large quantities can be accomplished using two facilities at a slightly higher cost.

5.2 DETAIL COST ESTIMATES

Description	Cost/Unit 10 Units ($)	Cost/Unit 25 Units ($)	Cost/Unit 50 Units ($)
Cask Body	1,282,000	1,176,000	1,128,000
Basket (21 PWR)	211,000	199,000	189,000
Basket (52 BWR)	317,000	298,000	284,000
Impact Limiters (2 per)	177,000	159,000	143,000
Assembly/Testing/P.M.	55,000	55,000	55,000
Total Cost BR-100 PWR	1,725,000	1,589,000	1,515,000
Total Cost BR-100 BWR	1,831,000	1,688,000	1,610,000

5.3 SCHEDULE

The first cask is anticipated to be delivered within 24 months after order placement. Most of the fabrication time is necessary for procurement of the long lead items and for the preparation of facilities, preparation of detailed procedures, and training of personnel. Using one facility, a delivery of one cask every two months after the first cask is anticipated. In that scenario, the delivery of the series would be as follows:

10 Casks	42 months
25 Casks	72 months
50 Casks	122 months

6.0 TECHNICAL CERTIFICATION ISSUES

Babcock & Wilcox has had many topical reports approved and many products certified by the NRC. The key to any successful certification effort is good communications interface between the design and analysis engineers and the NRC reviewers. With this strategy, certification issues may be identified early and NRC concerns may be addressed as part of the normal design development process.

To establish an understanding of what the NRC considers necessary for a successful design review, BWFC has met with the NRC's Transportation Branch three times during the preliminary design phase. Representatives from DOE-HQ and EG&G were present for these presentations. NRC personnel representing all the major technical areas of cask review attended the meetings. BWFC used these meetings to brief the NRC staff on the BR-100 cask design and the proposed analysis and testing plans for evaluating the cask materials and design. Feedback from the NRC during these discussions helped identify potential concerns that could escalate into certification issues during the SARP review. The informal format used for these presentations was conducive to an open exchange of ideas and concerns between the NRC and BWFC. Of special concern were areas of discussion that are uniquely applicable to the BR-100 design. The meeting minutes documented the major areas of discussion and were used as a basis for developing an integrated plan to address the NRC concerns during the final design phase of the BR-100 development program. The NRC has assigned Docket Number 71-9230 to the BR-100 Cask.

Unique features of the BR-100 cask design that were identified by the NRC for special emphasis are listed below:

1. Thermal Switch/Neutron Shielding - The qualification of the borated concrete, both as a new material and with regard to its role in the overall performance of the cask system, was the subject of several comments from the NRC. Since the concrete is not a standard ASTM material, BWFC must qualify its performance. The engineering test program will verify the properties and performance of the concrete and characterize it in terms of chemical composition, consistency, structural behavior, and thermal parameters, including the affects of aging. Concrete performance, as related to its structural role during the drop accident and as part of the thermal switch during thermal accidents, will be addressed

using analysis techniques that have been benchmarked by testing of prototypical samples.

2. Criticality Control - B_4C Cermet - During the discussions on the B_4C Cermet, the NRC expressed interest in the Cermet fabrication techniques, especially in the control and verification of boron density. BWFC feels that the fabrication of the Cermet is a more controlled process than that used for Boral plates and that the Cermet can be readily inspected using nondestructive techniques as part of the manufacturing quality assurance inspection. Therefore, a boron distribution penalty factor may not be required for the Cermet plates. Qualification tests by BWFC as part of the engineering test program will verify the consistent boron loading as well as the structural properties of the Cermet.

3. Closure Seals - The NRC has indicated that testing of the closure seals should address the full range of temperatures associated with operational and accident conditions and that full-scale testing of the seal configuration is preferred. BWFC will address these concerns in the qualification testing of the seals. Results from the seal testing being performed by SNL will be used in establishing the seal design for the BR-100 and in the selection of the seal material.

4. Impact Limiter Design and Verification - Areas of concern, identified by the NRC during discussions related to the impact-limiter design, included the role of the Kevlar composite in the performance of the impact limiter, fabrication techniques for both the Kevlar and the balsa/redwood sections, consequences of a thermal accident, and the type and amount of testing to be performed to verify the design. As part of the engineering testing, BWFC plans to fully characterize the behavior of the limiter for both normal operation and hypothetical accident conditions. Force deflection data for the limiter at various impact angles will be available to the NRC for use in confirmatory analysis.

   BWFC plans to base the impact-limiter design to a large extent on the results from the engineering test program. Analysis techniques will be used to determine the worst-case angle of impact for the oblique drop case. The ILAN computer code is being developed by BWFC to determine the relationship between the angle of impact and the stress levels in the various cask components. The code will be benchmarked using the results from the testing program.

5. Burnup Credit - The BR-100 is subcritical for most fuel types using a fresh fuel assumption in the criticality analysis. An exception is shipments of some selected fuel types, mainly fuel with higher initial enrichments where BWFC

the DOE is pursuing the development of a means of measuring or otherwise verifying fuel burnup. The SARP for the BR-100 will identify specific requirements for the cask contents. BWFC plans to request that the NRC evaluate the cask design performance based on these restrictions. After a successful review, the NRC would identify these restrictions on the Certificate of Compliance. This approach would effectively decouple the BWFC cask certification effort from the burnup measurement issue being addressed from a more generic perspective by the DOE.

cycling, the samples will be examined for changes in concrete integrity, lead/copper joint cracking, and any material interface interactions.

6. Flat, circular disks with combinations of stainless steel, concrete, lead, and thickness of stainless steel will be impact loaded to establish the deformation resistance of the thermal/neutron shield materials under impact loading conditions. Weights and drop heights will be varied to span a range of impact conditions.

7.2 ALUMINUM BASKET

BWFC is using aluminum in the BR-100 basket for structural applications by applying several constraints. Low temperatures, enhanced wear and corrosion protection, use of ASME-grade material, and avoidance of welds are used to optimize performance and licensability. Concerns about brittle fracture are minimized by carefully chosen design parameters and a rigorous fracture mechanics analysis. A test program has also been established to confirm the reliability of the aluminum under simulated worst-case environments. The program includes the following elements:

1. Aluminum wear testing will be conducted on hard-anodized aluminum samples using typical fuel assembly components as the opposing wear surface. Both abrasive wear and contact wear properties will be investigated to confirm the wear resistance of the aluminum afforded by the hard-anodizing treatment.
2. Corrosion testing of the anodized aluminum will be conducted by exposing samples to alternating environments of simulated spent-fuel storage-pool water and an elevated-temperature helium gas. The tests will be conducted on scratched and bare aluminum as well as anodized aluminum samples to demonstrate the effects of the hard-anodizing treatment on the corrosion resistance of the fuel cell material.
3. Tension and compression tests will be conducted on specimens cut from a full-size fuel cell manufactured using prototypical fabricating techniques. The tension and compression strength and ductility properties will be measured at nominal strain rates as well as at rates anticipated during a cask drop accident.
4. Full-size fuel cell sections will be subjected to cask drop accident loading conditions including both fuel assembly and fuel cell loads. Various drop orientations will be simulated. The mechanical response of the fuel cell to the drop accident loading will be confirmed by these tests.

7.3 CERMET NEUTRON ABSORBER

BWFC has, in coordination with Advanced Refractories Technologies, developed an innovative ceramic-metallic (Cermet) material that uses powder metallurgy to provide a high-density B_4C product. The Cermet has a core composed of approximately 60% B_4C and 40% aluminum, all clad with a sheet of 0.005- to 0.010-in aluminum. To provide data on the chemical, neutron absorption, and mechanical properties of this Cermet, the following tests have been planned:

1. Bend tests will be conducted on prototypical neutron absorber plates to simulate potential loading of the plates by the fuel cell walls during a drop accident. The plates will be tested in the as-fabricated condition and after exposure to both thermal cycling and vibrations anticipated during operation of the BR-100 cask.
2. The neutron attenuation characteristics of the neutron absorber plates will be established using neutron source/detection methods. This will be done on a number of plates fabricated at different times to determine the variability of the manufacturing process. The homogeneity of the B10 within the plates will be determined by sectioning a plate and measuring the B10 as a function of position using surface analysis techniques.
3. The resistance of the neutron absorber plate to corrosion in the spent fuel storage pool water will be measured by exposure to simulated storage pool water. The integrity of the aluminum coating will be confirmed by analyzing the test water for boron content.

7.4 WOOD/KEVLAR IMPACT LIMITER

The BR-100 has an innovative impact limiter that provides cushioning of impact loads in a package that weighs as little as half of other designs. By using balsa and redwood for energy absorption combined with a Kevlar containment barrier, an extremely efficient package is formed. Although a proprietary performance code is being used to predict optimal angles of impact, the design is based on test iteration of progressive models. Static and dynamic tests at various angles of impact are being used to derive an acceptable design.

7.5 CASK OUTER COATING

A coating is planned for the BR-100 outer surface for two reasons. First, the thermal advantage of a coating with emissivity values in the infrared band of about 0.90 is significant, resulting in a temperature drop of about 20°F on the cask surface when compared to a standard unpainted surface. Second, a hard, durable, painted surface may provide ease of surface decontamination and minimize "weeping." A two-part epoxy paint has been recommended by several manufacturers. Testing is planned to ensure the thermal characteristics of the proposed coating. The emissivity of the outer surface coating will be measured over both the solar and infrared band of wavelengths to help establish the effectiveness of minimizing the cask outer surface temperature.

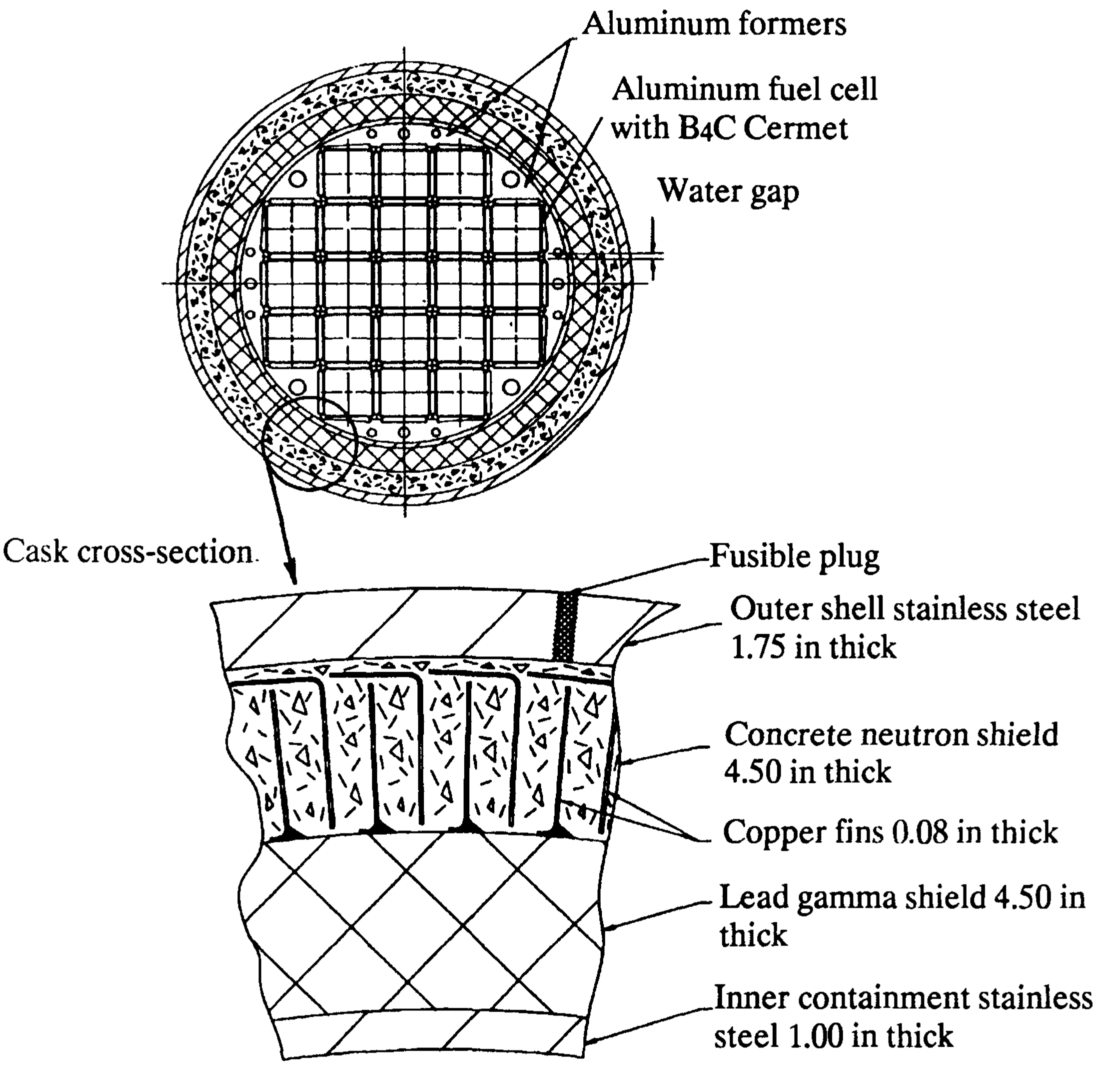
7.6 SEALS

The BR-100 uses a bolted closure lid with double O-ring face seals made of a low-temperature Viton. Sandia National Laboratories is performing preliminary tests on the Viton material. If those tests indicate acceptable performance, full-scale component tests will be run to verify seal leaktightness with the specific BR-100 seal configuration.

7.7 QUARTER-SCALE MODEL TESTS

To complete its set of regulatory tests, BWFC plans to perform three drop tests (end, side, and oblique) and two puncture tests (end and side). Those tests will be performed sequentially on one model. Several impact limiters will be used. Based upon discussions with the NRC, it is believed that quarter-scale testing is acceptable. Thermal and immersion tests are not planned because of the accuracy of computer models and the magnitude of the predicted performance margins.

Figure 7-1
BR-100 Cask
Multilayer Cask Wall



8.0 RAILCAR DESIGN

The railcar designed for transportation of the BR-100 cask is shown in Figure 8-1. It is designed to be approved by AAR for unlimited interchange service, therefore, design and operation will comply with the following AAR requirements:

1. AAR Mechanical Division Manual of Standards and Recommended Practices, Sections A-L;
2. Field Manual of the AAR Interchange Rules;
3. Office Manual of the AAR Interchange Rules;
4. Hazardous Materials Regulations of the Department of Transportation by Air, Rail, Highway, Water and Military Explosives by Water, Including Specifications for Shipping Containers (AAR Bureau of Explosives Tariff BOE-6000-F);
5. Emergency Handling of Hazardous Materials in Surface Transportation (AAR Bureau of Explosives);
6. The Official Railway Equipment Register; and
7. Railway Line Clearances.

The railcar design is based upon AAR Specification M-1001 and special BWFC/Federal Railroad Administration (FRA) requirements. To insure that the cask is designed for operation to the highest standards of safety and reliability, some interactions with the AAR Car Construction Committee are anticipated during the final design phase. BWFC is using an independent consultant to review the railcar design. The consultant will also be used to generate maintenance and operation manuals/procedures.

The railcar will be of all-welded construction using ASTM A-572 low-alloy high-tensile steel plates, bars and shapes. This material has a minimum yield strength of 50 ksi with an option to use higher grades if necessary for weight reduction.

The railcar will be designed to allow for visual inspection of load bearing welds and consist of the following:

- o A longitudinal box beam between truck centers.
- o Longitudinal draft arms extending from the box beam to support the couplers and associated end-of-car cushion units.

- o Transverse body bolsters at the truck centers to provide for side bearings and jacking requirements.
- o Transverse supports and platforms just inboard of the couplers to provide for safety appliances and cross-over platforms to be used by railroad crews (FRA requirement).
- o Local reinforcements and transverse extensions to the central box beam to provide shear connection and support for the cask cradle.

The railcar running gear will consist of:

- o Trucks will be standard AAR three-piece cast-steel construction with built-in snubbers and D-5 springs and will include 36-in diameter steel wheels, 6-1/2 x 12-in roller bearings, 4-1/4-in spring travel, and column guide friction snubbing.
- o Brakes will be a standard ABDW system with SC-1 load/empty feature with 8% minimum net braking ratio for a loaded car and 27% maximum net braking ratio for an empty car at 50 psi brake-cylinder pressure. Brakes will also include truck-bolster mounted brake cylinders and a mechanical hand brake mounted at one end of the car and acting on the adjacent truck. The hand brake will be AAR certified with a net braking ratio of 11% minimum and 12% maximum.

Draft arrangement will consist of a bottom shelf type "E" coupler and a 15-in stroke, gas return end-of-car cushion unit.

General Dimensions of the Railcar are as follows:

o	Length over side of couplers	47' 6"
o	Length over strikers	42' 6"
o	Length between truck centers	28' 6"
o	Deck height - Light car above top of rail	3' 6"
o	Extreme width	10' 6"
o	Clearance diagram	AAR Plate "B"
o	Estimated weight	45,000 lb max

The dimensions comply with the minimum length requirements of AAR Specification M-1001 and with Cooper's E60 requirements.

Optional provisions can be made on the car for auxiliary equipment which can either be permanently installed or removable. These can include:

- o Personnel barrier
- o Platforms, walkways, ladders, etc.

- o Cradles with or without tracks and trolleys for handling impact limiters on the car.

Safety

There will be no open areas on the railcar deck that would allow potential of concealment or placement of dangerous or undesirable materials.

The position of the center of gravity of the cask system is estimated to be 92 in above the top of the rail which is close to the 98-in maximum as defined in AAR M-1001 Section 2.1.3. Therefore evaluation of the necessity of damping to control harmonic roll will be performed during final design.

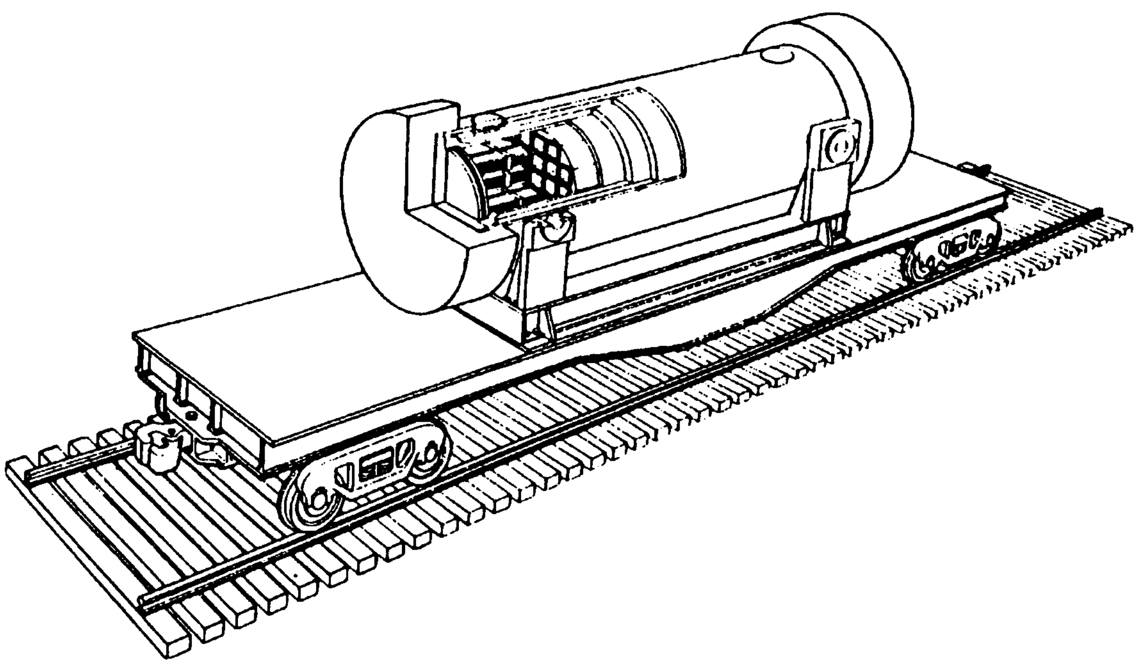
The BR-100 railcar will be subjected to a test program as specified in AAR M-1001 section 1.3 to assess its track worthiness.

It is not required by AAR regulations to specify the ride quality of a railcar transporting a spent fuel cask. However, in order to achieve the highest possible performance of the BR-100 cask system, an acceptable level of ride index will be specified during final design. This ride index will be consistent with structural analysis and testing results on the cask system components.

The Gross Vehicle Weight (GVW) of the railcar/skid/cask package will be close to the 263,000-lb limit when loaded with the heaviest design payload. Because of that weight, no supplemental handling equipment will be carried on this railcar. Should the allowable GVW be increased to 312,000 lb, features will be added to allow concurrent shipment of the tooling and spare parts needed for reactor use of the BR-100.

Figure 8-1

BR-100 Cask



9.0 ANCILLARY EQUIPMENT DESIGN

Ancillary Equipment is defined in the contract Statement of Work, Appendix B, to include protective enclosures, lifting and tiedown devices, impact limiters, special tools, placards and labels/marking, sensors and instrumentation, draining/drying/inerting/testing equipment, contamination control and removal equipment, operating and maintenance manuals, skids/transport frames, intermodal equipment, safeguard devices, spare parts, and other miscellaneous equipment.

For the purposes of B&W's Work Breakdown Structure, several items were removed from this category and addressed in other sections of the main design report: Impact limiters are considered part of the licensed cask system; and Operating and Maintenance (O&M) Manuals for the cask, although O&M Manuals for the equipment will be supplied with them. Placarding is covered by DOT regulation and does not require discrete design efforts, while spare parts will be defined during the final design phase.

The balance of those items will be presented in this section to the extent that BWFC has developed them. The expenditure of significant efforts on the design of equipment whose function may change appreciably over the next year was judged not to be wise; accordingly, most of the equipment descriptions and designs will range from conceptual to preliminary. BWFC does have confidence that the final design of these items will meet all regulatory and customer requirements.

9.1 SHIPPING SKID

The BR-100 rail/barge cask and its associated railcar and shipping skid is depicted in Figure 9-1. The personnel barrier and impact limiters are shown in Figure 9-8. The shipping skid is designed for intermodal service by being compatible with railcar and barge interfaces and by allowing the cask to be lifted while fixed on the skid in a horizontal position.

Figure 9-2 is an isometric view of the shipping skid. It is fabricated from standard structural shapes and plates using high-strength steel and is welded into the concept depicted. The concept employs the use of saddle supports in the vicinity of the upper cask trunnions and trunnion supports at the lower trunnions. The skid is bolted to the transport vehicle, and shear blocks are bolted to the deck and shimmed to eliminate any potential for sliding.

The shipping g-loads of 4 g vertical, 7.5, g longitudinal and 1.8 g lateral were derived from Rule 88 A.1.d (Appendix A) of Association of American Railroads Field Manual of Interchange Rules. These factors provide a very conservative design requirement and will result in a rig which approaches the maximum weight while providing assurance for safe use.

9.2 LIFTING AND TIEDOWN DEVICES

The upper cask trunnion lifting/upending fixture (Figure 9-3) is used by itself to transport the cask to or from the shipping skid. It is also designed to support a portion of the weight of the skid and cask when moving the skid/cask assembly to or from the transporter. The lifting/upending fixture is designed to be compatible with double-slung crane-hook systems and uses two cask trunnions for all lifting and upending functions. It fully meets all criteria of NUREG-0612. The cask lifting yoke fixture is capable of remote, automated operation. The electric motor with screw drive (or pneumatic drive) causes rotation of vertical arms (Figure 9-3) which can be attached or removed from the lifting trunnions remotely.

To be installed on the skid, the cask is first lifted by the upper cask trunnion lifting fixture, which attaches to two of the upper trunnions of the BR-100 cask (Figure 9-4). After positioning the cask over the trunnion stanchion on the shipping skid, the cask is lowered until the cask trunnions engage the trunnion stanchions. The lower trunnions are set 1 inch off of the cask center of gravity, thus causing the cask to tip in the correct direction for downending. The trunnion caps would then be loosely installed to prevent the cask from coming out of the trunnion fixture during the cask rotation. Slowly traversing the crane toward the saddles while lowering the cask causes the cask to settle into the saddles which are shaped to the cask outside diameter.

The lifting fixture is then removed and U-bolts placed over the cask and threaded into the supports at the saddles. The U-bolts and trunnion caps can now be final torqued for shipment.

Intermodal lifting is accomplished with the lifting-upending fixture and the lower skid lift rig (figures 9-5 and 9-6). The upending fixture attaches directly to the cask trunnions. The lower rig attaches to the trunnions on the skid. Intermodal lifting alternatives include two crane lifting, double hook or double-slung hook systems and single point lift with spanner bar (Figure 9-7).

9.3 PERSONNEL BARRIER

The personnel barrier (Figure 9-8) is installed after the cask is placed on the skid. The cask/skid assembly cannot be moved with the personnel barrier in place since it makes the upper trunnions inaccessible. The personnel barrier may be used while the cask/skid assembly is stored on site or while being moved by rail or barge.

The personnel barrier fits around the cask following the outer contour of the impact limiter and attaches to the skid. Both cask trunnions will be covered by the aluminum angle frame/chain-link barrier. The maximum space between the barrier and the impact limiters is estimated to be 1 in.

The personnel barrier may be removed for access to the cask trunnions and skid U-bolts by unbolting it from the skid. Lifting lugs on the top of the barrier permit it to be removed without further disassembly. Access openings may be installed in the barrier should specific areas need to be reached.

9.4 SPECIAL TOOLS

Several special tools are anticipated for operation and maintenance of the BR-100 cask. The closure lid bolts are torqued and untorqued using a unique one-way spinner/ratchet mechanism that provides antitamper safeguards. The closure lid and shield plug are handled by means of a shared lifting tool that attaches to a crane hook and provides a hand-actuated locking feature. Commonly used slings and hand tools will be required for several operations, but they should be routinely available.

9.5 SENSORS AND INSTRUMENTATION

No sensors or instrumentation will be used on the cask itself. A mounting location on the skid will be provided for the satellite tracking system transmitter after its interfaces are defined.

9.6 DRAINING, DRYING, INERTING, AND TESTING EQUIPMENT

The dewatering of the BR-100 cask is performed before the cask is lifted from its loading location in the spent fuel pool. A control system that contains all the pumps, flowmeters, and instrumentation will sit poolside and pressurize the cask with dry air or nitrogen, thus displacing the interstitial water through a drain tube within the cask (only one 2-in line will go into the pool for this task). The cask will be further dried by using a vacuum system contained within the control panel. The cask will then be inerted with a partial atmosphere of helium also by using the control panel.

The performance of the check port and closure seals will be tested by portable helium leak-detection equipment commonly used at reactor sites.

9.7 CONTAMINATION CONTROL AND REMOVAL EQUIPMENT

The BR-100 cask is coated on its sides with a hard epoxy paint which minimizes "weeping" problems.[1] This paint is expected to last for several years without needing replacement. Its removal is expected to be accomplished using grit blasting equipment routinely employed at maintenance facilities. No special tooling is anticipated.

9.8 INTERMODAL EQUIPMENT

The shipping skid is compatible with intermodal usage, thus requiring only a spanner bar lifting tool (Figure 9-7) to allow it to be used in that fashion. The intermodal lifting tool uses as one of its components the upper cask lifting fixture described in Section 9.2. The cask/skid assembly is lifted using two cask trunnions and two trunnions integral to the skid. No other equipment is anticipated for intermodal use of the BR-100.

9.9 SAFEGUARD DEVICES

Other than the tamper-proof bolts used on the closure lid, no safeguards are anticipated for BR-100 cask shipments. The size and complexity of the package precludes any quick action to obtain access to the spent fuel, even if that were desired, while the satellite tracking system would prevent mislocation of the railcar and its contents.

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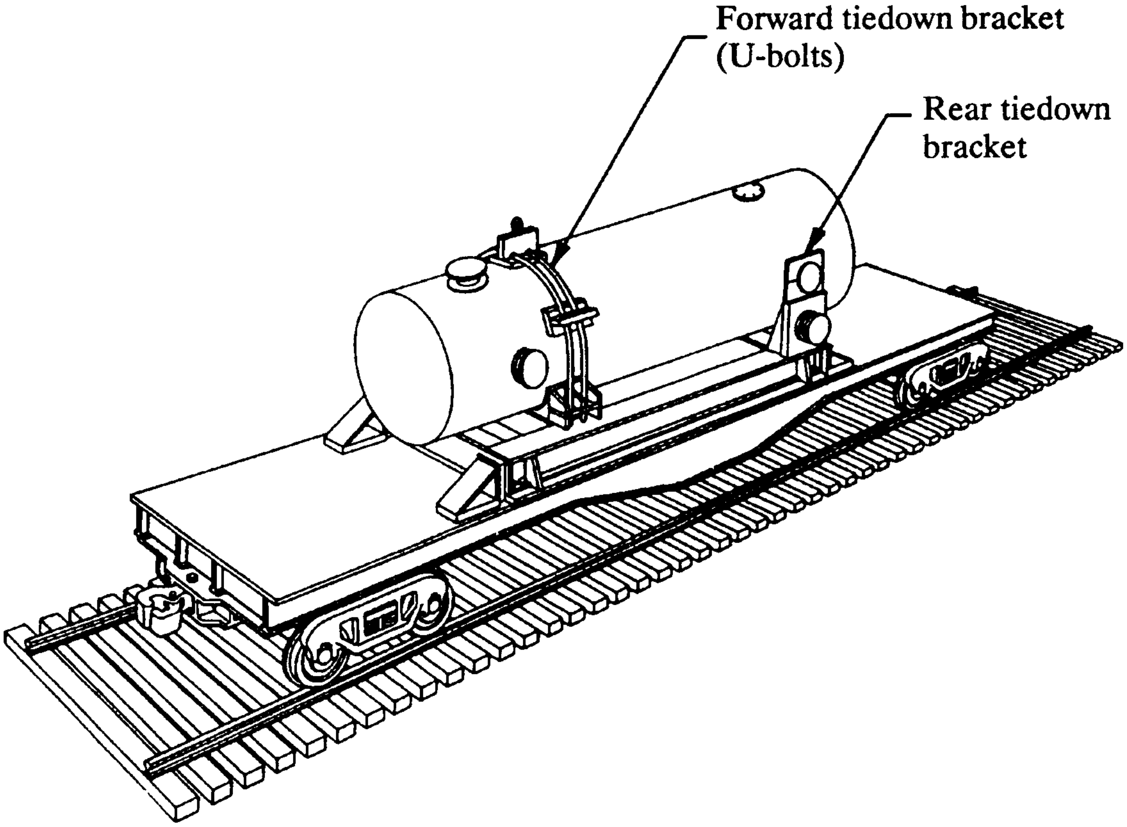
[1] P. C. Bennett, *et. al.*, "In-Service Analysis of Cask Contamination Weeping," SAND--89-0914C, 1989.

Figure 9-1

Cask Tiedown



Note: Personnel barrier and impact limiters not shown for clarity.

Figure 9-2
Cask Shipping Skid

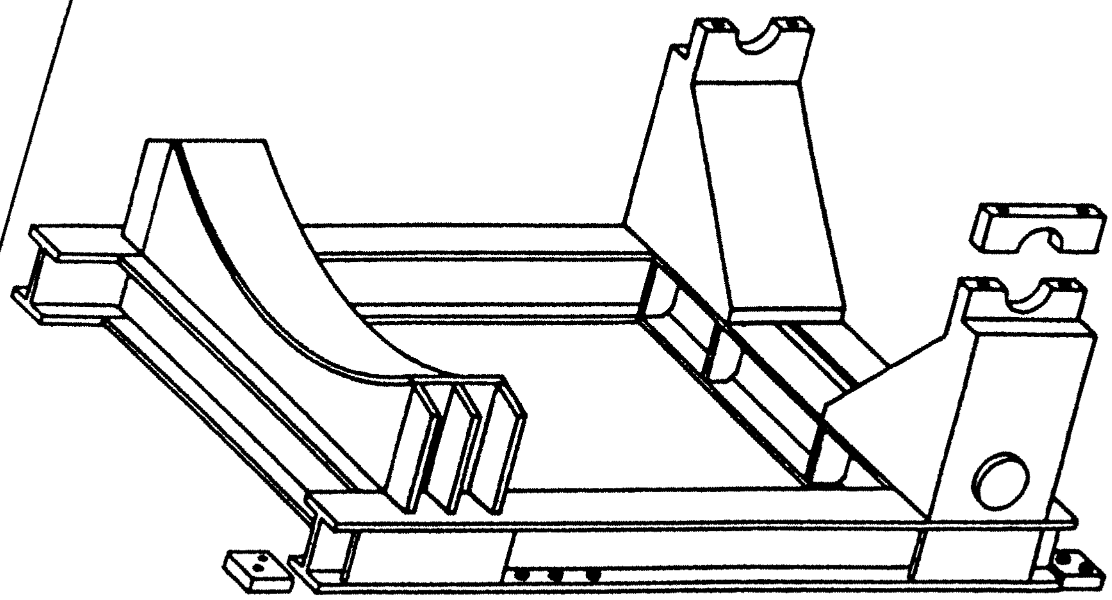


Figure 9-3
Upper Cask Trunnion Lifting/Upending Fixture

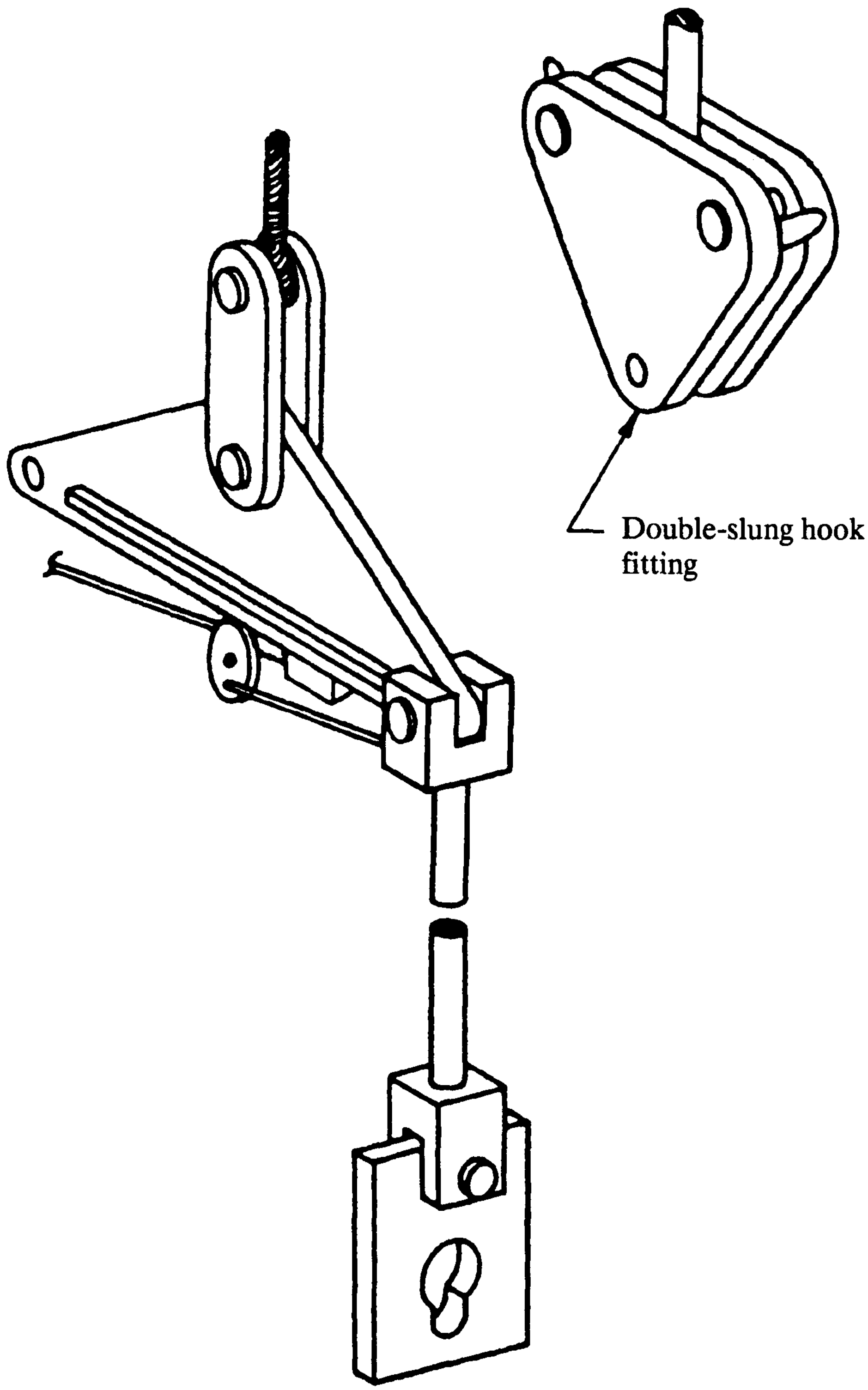


Figure 9-4
Cask Lifting

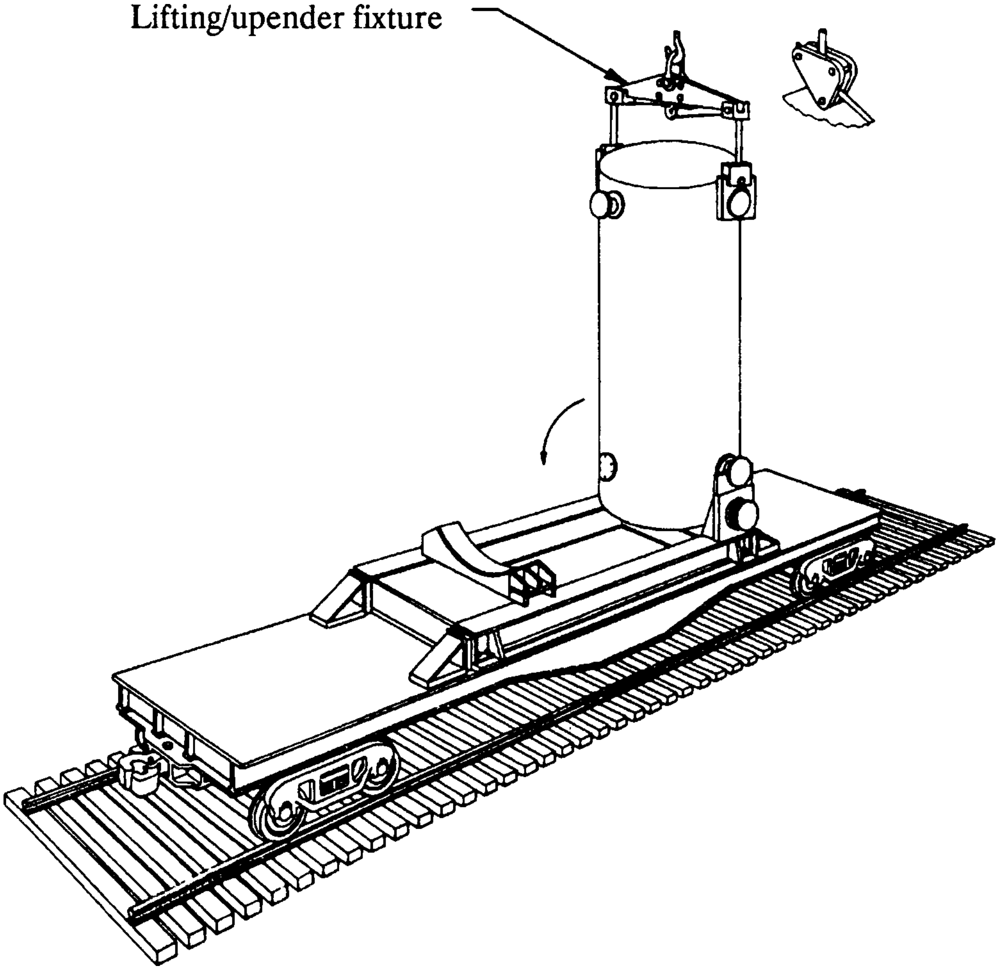


Figure 9-5
Lower Skid Trunnion Lift Rig

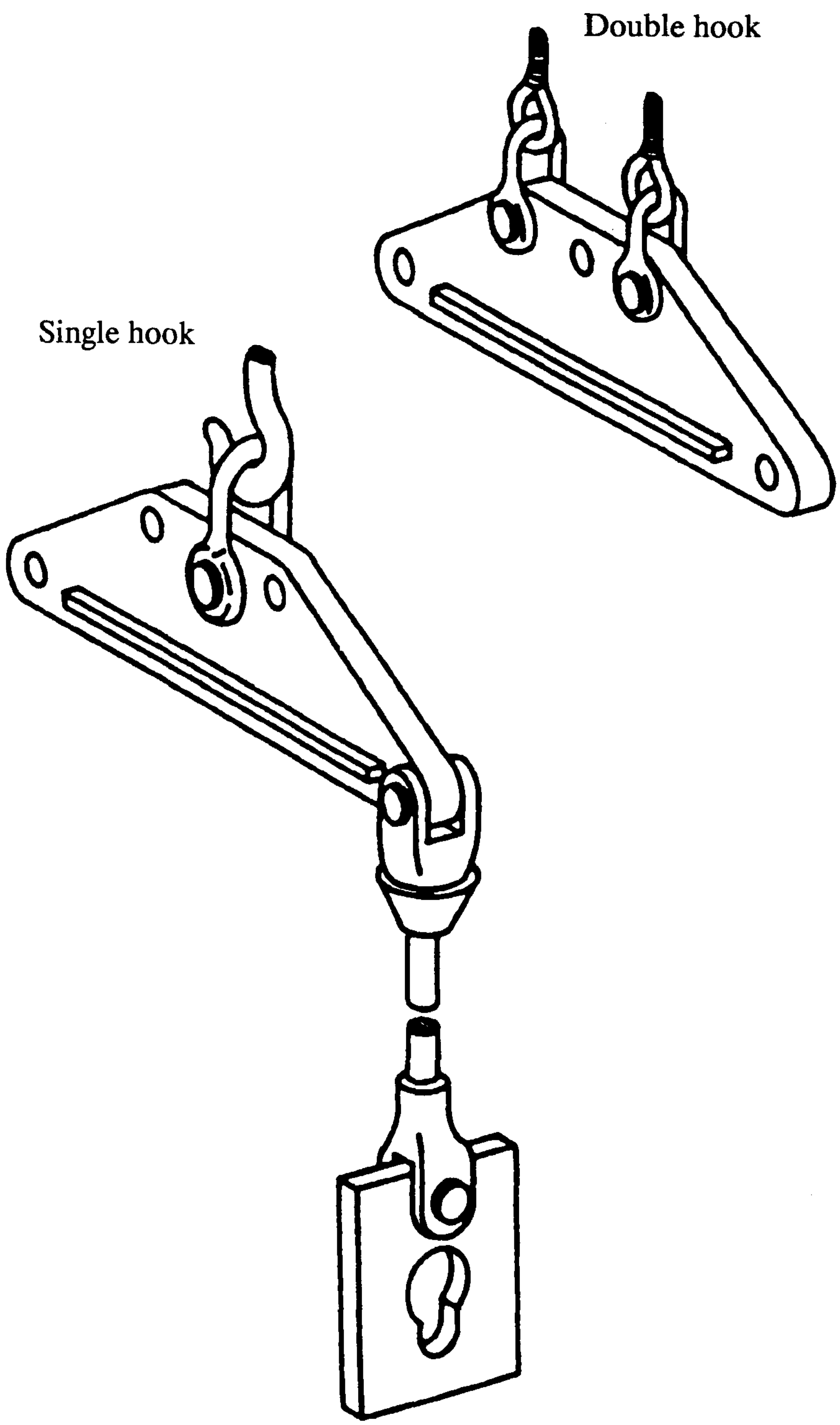


Figure 9-6
Intermodal Lifting

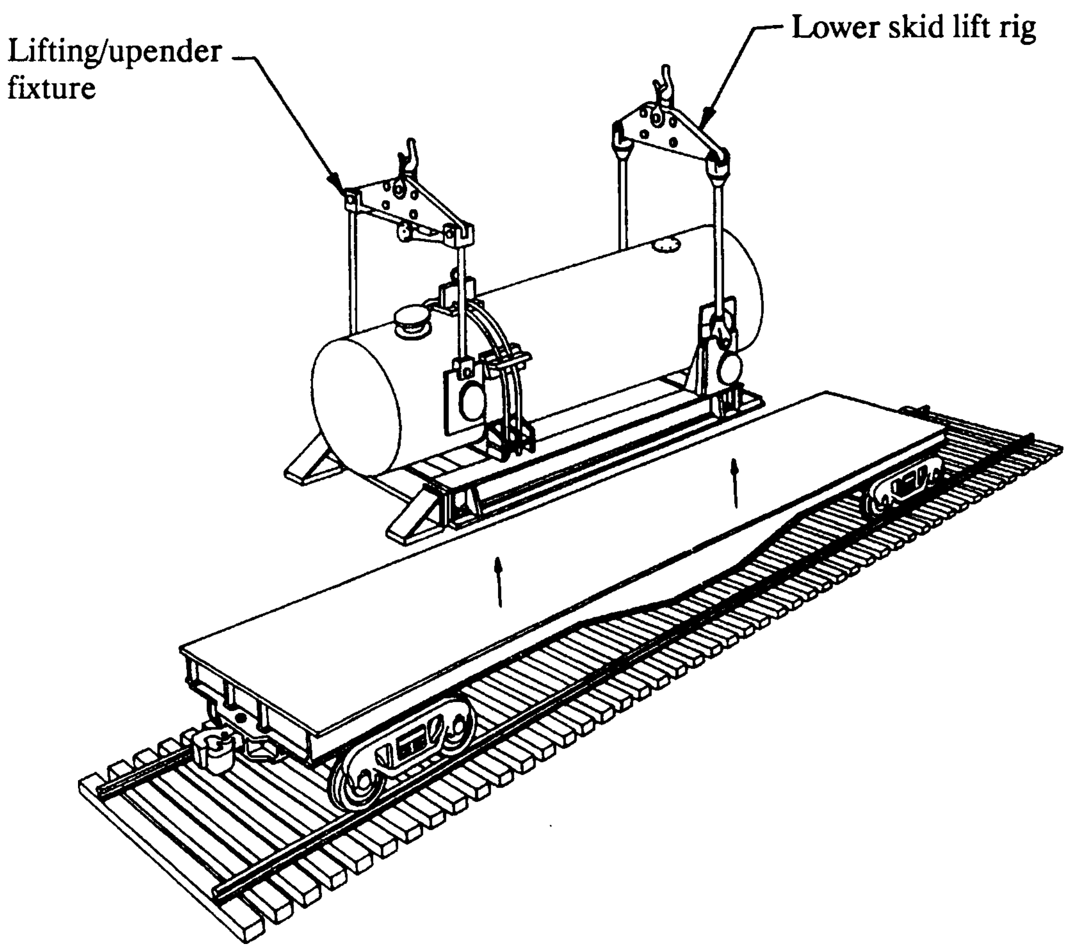


Figure 9-7
Intermodal Lifting Alternatives

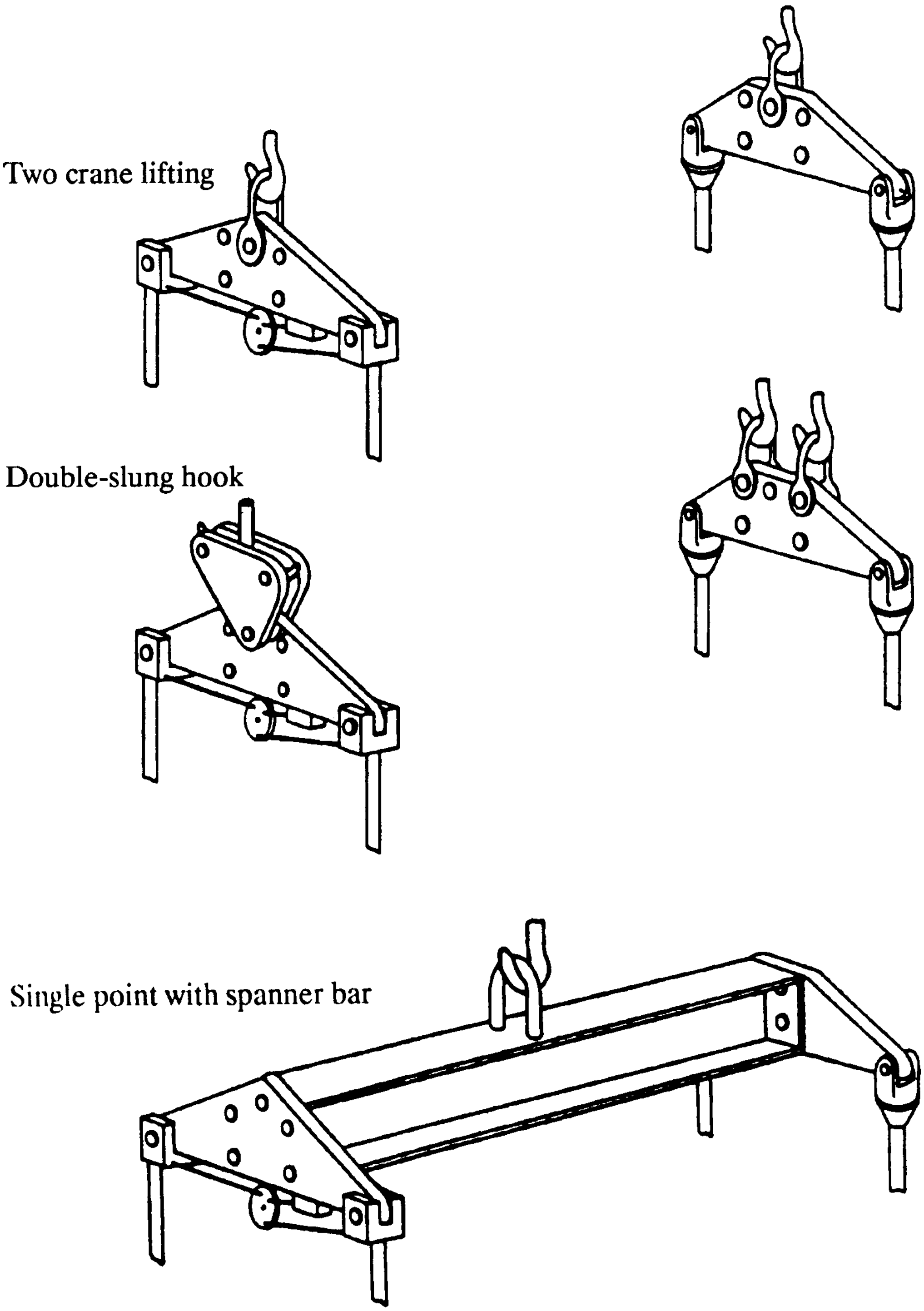
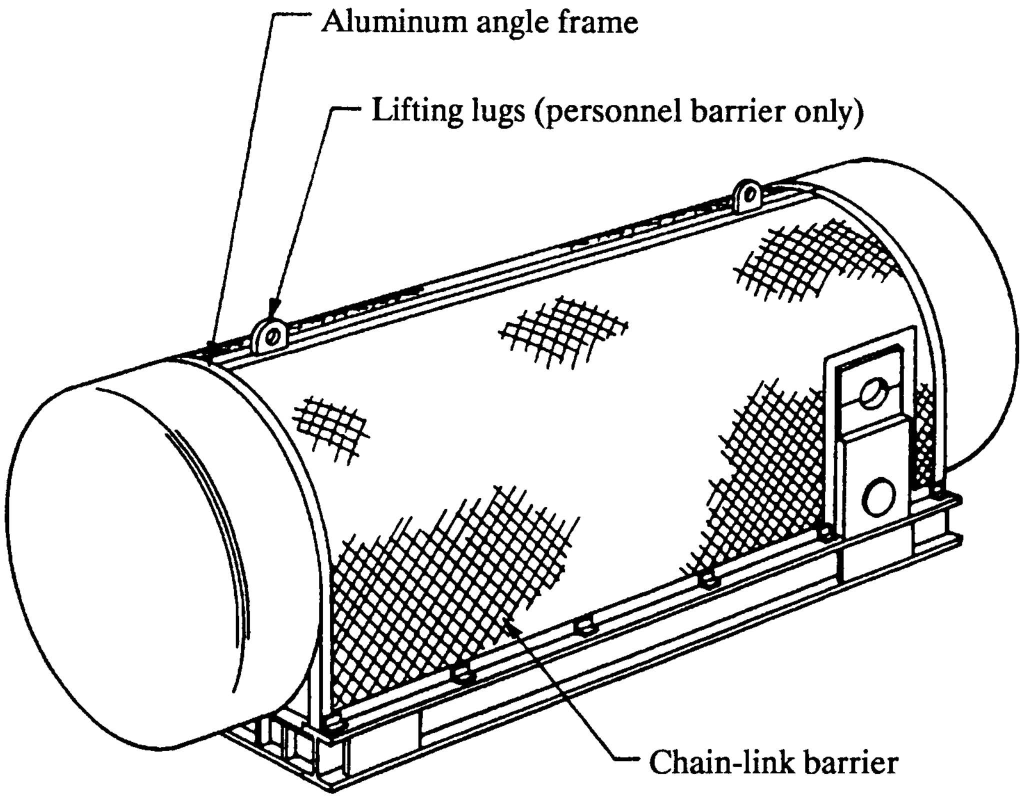


Figure 9-8
Personnel Barrier



10.0 CASK SYSTEM EXTERNAL INTERFACES

10.1 REPOSITORY INTERFACE

The casks that transport spent fuel or high-level waste to a repository or MRS facility must be compatible with several interfaces at those locations. The federal facilities will be designed for high-throughput, automated operations where robotics are widely used. The BR-100 system is designed to provide compatibility with such a system. At receipt the personnel barrier is designed for quick removal and storage on the railcar. The impact limiters are then simultaneously detached using quick-disconnects and rolled back to storage locations on the car using car-mounted trolleys (no crane is required). Surface contamination and cavity atmosphere checks are easily accomplished; the vent/purge system is accessed by removing a cover plate on the lid. The BR-100 has a hot-cell sealing surface defined in Section VI-4 which makes lid and shield plug removal by robotic manipulation extremely simple.

After the fuel has been removed, the BR-100 can be returned to service or have its configuration changed by a quick changeout of basket configuration. The baskets, either PWR or BWR, are handled as a unit but can be easily disassembled for repair, inspection, or decontamination activities. The inner cavity is a smooth surface with no crevices or penetrations, so after the basket is removed, inspection or decontamination is also easily performed.

The BR-100 is capable of storing its payload for extended periods, either in the vertical or horizontal position. Its use for lag storage at the federal facility will present no safety or operational problems.

10.2 REACTOR INTERFACE

The BR-100 is expected to be compatible with nearly two-thirds of the reactors supplying spent fuel to the DOE. Several of the operating constraints on cask design were imposed to ensure compatibility to those "customers" of the Federal Waste Management System. The 100-ton hook weight limit was implemented in recognition of the weight limitations at many reactors. Limits such as laydown areas, pool size, floor loadings, and handling heights are being determined on a reactor-by-reactor basis in a Facility Interface Capability Assessment (FICA) project being performed by Nuclear Assurance Corporation for DOE. As the FICA data becomes available and the dimensional and service constraints are identified, the BR-100 design will be modified as necessary to ensure compatibility.

To provide as much compatibility as possible in advance of those constraints, the BR-100 has incorporated features that give flexibility to the reactor interface. For example, the BR-100 hook weight is calculated assuming that no dewatering has occurred in the spent fuel pool. In actuality, before the cask is lifted from the pool, nearly all of the 10,000 lb of water in the cask will have been removed in a quick dewatering step that uses a 2-in drain line specially designed for that task. The BR-100 operational sequence has been designed to minimize in-pool operations by getting the loaded and dewatered cask quickly out of the pool and onto the work platform. The separate shield plug, used with a dewatering fixture plate, allows the lid to be installed at the work platform. The lid is installed using continuous torque, quick-fastening bolts, the cavity is dried with an air circulation/vacuum system completely routed through the lid, the payload is inerted with a partial atmosphere of helium, and the O-rings are helium leak-checked, all in a logical sequence that minimizes worker exposure and maximizes operational efficiency.

The BR-100 and its associated handling equipment are designed to work with a two-trunnion lift, allowing the cask to go directly from the work platform to the skid on the railcar and then be rotated into the horizontal (shipping) position. The handling equipment is compatible with single- or double-hook systems. The hard, smooth paint on the cask outer surface will help decontamination without subsequent "weeping" problems.

The separate shield plug/closure lid system used on the BR-100 also makes it extremely compatible with the potential dry transfer of fuel or canisters at an Independent Spent Fuel Storage Installation (ISFSI) or in the reactor fuel handling area. A transfer cask system, such as proposed by Edison Power Research Institute (EPRI) in a recent Request for Proposal, could easily be interfaced with the BR-100 to transfer fuel or canisters from practically any spent fuel storage system in use or proposed to date. (An exception would be any canister over 58 in in diameter, over 180 in long, or over 50,000 lb in weight.)

10.3 TRANSPORTATION INTERFACE

The BR-100 is designed for rail or barge use. The Gross Vehicle Weight (GVW) of the package loaded on its specially designed railcar is estimated to be about 260,000 lb. All requirements for free interchange, as defined by the Association of American Railroads (AAR), have been factored into the design. An anticipated increase of the allowable GVW from 263,000 lb to 312,000 lb would allow ancillary equipment and spare parts to be shipped on the same railcar and could also provide for increasing structural margins on the car, if desired.

The skid used to mount the BR-100 to the railcar is also compatible with barge usage. B&W is using McDermott Marine Engineering, a sister company, to ensure that all maritime regulations are met and to determine appropriate arrays for shipment of several casks per barge. The cask/skid package would be lifted in a horizontal position using four pickup points on the skid and placed on or off the barge. This intermodal capability can provide DOE with significant flexibility in routing shipments to federal repository or storage locations.

The loaded BR-100 cask/skid package is expected to be transported with a satellite tracking system, TRANSCOM, monitoring its location at periodic intervals. Should an accident occur, the BR-100 has several features to facilitate recovery operations. The availability of four trunnions at each end of the cask could assist grapple/lift efforts, the protective encapsulation of the concrete neutron shield ensures a low exposure rate to recovery workers, and the unique thermal shield provides low fuel temperatures and protection against lead melt significantly beyond that required by federal regulation, even in extreme thermal accidents.

11.0 HUMAN FACTORS ENGINEERING

This section describes the approach made by the B&W Fuel Company (BWFC) to ensure that "human factors" are taken into consideration in designing the BR-100 cask system. Four different techniques are being used:

1. Incorporation into the BR-100 of a team of specialists with a background in "human factors" or with experience in cask handling and operations.

   John Mayer and John Henderson from the Lynchburg Research Center (LRC) Hot Cell and Cask Handling Facility were selected for this task. Mr. Henderson works for Mr. Mayer, who is responsible for the operations and maintenance area of the BR-100 project team. Their extensive experience in cask handling and operations helps ensure optimization of the safety, efficiency, and reliability of the BR-100.

2. Periodic review of the design (and project management) by an independent panel of senior specialists in various disciplines. That is the purpose of the BR-100 Advisory Review Board (ARB). This panel of specialists reviews the status of the BR-100 on a quarterly basis. Their extensive experience in fields as diverse as railroad equipment and operations, reactor pool operations, and nuclear industrial practices and their educational backgrounds help ensure a sound and feasible cask system. Particular emphasis on human factors is provided at this level by Dr. William Harris and Herbert Feinroth.

3. Reliability studies.

   During preliminary design and again at the end of the final design, BWFC performs reliability studies based on Failure Mode and Effects Analysis (FMEA). These studies are conducted by specialists such as Stanley Levinson or Robert Enzinna. Using their educational backgrounds and professional experience, they analyze the risks involved with the handling and operations of the BR-100 cask system and identify design or procedural ways to minimize them.

4. Final independent review.

During the final design phase, a review of the BR-100 cask system will be performed by Human Factors experts such as Robert Starkey, Dallas Scott, or David Hernandez. This review will be performed when the design is detailed enough to allow a complete analysis of operations. Robert Starkey's experience in engineering ergonomics, Dallas Scott's expertise in human factors applications, and David Hernandez's experience in training are such that we expect a final product that will present an optimal application of human factors engineering. We further intend to have Duke Power Company engineers responsible for spent fuel shipments review the BR-100 design and procedures for improvements and refinements.

Section VI-3 contains the resumes of the people involved in this process:

o Robert Enzinna	B&W
o Herbert Feinroth	B&W Consultant, ARB member*
o William Harris	B&W Consultant, ARB member*
o John Henderson	B&W
o David Hernandez	B&W
o Stanley Levinson	B&W
o John Mayer	B&W
o Dallas Scott	B&W
o Robert Starkey	B&W

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*ARB member resumes are in Section VI-1.

12.0 LIFE CYCLE COST

B&W approaches the minimization of Total Transportation Life Cycle Cost (TTLCC) as one of the most important goals of the BR-100 design effort. Everything possible to reduce the TTLCC without compromising the safety, As Low As Reasonably Achievable (ALARA), and licensability objectives is incorporated as the design progresses. To achieve this goal, B&W has implemented the following activities:

1. Developed a TTLCC model to use as a basis for sensitivity studies, priority setting, and trade-off analyses. This model was developed before to the start of the project and was used to determine the basic BR-100 configuration. It is based on the data supplied in the report PNL-5797, Truck and Rail Charges For Shipping Spent Fuel and Nuclear Waste, prepared for the U.S. Department of Energy by Battelle Pacific Northwest Laboratory in 1986.
2. Evaluated all proposed changes to our technical baseline from a TTLCC perspective. This practice is described and implemented through our Configuration Management Plan.
3. Performed periodic reviews of the design using independent personnel. This is one of the objectives of the Advisory Review Board, composed of senior personnel from the BR-100 team members and includes B&W, Robatel, and Duke Power personnel and senior consultants Herbert Feinroth and Dr. William Harris (resumes are in Section VI-1).

BWFC's proprietary model was used to perform sensitivity studies on significant parameters. Among the parameters investigated were capacity, development and certification costs (not including prototype fabrication), turnaround time, handling cost, fabrication cost, maintenance cost, and utilization. This model and the analyses performed were sufficient to evaluate the preliminary design of the BR-100. A summary of the results from the sensitivity studies is presented in Table 12-1.

As a result of this sensitivity study, a prioritized list of key parameters was developed for the BR-100 program. Cask capacity, fabrication costs, and maintenance costs were determined to be keys to minimizing TTLCC while still meeting regulatory and contractual requirements. As a result, the cask design process maximized performance while minimizing fabrication and maintenance costs. Within the confines of contractual weight restrictions, the principal factors limiting capacity are regulatory limits on dose rate (shielding), ensuring subcriticality, and maintaining the structural integrity of the fuel payload. Fabrication operations available to address these factors include the selection of shielding materials (lead or depleted uranium(DU)), choice of neutron-absorbing material to control criticality, and designing a basket that maintains fuel rod cladding temperatures within acceptable limits. Second tier improvements in LCC were obtained by minimizing maintenance and operational costs. This includes incorporating low maintenance requirements into the design while reducing the complexity of site interface operations to permit quick turnaround times with minimum personnel exposure.

Lead was chosen for the BR-100 gamma shield instead of DU because the potential gain in capacity with DU (24 vs 21 PWR assemblies) was outweighed by increased production fabrication costs (at least $1.5M/cask difference), increased development costs (an additional $1M), and increased prototype fabrication costs ($3M for two casks). The relative advantage of lead with those assumptions was 7% in LCC.

EG&G/DOE has developed a TTLCC code, CASKOM, which is expected to be used to evaluate all CSDP systems on a common basis. CASKOM will be used in the final design phase to check the validity of design features and prepare accurate and significant life cycle cost data for the final design package.

Table 12-1
SUMMARY OF LIFE CYCLE COST SENSITIVITY STUDY

Key Parameters	Base Case Values	Range of Values	Impact on LCC
Direct Factors			
Capacity (PWR FAs)	21	26 to 18	-16% to +13%
Fabrication Cost	$1.5M	$1.0M to 3.5M	- 4% to +16%
Maintenance Cost	$83.5K/yr	$60K to 120K/yr	- 2% to +4%
Cask Weight (lb)	165K	155K to 170K	- 3% to +2%
Development Certification Cost	$6M	$4M to $8M	- 2% to +2%
Handling Cost	$102K/yr	$70K to 120K/yr	- 2% to +1%
Indirect Factors			
Utilization	70%	90% to 50%	- 5% to +10%
Turnaround Time	30 hr	24 hr to 78 hr	- 0% to +3%

BR-100 BASELINE PRELIMINARY DESIGN DRAWING LIST

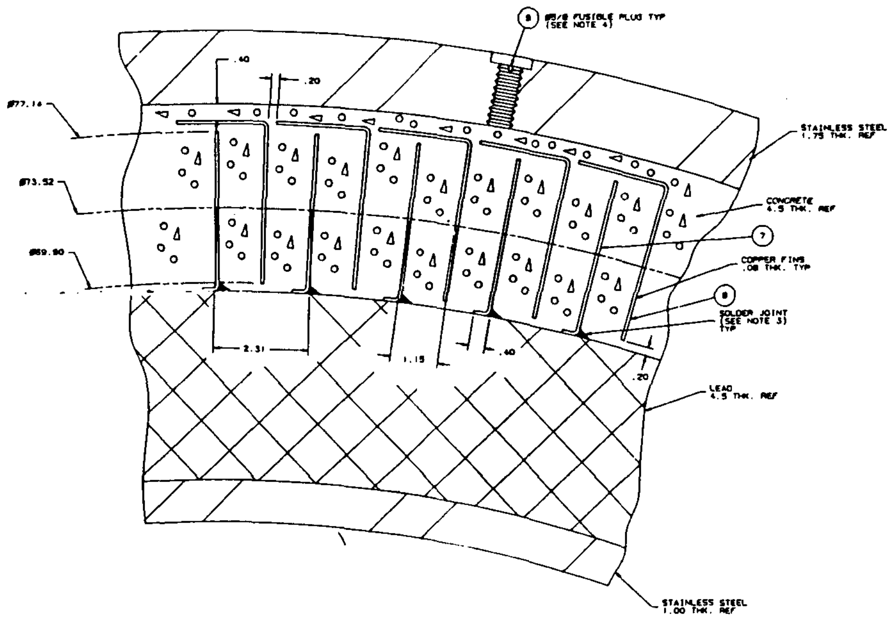
DWG NUMBER	TITLE
02-1192015E	BR-100 CASK CASK ASSEMBLY
02-1192003E	BR-100 CASK CASK ASSEMBLY SECTION U-U
02-1192002E	BR-100 CASK CASK BODY ASSEMBLY
02-1192000E	BR-100 CASK CASK BODY SECTION U-U (SHIELDING ARRANGEMENT)
02-1192027E	BR-100 CASK REINFORCEMENT RING ASSEMBLY
02-1192006E	BR-100 CASK CLOSURE SYSTEM SHIELD PLUG
02-1192007E	BR-100 CASK CLOSURE LID ASSEMBLY
02-1192011E	BR-100 CASK CLOSURE LID SECTIONS
02-1192008E	BR-100 CASK CLOSURE BOLT
02-1192216E	BR-100 CASK PWR BASKET ASSEMBLY LONGITUDINAL SECTION
02-1192212E	BR-100 CASK PWR BASKET CROSS SECTION
02-1192203D	BR-100 CASK PWR BASKET INDIVIDUAL FUEL CELL
02-1192208E	BR-100 CASK PWR BASKET FORMER A
02-1192209E	BR-100 CASK PWR BASKET FORMER B
02-1192213E	BR-100 CASK PWR BASKET BOTTOM PLATE
02-1192215E	BR-100 CASK PWR BASKET UPPER GRID
02-1192026D	BR-100 CASK BASKET ASSEMBLY DETAIL PARTS
02-1192020E	BR-100 CASK BWR BASKET ASSEMBLY LONGITUDINAL SECTION
02-1192021E	BR-100 CASK BWR BASKET CROSS SECTION

02-1192204D	BR-100 CASK BWR BASKET INDIVIDUAL FUEL CELL
02-1192023E	BR-100 CASK BWR BASKET FORMER A
02-1192024E	BR-100 CASK BWR BASKET FORMER B
02-1192022E	BR-100 CASK BWR BASKET BOTTOM PLATE
02-1192025E	BR-100 CASK BWR BASKET UPPER GRID

02-1192009E	BR-100 IMPACT LIMITER ENVELOPE
02-1193037E	BR-100 CASK SYSTEM INTERFACE

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

REV	DESCRIPTION
2	REVISED AND REDRAWN



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS ARE SPECIFIED ON CASK BODY ASSEMBLY DRAWING NO. 1192002E.
3. SPECIFICATION FOR SOLDERED JOINT (LATER).
4. SPECIFICATION FOR FUSIBLE PLUG AND LOCATIONS ARE ON DRAWING NO. 1192002E.
5. FOR ITEMS SHOWN, SEE BILL OF MATERIAL ON DRAWING NO. 1192002E.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

TOLERANCES UNLESS OTHERWISE SPECIFIED

J. WOOD

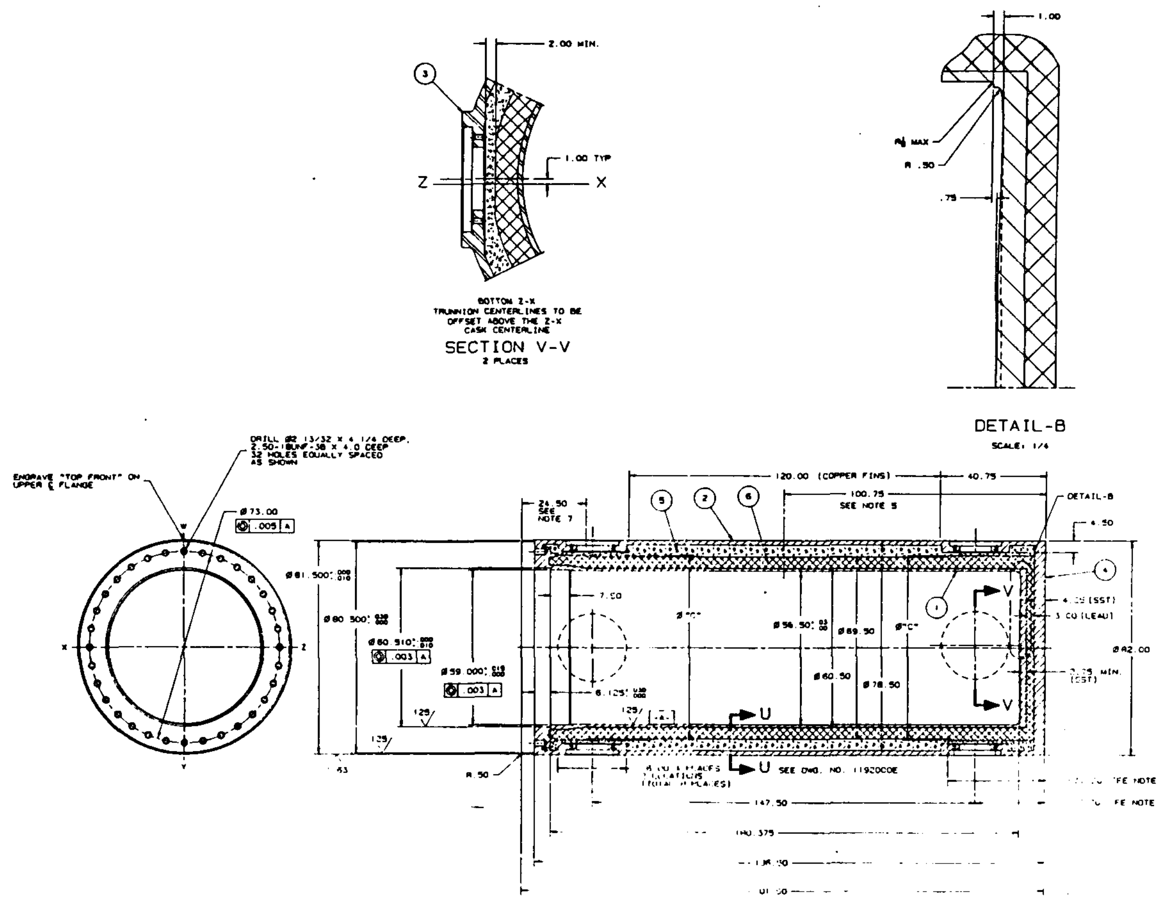
BR-100 CASK
CASK BODY
SECTION U-U
(SHIELDING ARRG'T)

FULL

1192000 E 2

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

REV	DESCRIPTION	DATE	APPROVAL
2	REVISED AND REDRAWN	[illegible]	RB 955 RC



						BILL OF MATERIAL
1	1	LATER			INNER SHELL ASSEMBLY	SEE NOTE 2
2	1	LATER			OUTER SHELL	SEE NOTE 2
3	8	1192027	001	E	REINFORCEMENT RING ASS'Y	SEE NOTE 2
4	1	LATER			BOTTOM HEAD	SEE NOTE 2
5	A/R	1192000	001	E	CONCRETE SHIELD	SEE NOTES 2 AND 3
6	A/R	1192000	002	E	GAMMA SHIELD (LEAD)	SEE NOTE 2
7	A/R	1192000	003	E	COPPER FIN A	SEE NOTE 2
8	A/R	1192000	004	E	COPPER FIN B	SEE NOTE 2
9	12	1192000	005	E	FUSIBLE PLUG	SEE NOTE 2

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS:
   - A. ITEMS 1,2&4 - SHELL PLATE AND HEAD FORGING TO BE ASME SA-240, 304L (PLATE) AND ASME SA-182, 304L (FORGING) SOLUTION ANNEALED 1925-1975°F AND WATER QUENCHED.
   - B. ITEM 5 - CONCRETE SHIELD TO BE PER SPECIFICATION BWFC NO. 08-1174391.
   - C. ITEM 6 - GAMMA SHIELD LEAD TO BE PER SPECIFICATION ASTM B29-79 (CORRODING LEAD).
   - D. ITEMS 7&8 - COPPER FINS TO BE PER ASTM B152-86, C-10200.
   - E. ITEM 9 - FUSIBLE PLUG TO BE A 6061, 40 C4, ALLOY.
3. LEAD POURING, CONCRETE W/COPPER FINS ASSEMBLY/ POURING TO BE IN ACCORDANCE WITH BWFC PROCEDURES (LATER).
4. BODY FINAL ASSEMBLY PRIOR TO FINAL MACHINING (AS SHOWN) TO BE IN ACCORDANCE WITH BWFC SPECIFICATION NO. (LATER).
5. INSTALL FUSIBLE PLUGS ON (THREE) LEVELS ON CASK OUTSIDE DIAMETER AT TRUNNION CENTERS AND CASK CENTER. ONE FUSIBLE PLUG IN EACH QUADRANT AND 45° BETWEEN TRUNNION PLANES. TOTAL OF 12 PLACES.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. DIAMETER "C" IS A LOCAL INCREASE OF 1.0 INCHES ON THE LEAD DIAMETERS AT TOP AND BOTTOM FOR THE LENGTHS SPECIFIED.
8. WEIGHT (CALCULATED) TO BE 136,000 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

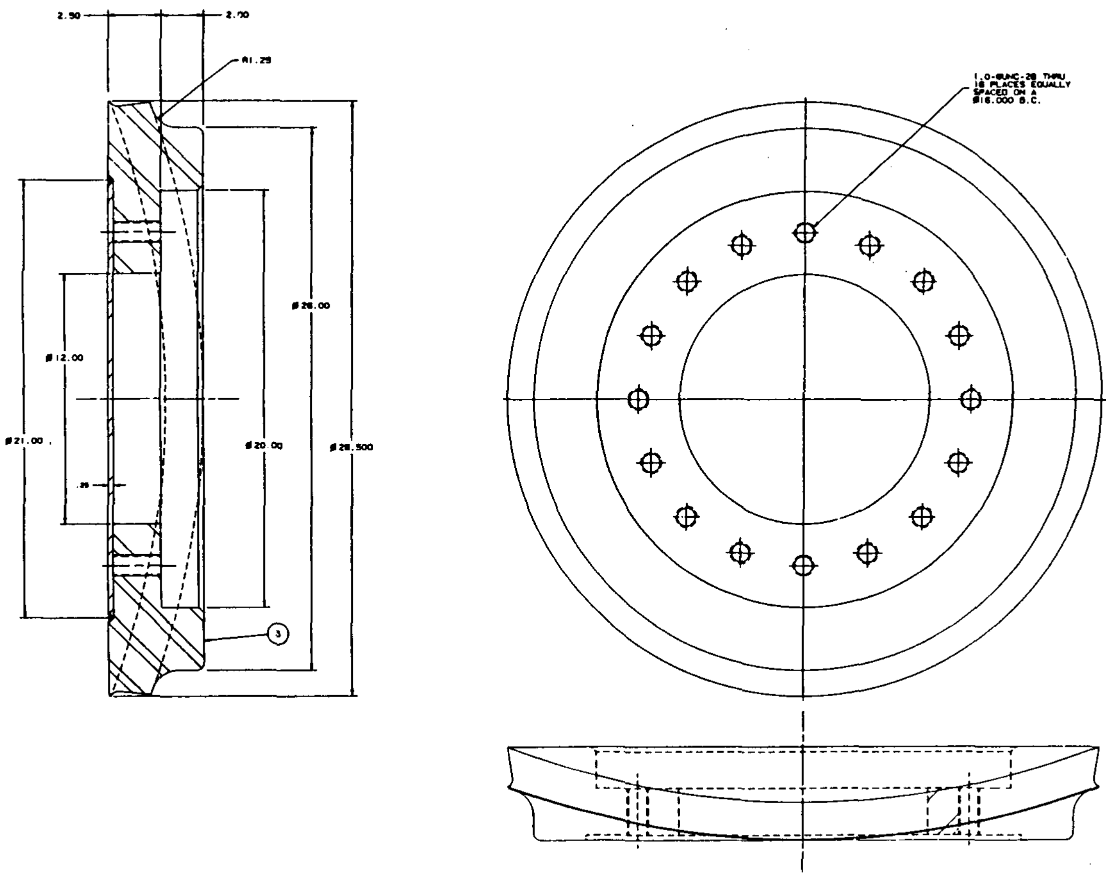
PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

RHODES

BR-100 CASK
CASK BODY
ASSEMBLY

1192002 E 2



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS:
   A. REINFORCEMENT RING TO BE ASME SA182, FXM-19, FORGING SOLUTION ANNEAL AT 1925-1975°F, WATER QUENCH FOR ASME CLASS 1 COMPONENT USE.
   B. BACKING PLATE TO BE ASME SA 240, 304L, SOLUTION ANNEALED AT 1925-1975°F WATER QUENCHED.
3. WEIGHTS (CALCULATED) IN LBS:
   A. REINFORCEMENT RING - 529 EACH
   B. BACKING PLATE - 29 EACH
4. FOR BILL OF MATERIAL SEE DRAWING NO. 1192002E.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

J. WOOD

7/11/89

BR-100 CASK
REINFORCEMENT
RING ASSEMBLY

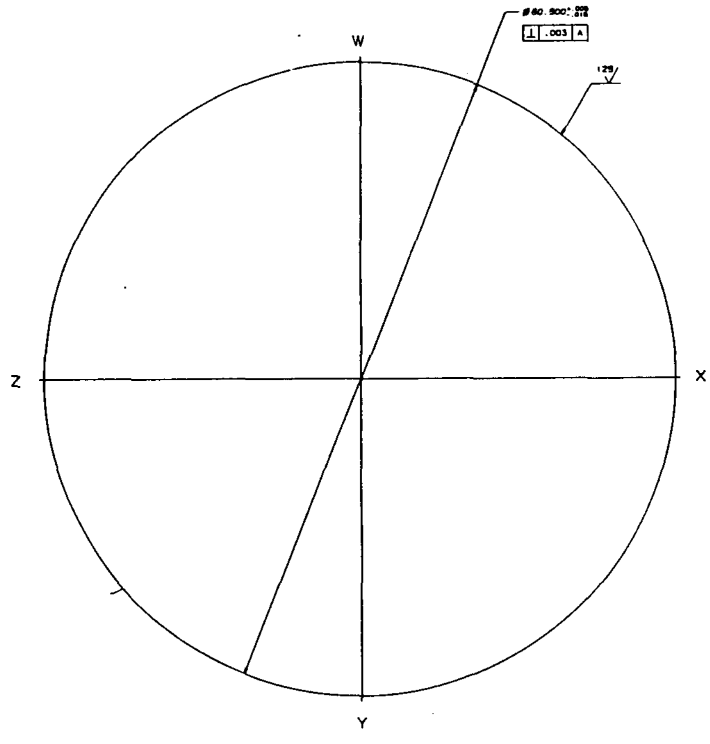
1/2

1192027 E 0

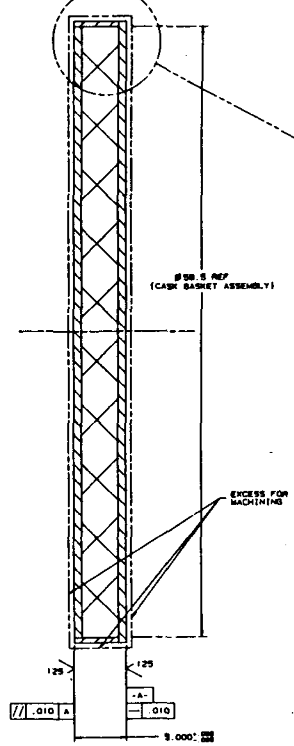
09-14-89

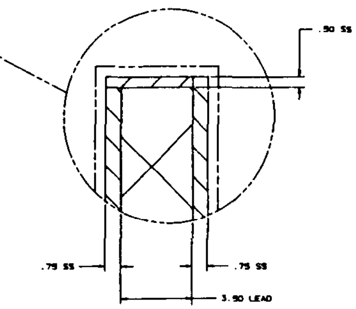
FOR PREVIOUS REVISIONS SEE MICROFILM
IN RECORDS CENTER

REV	DESCRIPTION	DATE	APPROVAL
2	RENUMBERED EXISTING NOTE 3 TO 7. ADDED NEW NOTE 3 AND NOTES 4,5 AND 6.		



TOP VIEW





NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. STAINLESS STEEL (SS) PLATE MATERIAL TO BE TO ASME SA240, XM-19, SOLUTION ANNEALED AT 1925-1975°F, WATER QUENCH.
   B. LEAD TO BE TO ASTM B29-79 (CORRODING LEAD).
3. LEAD POURING TO BE IN ACCORDANCE WITH BWFC PROCEDURE NO. (LATER).
4. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
5. SEAL INTEGRITY CHECK LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. LIFTING/HANDLING FITTINGS, DEVICES, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
8. TYPICAL WEIGHT (CALCULATED) TO BE 5300 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM
IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

TOLERANCES UNLESS OTHERWISE SPECIFIED

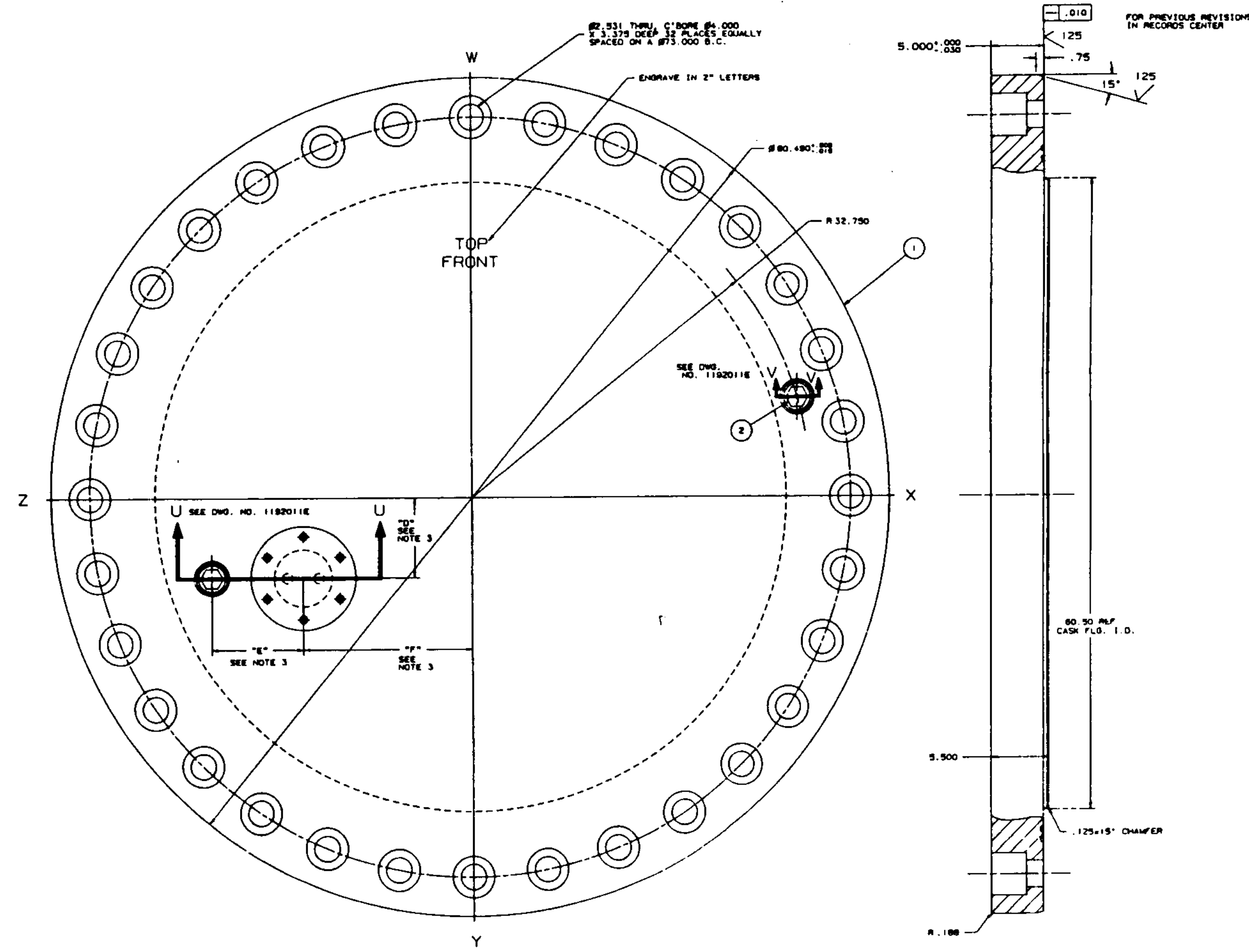
RHODES

BR-100 CASK
CLOSURE SYSTEM
SHIELD PLUG

1/4

1132006 E 2

09-14-89



FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

BILL OF MATERIAL						
1	1	1192007	001	E	CLOSURE LID ASSEMBLY	SEE NOTE 2
2	2	LATER			CLOSURE PLUG(SEAL CHECK PORT)	SEE NOTES 3 AND 4
3	1	LATER			COVER PLATE(FOR DRAIN AND PURGE)	SEE NOTES 3 AND 4
4	2	LATER			QUICK DISCONNECT COUPLERS	SEE NOTES 3 AND 4

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. PLATE MATERIAL TO SPECIFICATION ASME SA-240, XM-19, SOLUTION ANNEALED AT 1925-1975°F AND WATER QUENCHED.
3. DRAIN LINES, CONNECTORS AND ALL RELATED DIMENSIONS (INCLUDING D,E AND F) WILL BE PROVIDED IN DETAIL ON A LATER REVISION.
4. SEAL INTEGRITY CHECK LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
5. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. LIFTING/HANDLING FITTINGS, DEVICES, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. TYPICAL WEIGHT (CALCULATED) TO BE 7600 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

RHODES

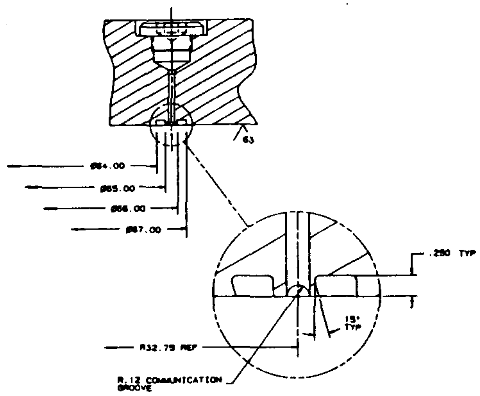
BR-100 CASK CLOSURE LID ASSEMBLY

1192007 E 2

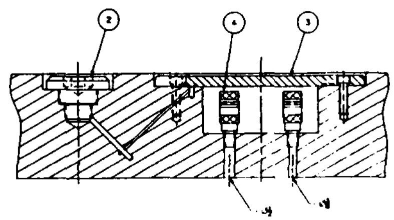
09-14-89

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

REV	DESCRIPTION	DATE	APPROVAL
Z	REVISED AND REDRAWN		



SECTION V-V



SECTION U-U

NOTES:

1. ALL DIMENSIONS ARE IN INCHES AT 68°F.
2. MATERIALS ARE AS SPECIFIED IN BILL OF MATERIALS ON DWG. NO. 1192007E.
3. SEAL INTEGRITY CHECK PLUGS, PORTS, CONNECTORS SEALS AND RELATED DIMENSIONS OR PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

RHODES

BR-100 CASK
CLOSURE LID
SECTIONS

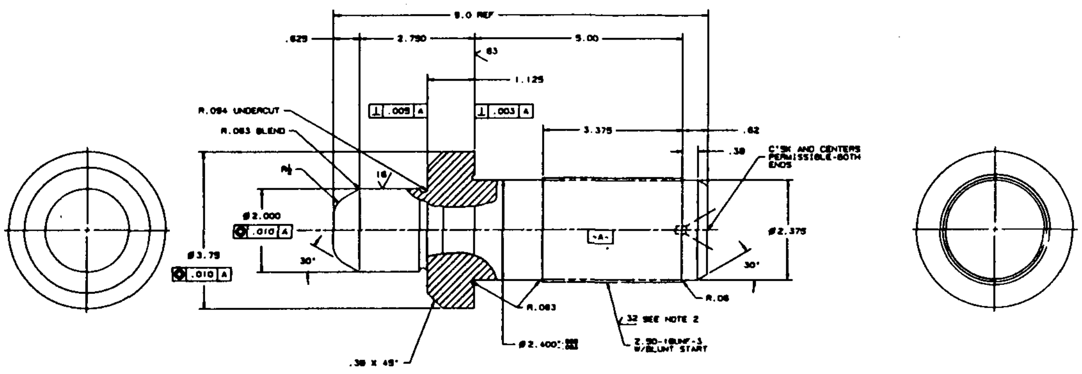
1/2

1192011 E Z

09-14-89

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

REV	DESCRIPTION	DATE	APPROVAL
3	REVISED AND REDRAWN	[illegible]	[illegible]



(1) BOLT

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   BOLT: MATERIAL TO BE INCONEL 718 TO SPEC. ASME SB-637 WITH CUT THREADS, AGE HARDENED AND FINAL GRIND THREADS.
3. TYPICAL WEIGHT (CALCULATED) OF BOLT - 10.0 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

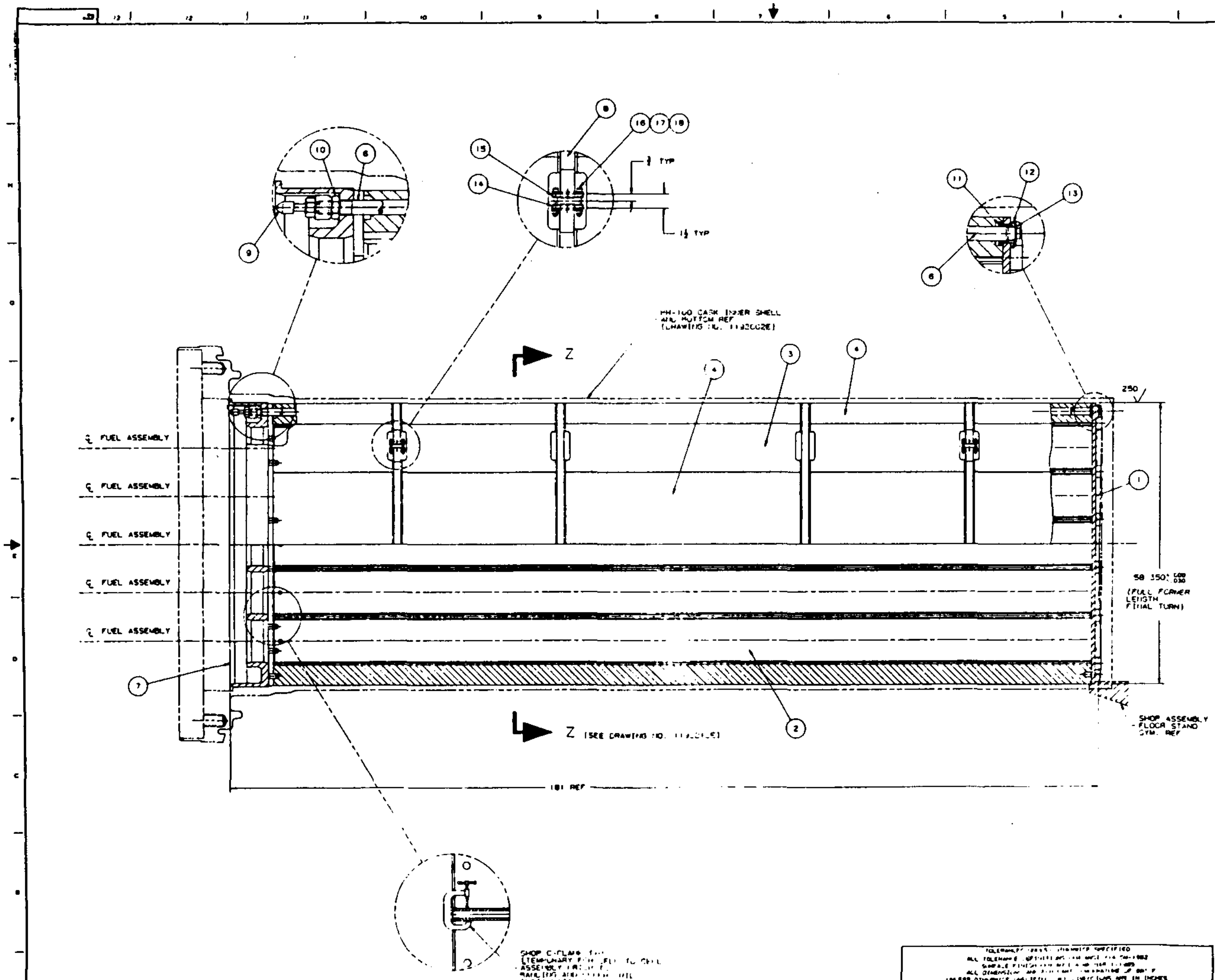
BASELINE DRAWING FOR ANALYSIS ONLY

RHODES

BR-100 CASK CLOSURE BOLT

22009 E 3

09-14-89



BILL OF MATERIAL

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	1	1192213	001	E	BOTTOM PLATE	SEE NOTE 2
2	21	1192203	001	D	PWR INDIVIDUAL CELL	SEE NOTE 2
3	4	1192208	001	E	FORMER A	SEE NOTE 2
4	4	1192209	001	E	FORMER B	SEE NOTE 2
5	-	LATER			PWR STANDOFFS (SEE NOTE 7)	SEE NOTE 2
6	8	1192026	001	E	TIE RODS	SEE NOTE 2
7	1	1192215	001	E	UPPER GRID	SEE NOTE 2
8	8	1192026	002	E	OUTER BAND SEGMENT (SEE NOTE 8)	SEE NOTE 2
9	8	1192026	003	E	TOP NUT	SEE NOTE 2
10	8	1192216	001	E	1 3/8-8UNC JAM NUT	304 S.ST.
11	8	1192026	004	E	LOCATING SPACER	SEE NOTE 2
12	8	1192026	005	E	BOTTOM NUT	SEE NOTE 2
13	8	1192216	002	E	"TRU-ARC" RETAINING RING NO. 5100-112 OR EQUAL	PH15-7MO S.ST.
14	8	1192026	006	E	BAND TENSIONER A (SEE NOTE 8)	SEE NOTE 2
15	8	1192026	007	E	BAND TENSIONER B (SEE NOTE 8)	SEE NOTE 2
16	16	1192216	003	E	3/8-24UNC-2A X 2 1/2 LG. SOCKET HEAD CAP SCREW	S.ST.
17	16	1192216	004	E	3/8 FLAT WASHER	S.ST.
18	16	1192216	005	E	3/8 "FLEXLOC" NUT OR EQUAL	S.ST.

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS ARE AS SPECIFIED ON DETAIL DRAWING.
3. ASSEMBLY TO BE PERFORMED ACCORDING TO B&W PROCEDURE NO. (LATER).
4. MAX. WEIGHT OF ASSEMBLY TO BE 9000 LBS.
5. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. FUEL ASSEMBLY STAND-OFF DETAILS WILL BE PROVIDED LATER.
8. EACH LEVEL OF BANDS CONSISTS OF 2 SEGMENTS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

RHODES
R. BERA
R. WISDAHL
R. CHILDRESS

BR-100 CASK
PWR BASKET
ASSEMBLY
LONGITUDINAL
SECTION

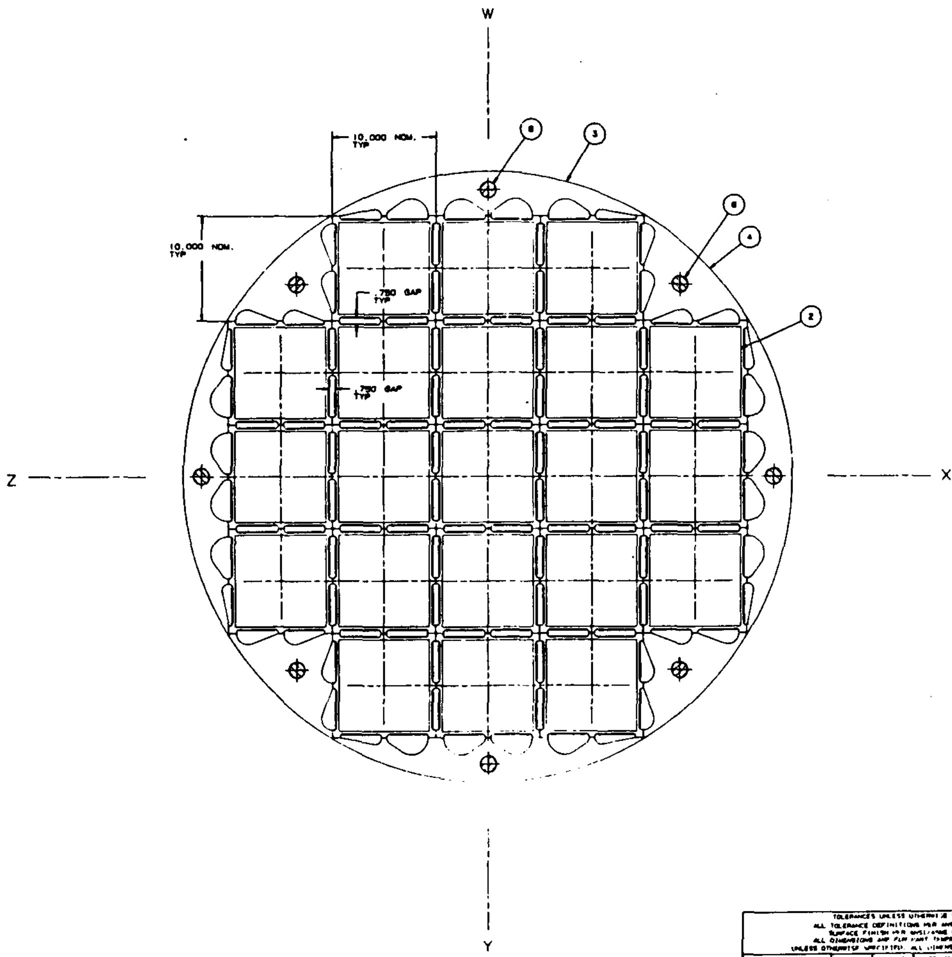
1:4

1192216 E 1

09-14-89

FOR PREVIOUS REVISIONS SEE MICROFILM
IN RECORDS CENTER

REVISIONS			
REV	DESCRIPTION	DATE	APPROVAL
2	REVISED AND REDRAWN	[illegible]	[illegible]



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. FOR BILL OF MATERIAL SEE DRAWING NO. 1192216E.
3. DRAIN LINES AND RELATED PROVISIONS WILL BE SHOWN ON A LATER REVISION.

FOR ORIGINAL SIGNATURES SEE MICROFILM
IN RECORDS

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

J. WOOD
R. BERA
R. VISEMAN
P. CHILDRESS

BR-100 CASK
PWR BASKET
CROSS SECTION

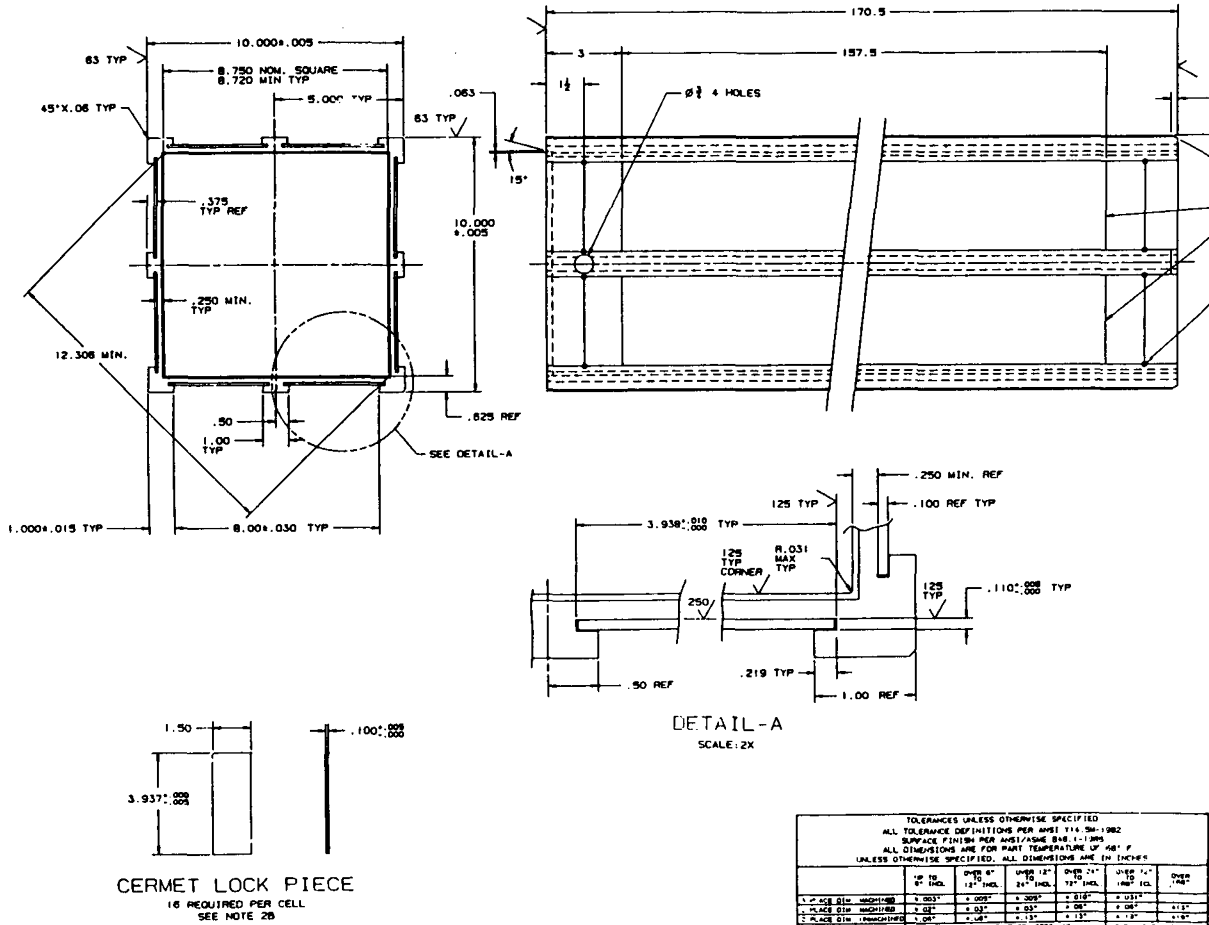
1/4

1192212 E 2

09-14-89

REV	DESCRIPTION	DATE	APPROVAL
4	DRAWING REVISED AND REDRAWN	7/11/89	RCB DJS / ACC

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. CELL: ALUMINUM EXTRUSION TO ASME SB-221, ALLOY 6061, TEMPER T6511. ALL EXTRUDED SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER. THIS MATERIAL TO MEET THE REQUIREMENTS OF ASME B&PV CODE SECTION III, SUBSECTIONS NB 2546 AND NB 2552 AND IT SHALL BE RECLASSIFIED TO CLASS I.
   B. LOCK PIECE: ALUMINUM SHEET TO ASTM B-209, 6061-T6 WITH A SURFACE FINISH OF 125 RHR OR BETTER.
3. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I, AFTER MACHINING AND BEFORE CERMET PLATE INSTALLATION.
4. (AL, B4C) CERMET PLATES (3.875x13.125 LG. in. BUTTED END TO END. NOMINAL .100 THK. TYP. INCLUDING ALUMINUM COVER SHEET. 24 REQUIRED PER SIDE.
5. A FREE PATH GAGE 8.650 INCH SQUARE WITH 0.015 INCH RADIUS CORNERS TO BE INSERTED AND TO PASS FREELY THROUGH THE FULL LENGTH TO ASSURE CLEARANCE. COMPLETE INTERNAL AND EXTERNAL GAGE DETAILS (LENGTH, ETC) LATER.
6. APPROXIMATE WEIGHT OF THE PWR INDIVIDUAL FUEL CELL TO BE 250 LBS. (INCLUDING 210 LBS. OF AL STRUCTURE AND 40 LBS OF CERMET).

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE
BASELINE DRAWING FOR ANALYSIS ONLY

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED. ALL DIMENSIONS ARE IN INCHES

	UP TO 6" INCL	OVER 6" TO 12" INCL	OVER 12" TO 24" INCL	OVER 24" TO 72" INCL	OVER 72" TO 148" INCL	OVER 148"
3 PLACE DIM MACHINED	±.003"	±.005"	±.005"	±.010"	±.031"	
2 PLACE DIM MACHINED	±.02"	±.03"	±.03"	±.06"	±.06"	±.13"
2 PLACE DIM UNMACHINED	±.06"	±.06"	±.13"	±.13"	±.13"	±.19"

FLATNESS	.001"/IN. OF SURFACE UP TO .020" MAX	
PERPENDICULARITY	.002"/IN. OF SURFACE UP TO .020" MAX	
CONCENTRICITY	.015" DIA	
ANGULARITY	±0° 10'	

J. WOOD
R.V. WISEMAN
F.C. CHILDRESS
2-8-89

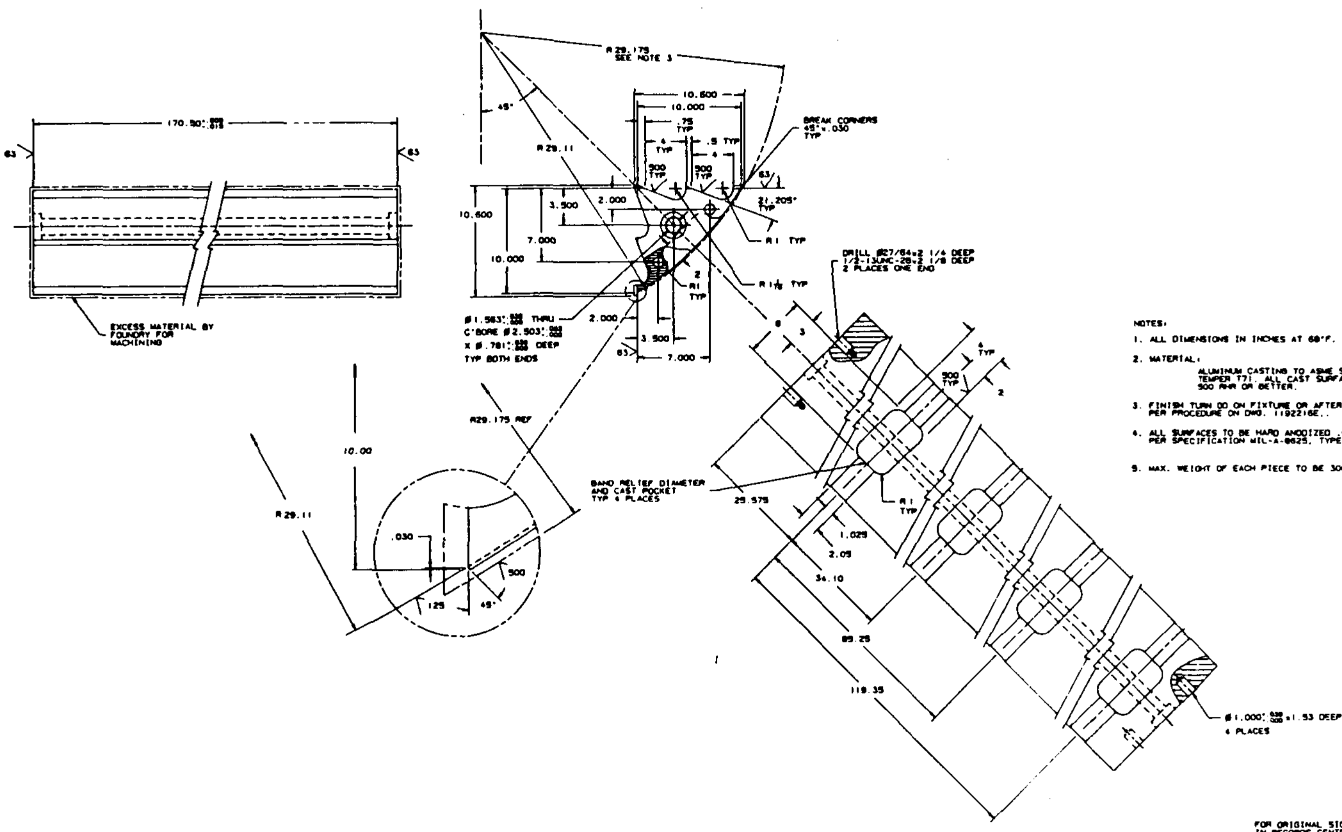
BR-100 CASK
PWR BASKET
INDIVIDUAL FUEL CELL

SCALE 1/2
1192203 D 4

09-14-89

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORD CENTER

REVISIONS		
2	REVISED AND REDRAWN	[illegible]



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   ALUMINUM CASTING TO ASME SB-26 ALLOY 5070A, TEMPER T71. ALL CAST SURFACES TO HAVE A FINISH OF 500 RHR OR BETTER.
3. FINISH TURN OD ON FIXTURE OR AFTER ASSEMBLY TO DIAMETER PER PROCEDURE ON DWG. 1192216E..
4. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I AFTER MACHINING.
5. MAX. WEIGHT OF EACH PIECE TO BE 300 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

RHODES

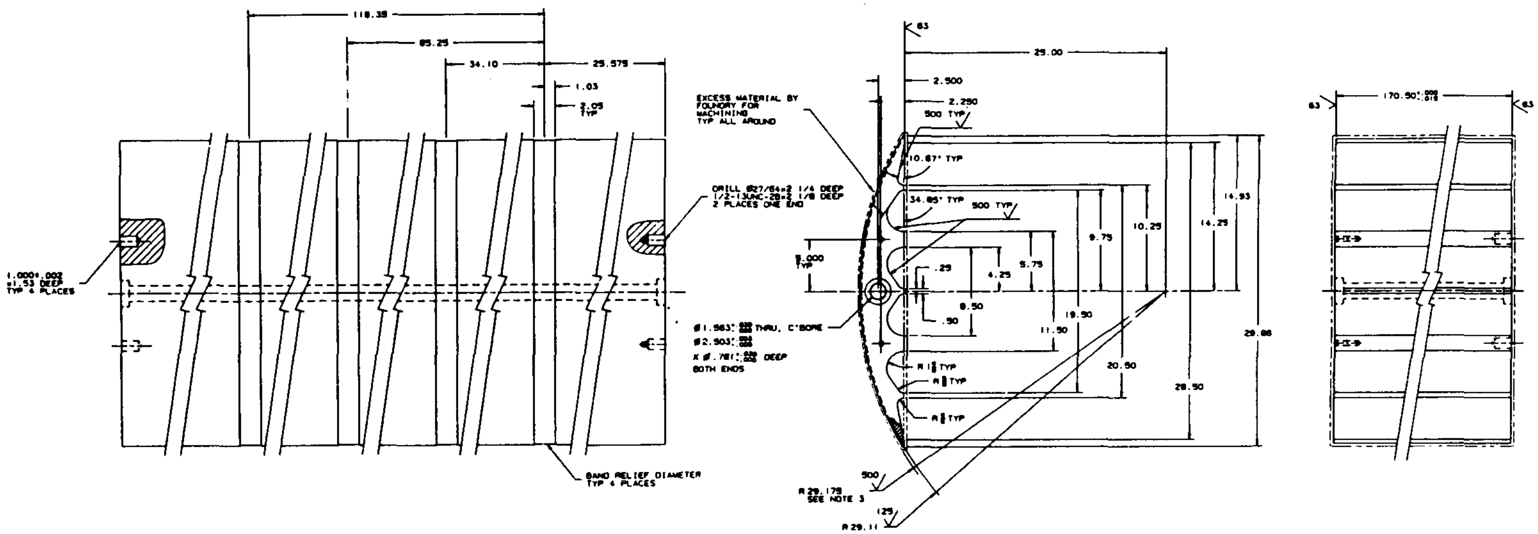
BR-100 CASK
PWR BASKET
FORMER A

1192208 E 2

09-14-89

FOR PREVIOUS REVISIONS REVISIONS SEE MICROFILM IN RECORDS CENTER

REV	DESCRIPTION	DATE	APPROVAL
2	REVISED AND REDRAWN		



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   ALUMINUM CASTING TO ASME SB-26 ALLOY S070A, TEMPER T71. ALL CAST SURFACES TO HAVE A FINISH OF 500 RHR OR BETTER.
3. FINISH TURN OD ON FIXTURE OR AFTER ASSEMBLY TO DIAMETER PER PROCEDURE ON DWG. 1192216E.
4. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I AFTER MACHINING.
5. MAX. WEIGHT OF EACH PIECE TO BE 500 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

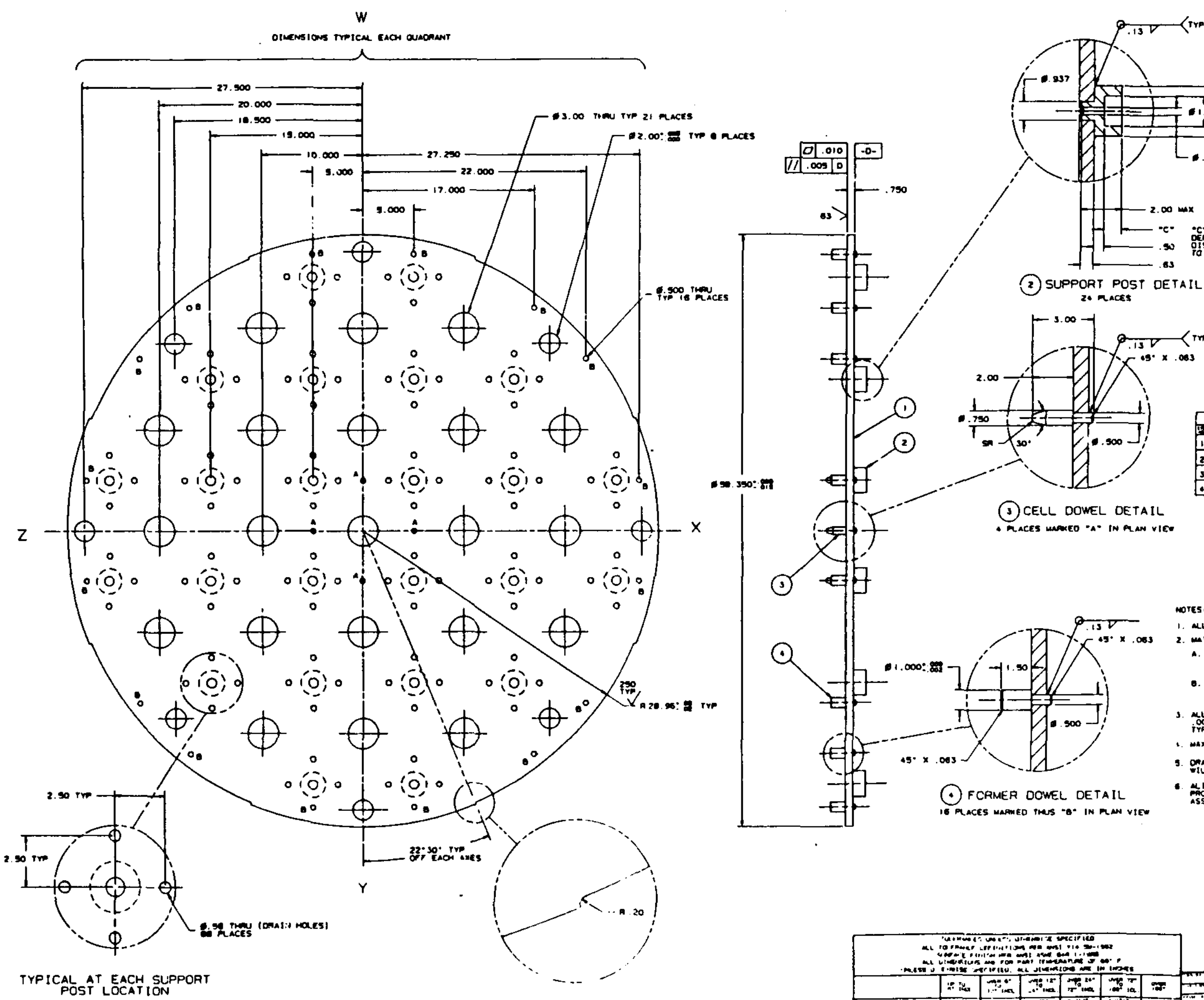
BASELINE DRAWING FOR ANALYSIS ONLY

RHODES
R.C. BERA

BR-100 CASK
PWR BASKET
FORMER B

1132209 E 2

09-14-89



BILL OF MATERIAL						
1	1	1192213	001	E	BOTTOM PLATE	SEE NOTE 2
2	24	1192213	002	E	SUPPORT POST	SEE NOTE 2
3	6	1192213	003	E	CELL DOWEL	SEE NOTE 2
4	16	1192213	004	E	FORMER DOWEL	SEE NOTE 2

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. ALUMINUM PLATE TO ASME SB-209 ALLOY 6061, TEMPER T6. ALL AS ROLLED SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER.
   B. ROUND BAR MATERIAL TO SPEC. ASME SB-221 ALLOY 6061, TEMPER T6. ALL EXTRUDED OR DRAWN SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER.
3. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS 1, AFTER MACHINING.
4. MAX. WEIGHT OF ASSEMBLED PLATE TO BE 190 LBS.
5. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

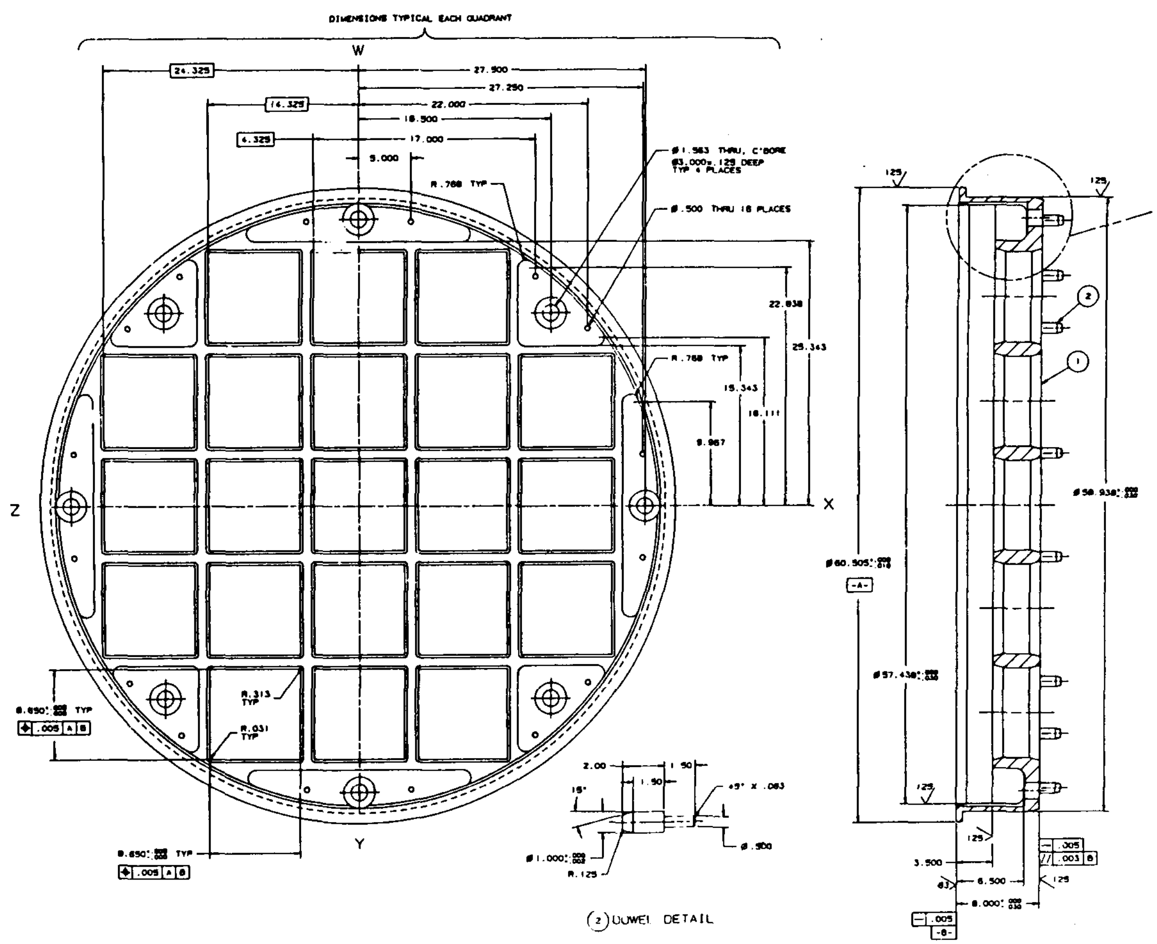
RHODES
R. BERA
R. WISEMAN
D. SANCHETTE

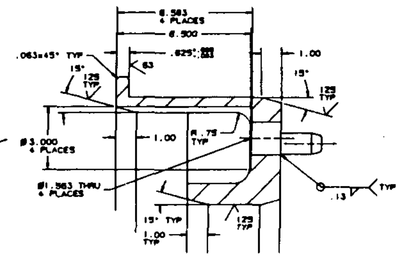
BR-100 CASK
PWR BASKET
BOTTOM PLATE

1192213E

09-14-89

REV	DESCRIPTION	DATE	APPROVAL
1	REVISED AND REDRAWN		





BILL OF MATERIAL						
1	1	1192215	001	E	UPPER GRID	SEE NOTE 2
2	16	1192215	002	E	DOWEL	SEE NOTE 2

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. ALUMINUM CASTING TO ASME SB-26, ALLOY 5070A TEMPER T71. SURFACES TO HAVE A FINISH OF 500 RHR OR BETTER.
   B. ROUND BAR MATERIAL TO SPEC. ASME-SB-221, ALLOY 6061, TEMPER T6. ALL SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER.
3. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS 1 AFTER MACHINING.
4. MAX. WEIGHT OF ASSEMBLED GRID TO BE 500 LBS.
5. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. LIFTING/HANDLING FITTINGS, DEVICES, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

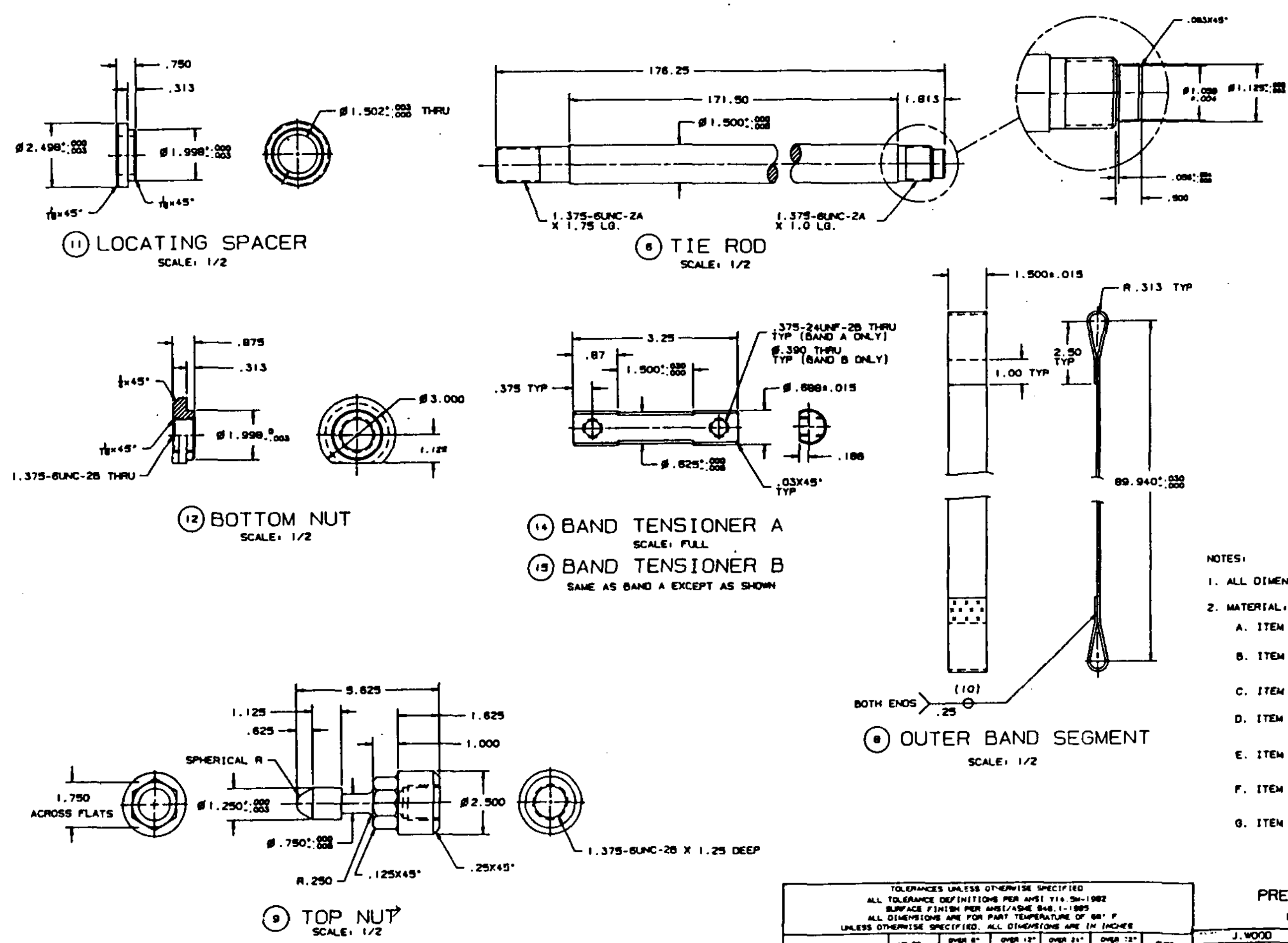
TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL DIMENSIONS ARE IN INCHES

RHODES
R. BERA
A. WISEMAN
P. CHILDRESS

BR-100 CASK
PWR BASKET
UPPER GRID

1/4

1192215 E 1



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.

2. MATERIAL:
   - A. ITEM 9 - TOP NUT - ASME,SA182, FXM-19. ALL SURFACES TO HAVE A FINISH OF 63 RHR.
   - B. ITEM 11 - LOCATING SPACER - ASTM B-211., ALUMINUM 6061-T6. ALL SURFACES TO HAVE A FINISH OF 63 RHR.
   - C. ITEM 12 - BOTTOM NUT - ASME,SA182, FXM-19. ALL SURFACES TO HAVE A FINISH OF 63 RHR.
   - D. ITEM 6 - TIE ROD - ASTM B-211., ALUMINUM 6061-T6. ALL SURFACES TO HAVE A FINISH OF 63 RHR.
   - E. ITEM 14 - BAND TENSIONER A - ASME SA479, TYPE 316 S.ST. ALL SURFACES TO HAVE A FINISH OF 63 RHR.
   - F. ITEM 15 - BAND TENSIONER B - ASME SA479, TYPE 316 S.ST. ALL SURFACES TO HAVE A FINISH OF 63 RHR.
   - G. ITEM 8 - OUTER BAND SEGMENT - 18 GA.(.0595) ASME SA-240, TYPE 316 S.ST.

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

	UP TO 6" INCL.	OVER 6" TO 12" INCL.	OVER 12" TO 24" INCL.	OVER 24" TO 72" INCL.	OVER 72" TO 180" INCL.	OVER 180"
3 PLACE DIM. MACHINED	±.003"	±.005"	±.005"	±.010"	±.031"	
2 PLACE DIM. MACHINED	±.02"	±.03"	±.03"	±.06"	±.06"	±.13"
2 PLACE DIM. UNMACHINED	±.05"	±.08"	±.13"	±.13"	±.19"	±.19"

FLATNESS	.001"/IN. OF SURFACE UP TO .020" MAX.	BREAK CORNERS .02" MAX. RADIUS OR CHAMFER
PERPENDICULARITY	.002"/IN. OF SURFACE UP TO .020" MAX.	
CONCENTRICITY	.015" DIA.	
ANGULARITY	±0°-30'	CHAMFERS ±5°

ALL MACHINED SURFACES TO HAVE 3.18 Ra(125μ in) FINISH UNLESS OTHERWISE NOTED

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

J. WOOD

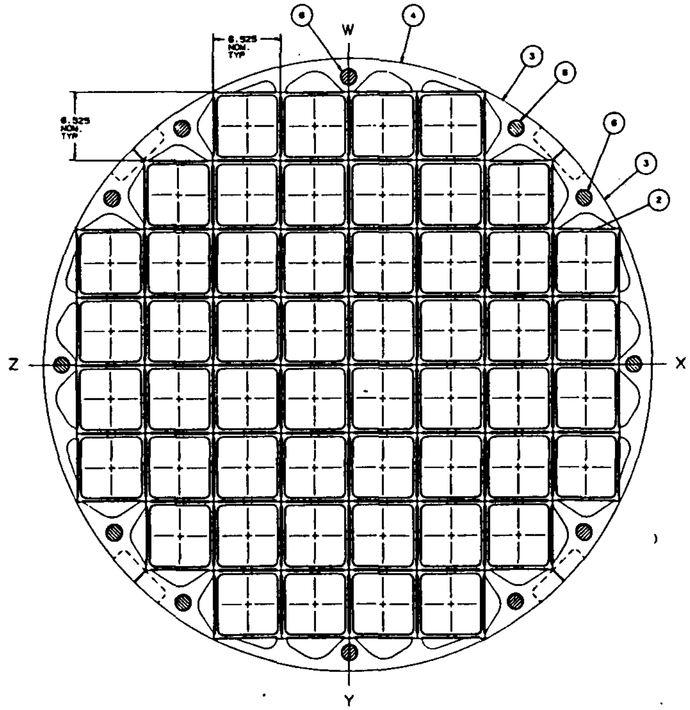
9/7/89

BR-100 CASK
BASKET ASSEMBLY
DETAIL PARTS

SCALE 1/2

1192026 D 0

09-14-89



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. FOR BILL OF MATERIAL SEE DRAWING 1192020E.
3. DRAIN LINES AND RELATED PROVISIONS WILL BE SHOWN ON A LATER REVISION.

PRELIMINARY DESIGN BASELINE

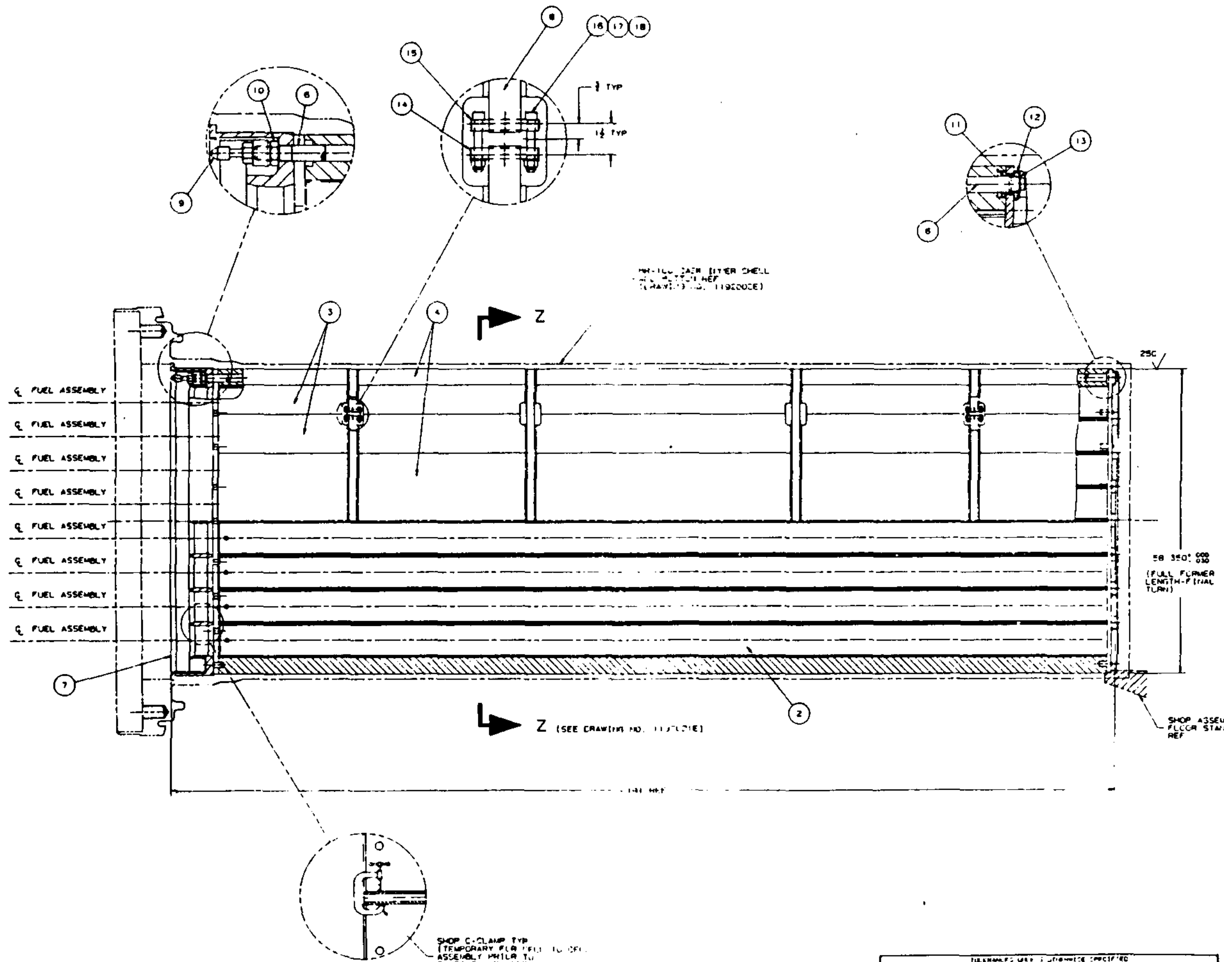
BASELINE DRAWING FOR ANALYSIS ONLY

J. WOOD

BR-100 CASK
BWR BASKET
CROSS SECTION

1192021 E 0

09-14-89



BILL OF MATERIAL						
1	1	1192022	001	E	BOTTOM PLATE	SEE NOTE 2
2	52	1192204	001	D	BWR INDIVIDUAL CELL	SEE NOTE 2
3	8	1192023	001	E	FORMER A	SEE NOTE 2
4	6	1192024	001	E	FORMER B	SEE NOTE 2
5	-	LATER			BWR STANDOFFS (SEE NOTE 7)	SEE NOTE 2
6	12	1192026	001	E	TIE RODS	SEE NOTE 2
7	1	1192025	001	E	UPPER GRID	SEE NOTE 2
8	8	1192026	002	E	OUTER BAND SEGMENT (SEE NOTE 8)	SEE NOTE 2
9	12	1192026	003	E	TOP NUT	SEE NOTE 2
10	12	1192020	001	E	1 3/8-8UNC JAM NUT	304 S.ST.
11	12	1192026	004	E	LOCATING SPACER	SEE NOTE 2
12	12	1192026	005	E	BOTTOM NUT	SEE NOTE 2
13	12	1192020	002	E	TRU-ARC RETAINING RING NO. 5100-112 OR EQUAL	PH15-7MO S.ST.
14	8	1192026	006	E	BAND TENSIONER A (SEE NOTE 8)	SEE NOTE 2
15	8	1192026	007	E	BAND TENSIONER B (SEE NOTE 8)	SEE NOTE 2
16	16	1192020	003	E	3/8-24UNF-2A X 2 1/2 LG. SOCKET HEAD CAP SCREW	S.ST.
17	16	1192020	004	E	3/8 FLAT WASHER	S.ST.
18	16	1192020	005	E	3/8 FLEXLOC NUT OR EQUAL	S.ST.

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS ARE AS SPECIFIED ON DETAIL DRAWING.
3. ASSEMBLY TO BE PERFORMED ACCORDING TO B&W PROCEDURE NO. (LATER).
4. MAX. WEIGHT OF ASSEMBLY TO BE 10,000 LBS.
5. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. FUEL ASSEMBLY STAND-OFF DETAILS TO BE PROVIDED LATER.
8. EACH LEVEL OF BANDS CONSISTS OF 2 SEGMENTS.

PRELIMINARY DESIGN BASELINE
BASELINE DRAWING FOR ANALYSIS ONLY

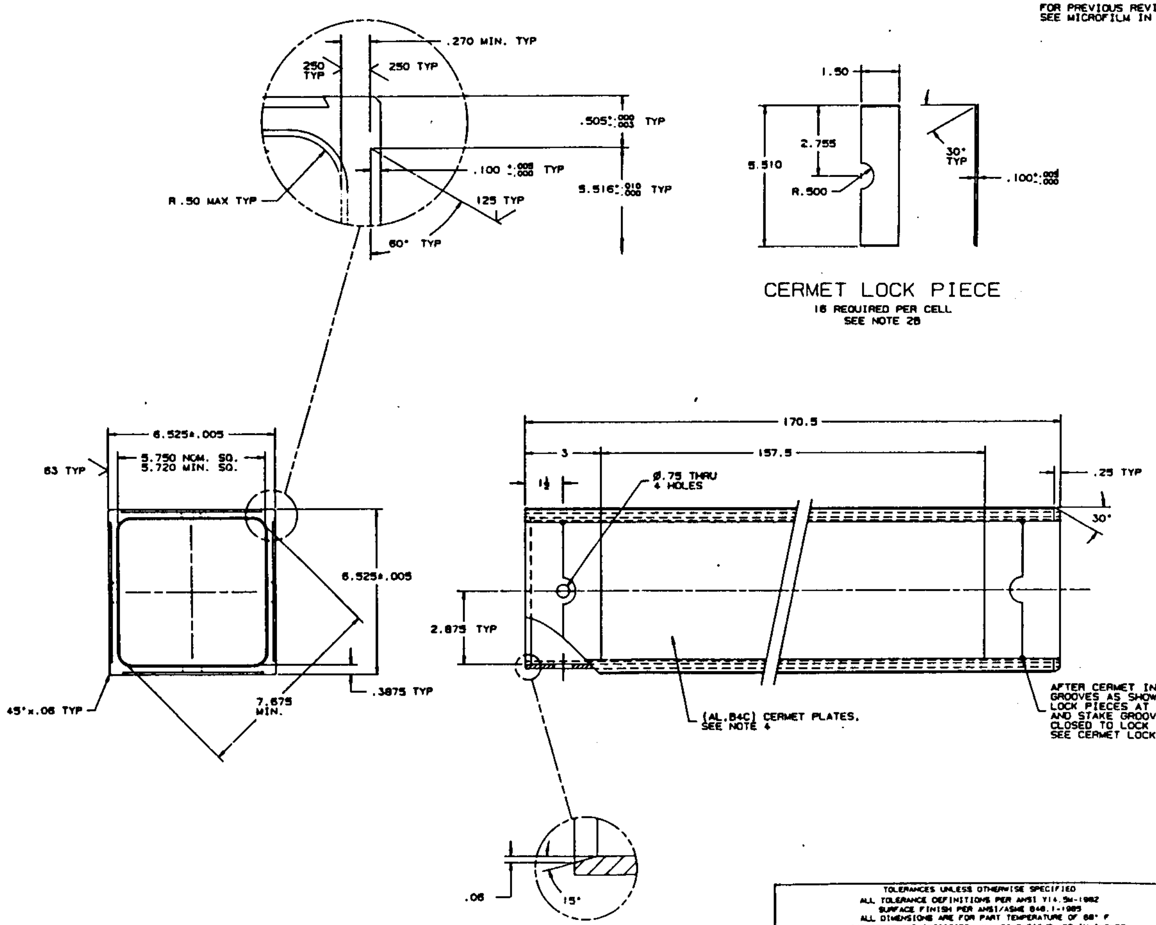
J. WOOD

BR-100 CASK
BWR BASKET
ASSEMBLY
LONGITUDINAL
SECTION

1192020 E 0

REV	DESCRIPTION	DATE	APPROVAL
3	REVISED AND REDRAWN	[illegible]	[illegible]

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. CELL: ALUMINUM EXTRUSION TO ASME SB-221, ALLOY 6061, TEMPER T6511. ALL EXTRUDED SURFACES TO HAVE A 250 RHR SURFACE FINISH OR BETTER.
   THIS MATERIAL TO MEET THE REQUIREMENTS OF ASME B&PV CODE SECTION III, SUB-SECTIONS NB 2546 AND NB 2552 AND IT SHALL BE RECLASSIFIED TO CLASS 1.
   B. LOCK PIECE: ALUMINUM SHEET TO ASTM B-209, 6061-T6 WITH A SURFACE FINISH OF 125 RHR OR BETTER.
3. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I, AFTER MACHINING AND BEFORE CERMET PLATE INSTALLATION.
4. (AL, B4C) CERMET PLATES (5.510 ACROSS BEVELED EDGES x 10.50 LG.) BUTTED END TO END. NOMINAL .100 THK. TYP. INCLUDING ALUMINUM COVER SHEET. 15 REQUIRED PER SIDE.
5. A FREE PATH GAGE 5.540 INCH SQUARE WITH 0.500 MAX. RADIUS CORNERS TO BE INSERTED AND TO PASS FREELY THROUGH THE FULL LENGTH TO ASSURE CLEARANCE. COMPLETE INTERNAL AND EXTERNAL GAGE DETAILS (LENGTH, ETC) LATER.
6. APPROXIMATE WEIGHT OF THE BWR INDIVIDUAL FUEL CELL TO BE 150 LBS. (INCLUDING 125 LBS. OF AL STRUCTURE AND 25 LBS OF CERMET).

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

	UP TO 6" INCL.	OVER 6" TO 12" INCL.	OVER 12" TO 24" INCL.	OVER 24" TO 72" INCL.	OVER 72" TO 180" INCL.	OVER 180"
3 PLACE DIM. MACHINED	±.003"	±.005"	±.005"	±.010"	±.031"	
2 PLACE DIM. MACHINED	±.02"	±.03"	±.03"	±.08"	±.08"	±.13"
2 PLACE DIM. UNMACHINED	±.06"	±.06"	±.13"	±.13"	±.18"	±.19"

FLATNESS	.001"/IN. OF SURFACE UP TO .020" MAX	BREAK CORNERS .02" MAX. RADIUS OR CHAMFER
PERPENDICULARITY	.002"/IN. OF SURFACE UP TO .020" MAX	
CONCENTRICITY	.019" DIA	
ANGULARITY	±0°-30'	CHAMFERS ±5°

ALL MACHINED SURFACES TO HAVE 3.18 Ra (125Ra) FINISH UNLESS OTHERWISE NOTED

PRELIMINARY DESIGN BASELINE
BASELINE DRAWING FOR ANALYSIS ONLY

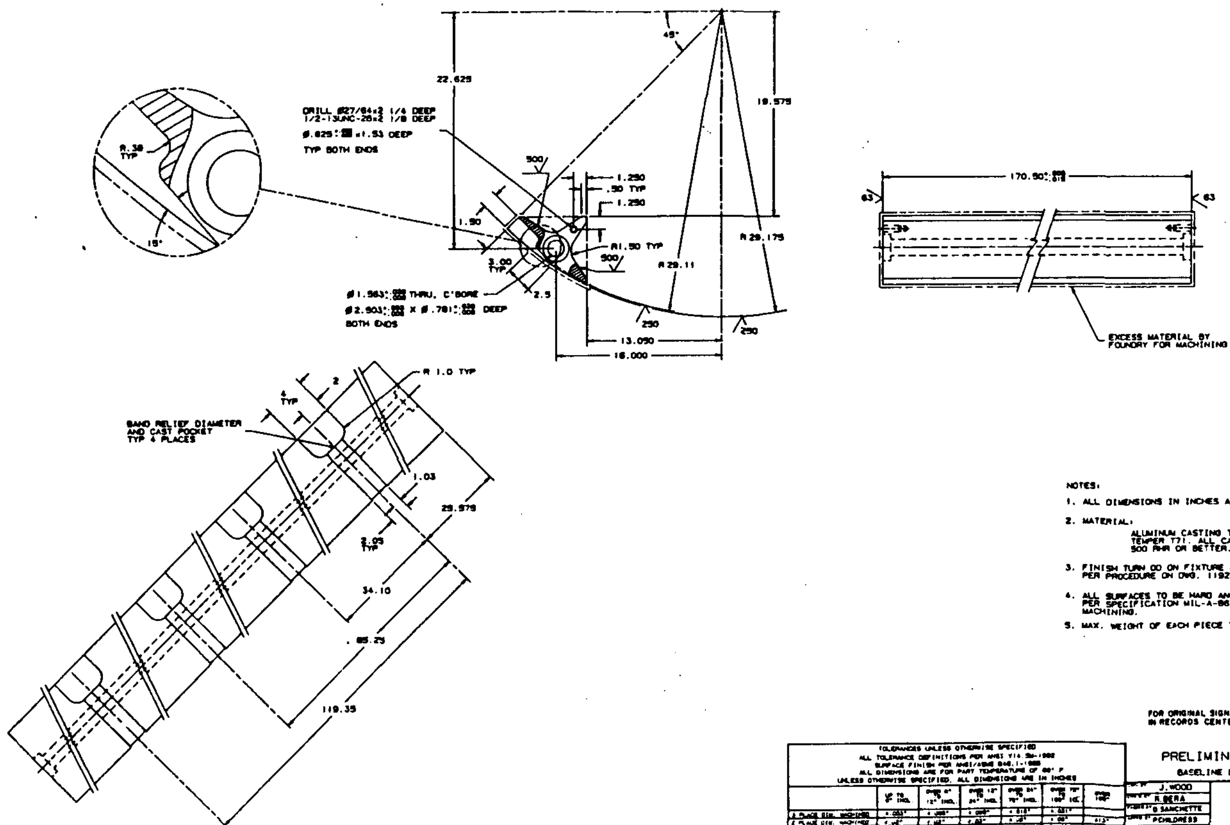
J. WOOD
R. BERA
R. WISEMAN
P. CHILDRESS
2/6/89

BR-100 CASK
BWR BASKET
INDIVIDUAL FUEL CELL

SCALE 1/2
1192204 D
REV 3

09-14-89

REV	DESCRIPTION	DATE	APPROVAL
1	REVISED AND REDRAWN		



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   ALUMINUM CASTING TO ASME SB-26 ALLOY 5070A, TEMPER T71. ALL CAST SURFACES TO HAVE A FINISH OF 500 RHR OR BETTER.
3. FINISH TURN OD ON FIXTURE OR AFTER ASSEMBLY TO DIAMETER PER PROCEDURE ON DWG. 1192216E.
4. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I, AFTER MACHINING.
5. MAX. WEIGHT OF EACH PIECE TO BE 125 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

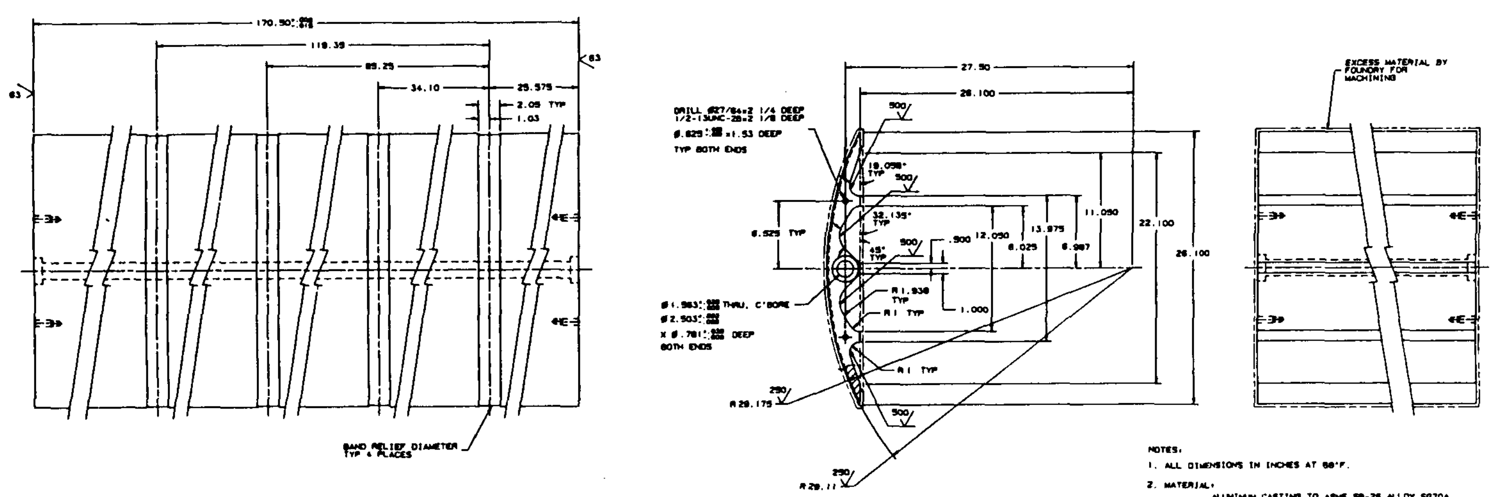
J. WOOD
R. BERA
G SANCHETTE
P CHILDRESS
DATE 7-14-89

BR-100 CASK
BWR BASKET
FORMER A

SCALE 1/4

1192023E 1

09-14-89



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   ALUMINUM CASTING TO ASME SB-26 ALLOY 5070A, TEMPER T71. ALL CAST SURFACES TO HAVE A FINISH OF 500 RHR OR BETTER.
3. FINISH TURN OD ON FIXTURE OR AFTER ASSEMBLY TO DIAMETER PER PROCEDURE ON DWG. 1192216E..
4. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I AFTER MACHINING.
5. MAX. WEIGHT OF EACH PIECE TO BE 250 LBS.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

REV	DESCRIPTION	DATE	APPROVAL
1	REVISED AND REDRAWN	[illegible]	[illegible]

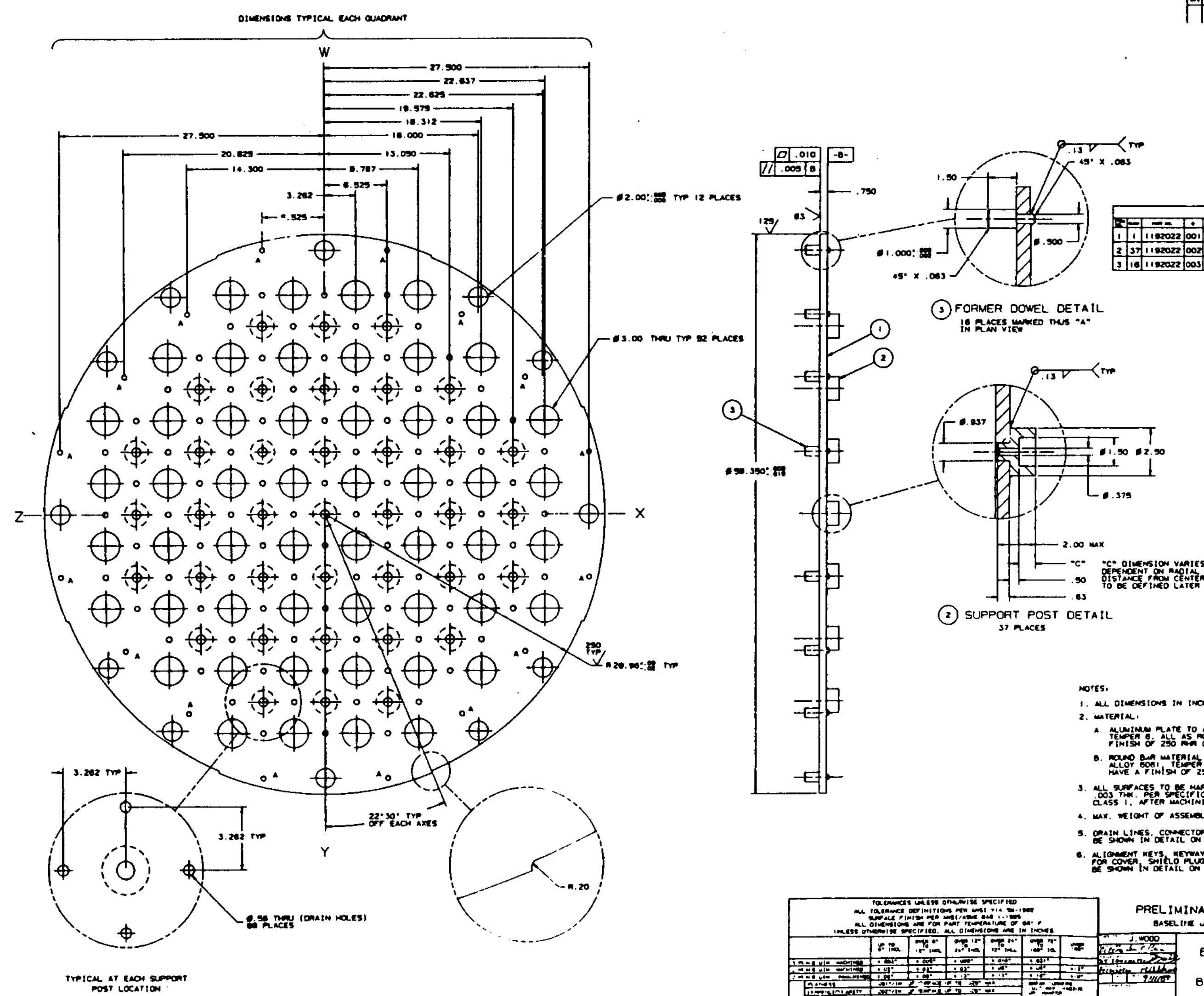
TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

J. WOOD
A. BERA
B. SANCHETTE
P. CHILDRESS
7-14-89

BR-100 CASK
BWR BASKET
FORMER B

1/4

1192024 E | 1



BILL OF MATERIAL						
1	1	1192022	001	E	BOTTOM PLATE	SEE NOTE 2
2	37	1192022	002	E	SUPPORT POST	SEE NOTE 2
3	16	1192022	003	E	FORMER DOWEL	SEE NOTE 2

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. ALUMINUM PLATE TO ASTM B-209-88 ALLOY 6061, TEMPER 6. ALL AS ROLLED SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER.
   B. ROUND BAR MATERIAL TO SPEC. ASME SB-221 ALLOY 6061, TEMPER T6511. ALL SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER.
3. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS 1, AFTER MACHINING.
4. MAX. WEIGHT OF ASSEMBLED PLATE TO BE 150 LBS.
5. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

J. WOOD

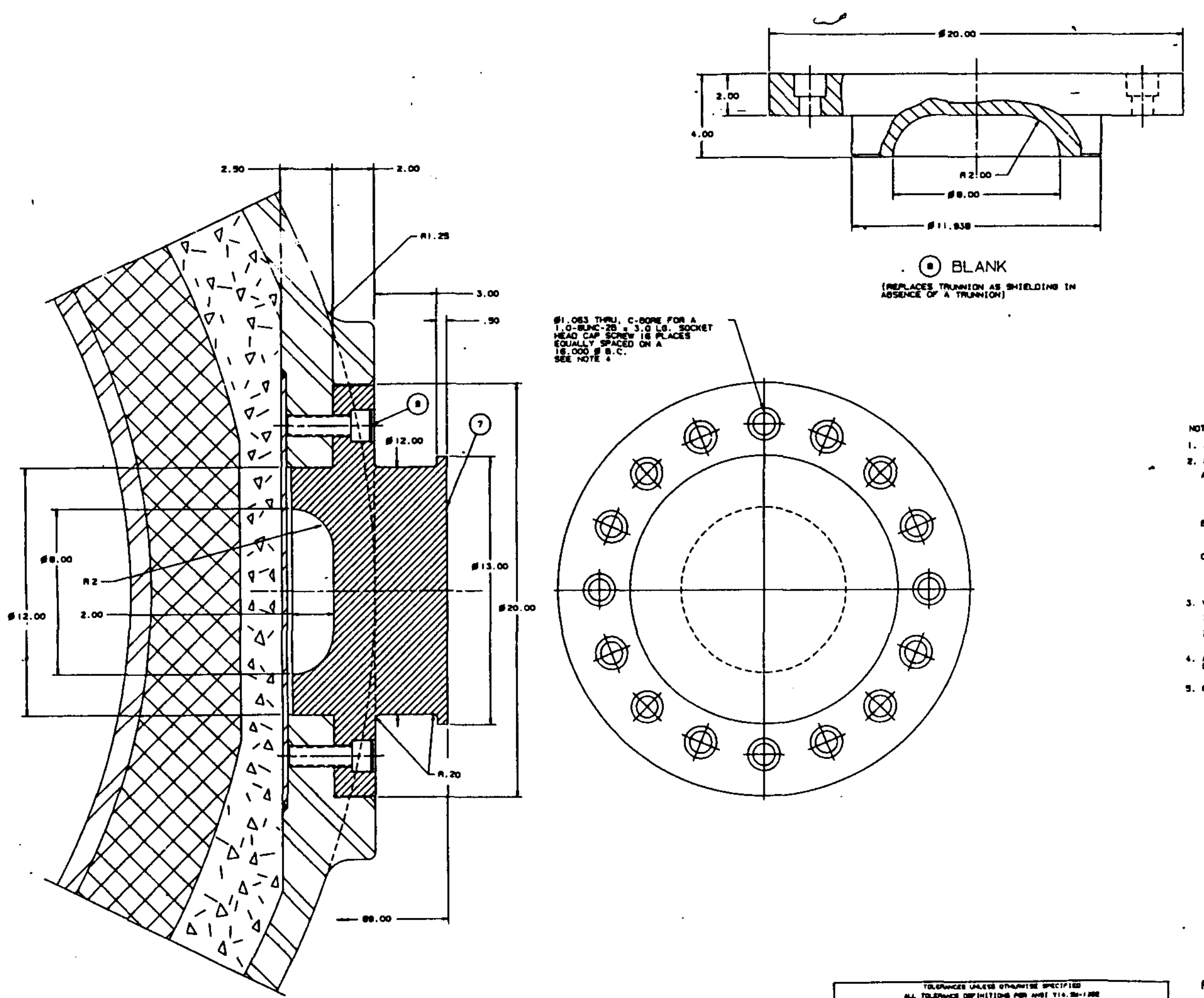
BR-100 CASK
BWR BASKET
BOTTOM PLATE

1/4

1192022 E 0

09-14-89

REV	DESCRIPTION	DATE	APPROVAL
1	REVISED AND REDRAWN	[illegible]	[illegible]



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS:
   - A. ITEM 7 - TRUNNION TO BE ASME SA 182, FXM-19 FORGING SOLUTION ANNEALED AT 1925-1975° F, WATER QUENCHED FOR ASME CLASS 1 COMPONENT USE.
   - B. ITEM 8 - BLANK TO BE ASME SA-182, 304L, FORGING, SOLUTION ANNEALED AT 1925-1975°F AND WATER QUENCHED.
   - C. ITEM 9 - SOCKET HEAD CAP SCREWS TO BE ALLOY 718 TO SPEC. ASME SB 637 WITH CUT THREADS AGE HARDENED AND FINAL GROUND THREADS.
3. WEIGHTS (CALCULATED) IN LBS:
   - ITEM 7 - 329.4 LBS EACH
   - ITEM 8 - 1.1 LBS EACH
4. AT INSTALLATION EACH BOLT TO BE TORQUED IN A DIAMETRICALLY OPPOSED SEQUENCE TO 240±3FT-LBS.
5. FOR BILL OF MATERIAL SEE DRAWING NO. 1192015E.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

TOLERANCES UNLESS OTHERWISE SPECIFIED
ALL TOLERANCE DEFINITIONS PER ANSI Y14.5M-1982
SURFACE FINISH PER ANSI/ASME B46.1-1985
ALL DIMENSIONS ARE FOR PART TEMPERATURE OF 68° F
UNLESS OTHERWISE SPECIFIED, ALL DIMENSIONS ARE IN INCHES

	UP TO 6" INCL.	OVER 6" TO 12" INCL.	OVER 12" TO 24" INCL.	OVER 24" TO 72" INCL.	OVER 72" TO 180" INCL.	OVER 180"
3 PLACE DIM. MACHINED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
2 PLACE DIM. MACHINED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
2 PLACE DIM. NONMACHINED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FLATNESS	[illegible]					
PERPENDICULARITY	[illegible]					
CONCENTRICITY	[illegible]					
ANGULARITY	[illegible]					

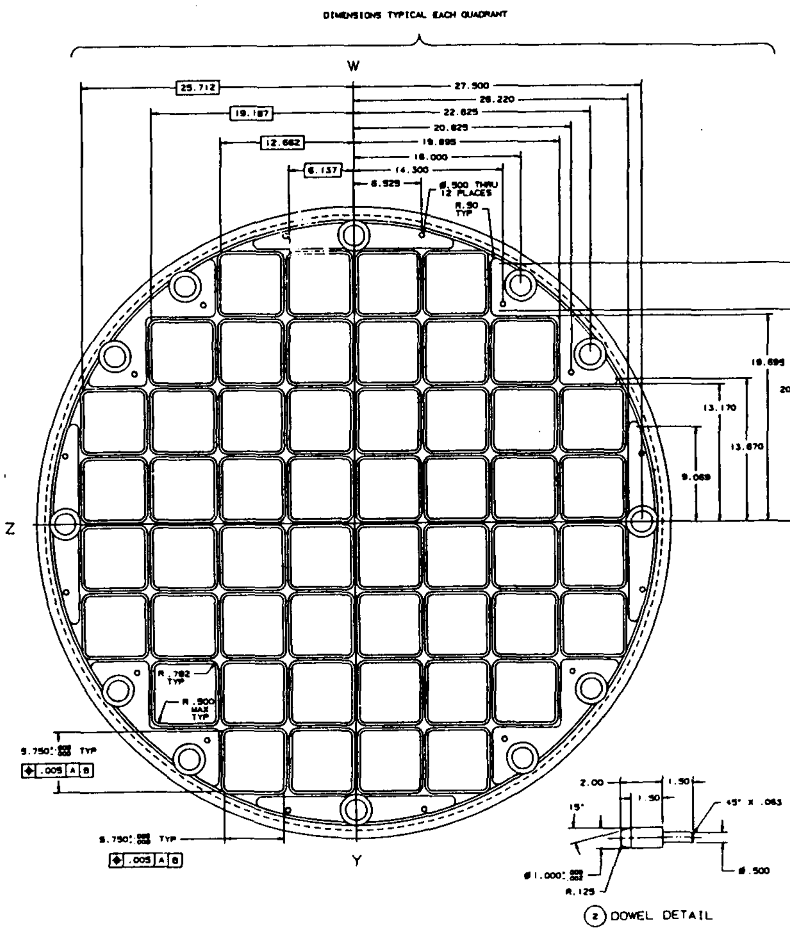
DRAWN BY	J. WOOD
CHECKED BY	A. C. [illegible]
[illegible]	R. [illegible]
[illegible]	F. C. [illegible]

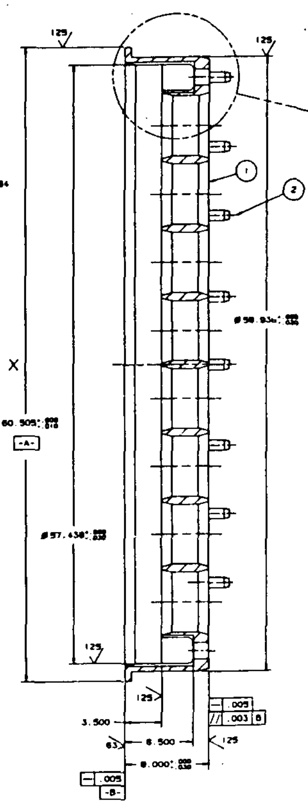
BR-100 CASK
CASK ASSEMBLY
SECTION U-U

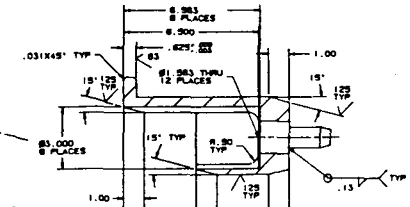
SCALE 1/2

1192003 E 1

09-27-89







BILL OF MATERIAL						
ITEM NO.	QUAN	PART NO.			DESCRIPTION	MATL SPEC
1	1	1192025	001	E	UPPER GRID	SEE NOTE 2
2	16	1192025	002	E	DOWEL	SEE NOTE 2

NOTES:

1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIAL:
   A. ALUMINUM CASTING TO ASME SB-26, ALLOY 5070A TEMPER T71. ALL CAST SURFACES TO HAVE A FINISH OF 500 RHR OR BETTER.
   B. ROUND BAR MATERIAL TO ASME SB 221, ALLOY 6061, TEMPER T6. ALL SURFACES TO HAVE A FINISH OF 250 RHR OR BETTER.
3. ALL SURFACES TO BE HARD ANODIZED .002 MIN. TO .003 THK. PER SPECIFICATION MIL-A-8625, TYPE III, CLASS I, AFTER MACHINING.
4. MAX. WEIGHT OF ASSEMBLED GRID TO BE 400 LBS.
5. DRAIN LINES, CONNECTORS, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.
6. ALIGNMENT KEYS, KEYWAYS, DOWELS, AND RELATED PROVISIONS FOR COVER, SHIELD PLUG, AND BASKET ONE-WAY ASSEMBLY WILL BE SHOWN IN DETAIL ON A LATER REVISION.
7. LIFTING/HANDLING FITTINGS, DEVICES, AND RELATED PROVISIONS WILL BE SHOWN IN DETAIL ON A LATER REVISION.

TOLERANCES UNLESS OTHERWISE SPECIFIED

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

J. WOOD

7/11/89

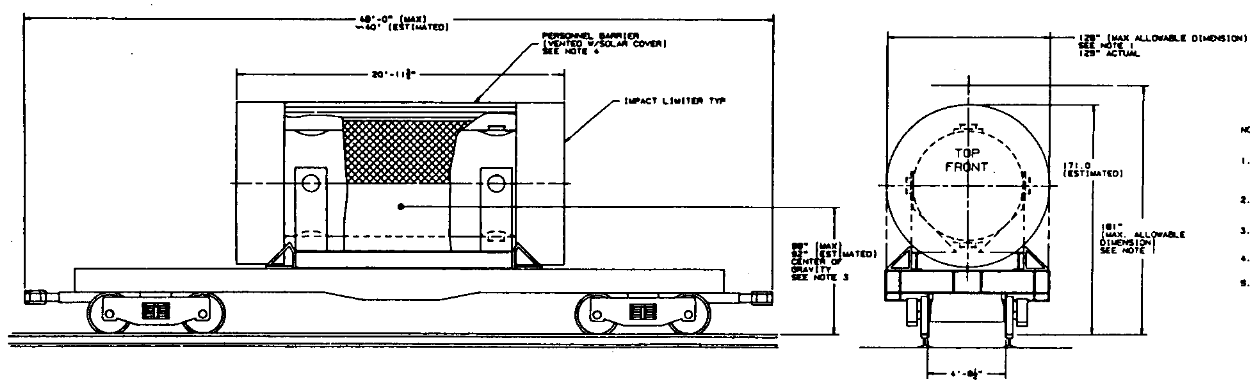
BR-100 CASK
HWR BASKET
UPPER GRID

1192025 E 0

09-14-89

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

REV	DESCRIPTION	DATE	APPROVAL
2	REVISED AND REDRAWN		



NOTES:

1. RAIL CAR WITH CASK, IMPACT LIMITER, PERSONNEL BARRIER AND SKID MUST BE WITHIN THE ALLOWABLE ENVELOPE AS DEFINED BY THE ASSOCIATION OF AMERICAN RAILROADS FOR UNRESTRICTED SERVICE.
2. MAXIMUM GROSS WEIGHT OF THE RAILCAR, LOADED CASK AND ALL OTHER EQUIPMENT ON THE RAILCAR IS LIMITED TO 283,000 lbs(?).
3. THE CENTER OF GRAVITY (C.G.) SHALL BE AS LOW AS POSSIBLE.
4. ONLY THE ENVELOPE OF THE PERSONNEL BARRIER IS REPRESENTED.
5. IMPACT LIMITER STORAGE LOCATIONS ON THE RAIL CAR WILL BE SHOWN IN A LATER REVISION.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

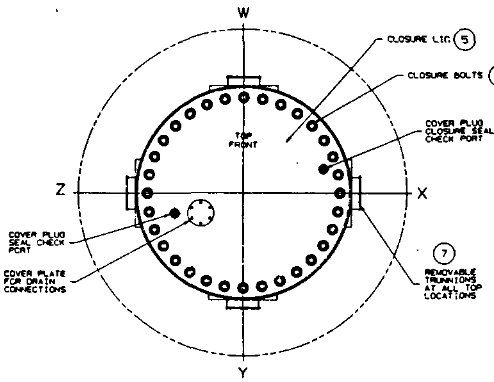
BR-100 CASK
CASK SYSTEM
INTERFACES

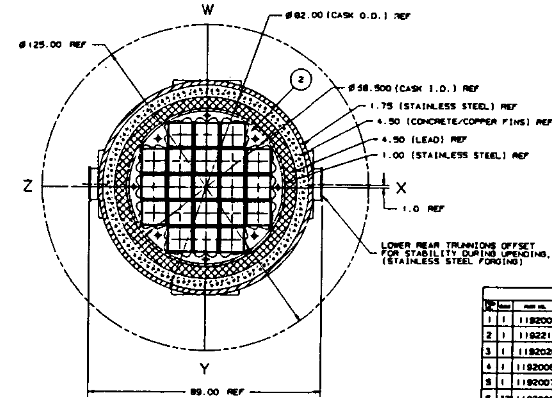
SCALE 1/32

1193037 E 2

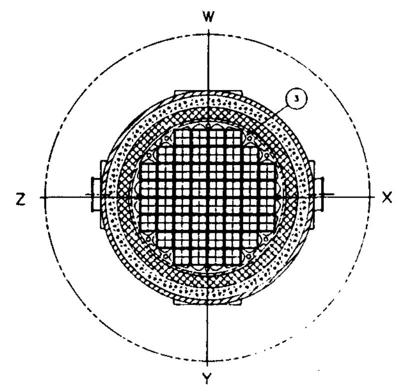
FOR PREVIOUS REVISIONS SEE MICROFILM
IN RECORDS CENTER

REVISIONS			
2	REVISED AND REDRAWN		

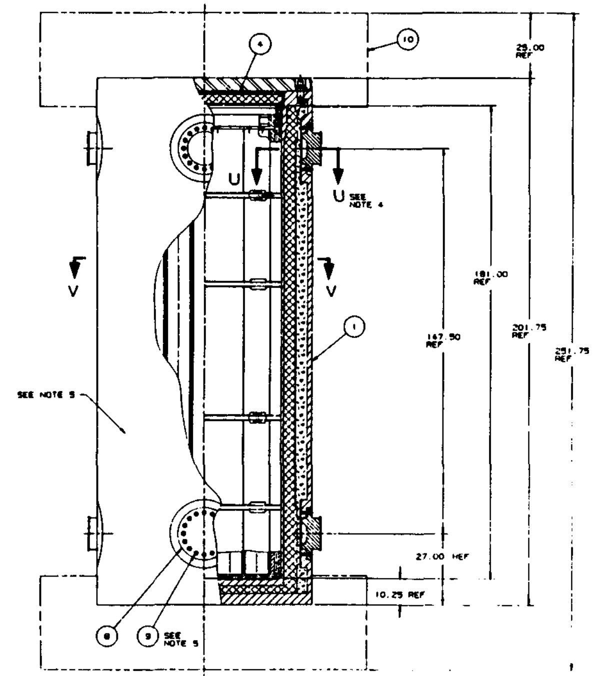




SECTION V-V
PWR ARRAY SHOWN
21 FUEL CELLS REF



SECTION V-V
BWR ARRAY SHOWN
52 FUEL CELLS REFERENCE



BR-100 CASK
LONGITUDINAL SECTION

BILL OF MATERIAL						
1	1	1192002	001	E	CASK BODY	SEE NOTE 2
2	1	1192216	001	E	PWR BASKET ASSEMBLY	
3	1	1192020	001	E	BWR BASKET ASSEMBLY	
4	1	1192006	001	E	SHIELD PLUG	
5	1	1192007	001	E	CLOSURE LID	
6	32	1192008	001	E	CLOSURE BOLT	
7	6	1192003	001	E	TRUNNION	
8	2	1192003	002	E	TRUNNION BLANK	
9	128	1192003	003	E	TRUNNION BOLTS	
10	2	1192009	001	E	IMPACT LIMITER ENVELOPE	

NOTES:
1. ALL DIMENSIONS IN INCHES AT 68°F.
2. MATERIALS SPECIFICATIONS PER ABOVE PART DRAWINGS.
3. APPROXIMATE WEIGHT OF THE CASK SYSTEM, IN THE PWR CONFIGURATION, NOT LOADED, AND W/O IMPACT LIMITERS, TO BE 161,000 LBS (169,000 LBS W/IMPACT LIMITERS) [202,000 LBS W/MAX. PAYLOAD AND W/IMPACT LIMITERS].
4. FOR SECTION U-U SEE DRAWING NO. 1192003E.
5. EXTERIOR COATING TO BE WHITE EPOXY PER SPECIFICATION (LATER).

FOR ORIGINAL SIGNATURES SEE MICROFILM
IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

RHODES

BR-100 CASK
CASK ASSEMBLY

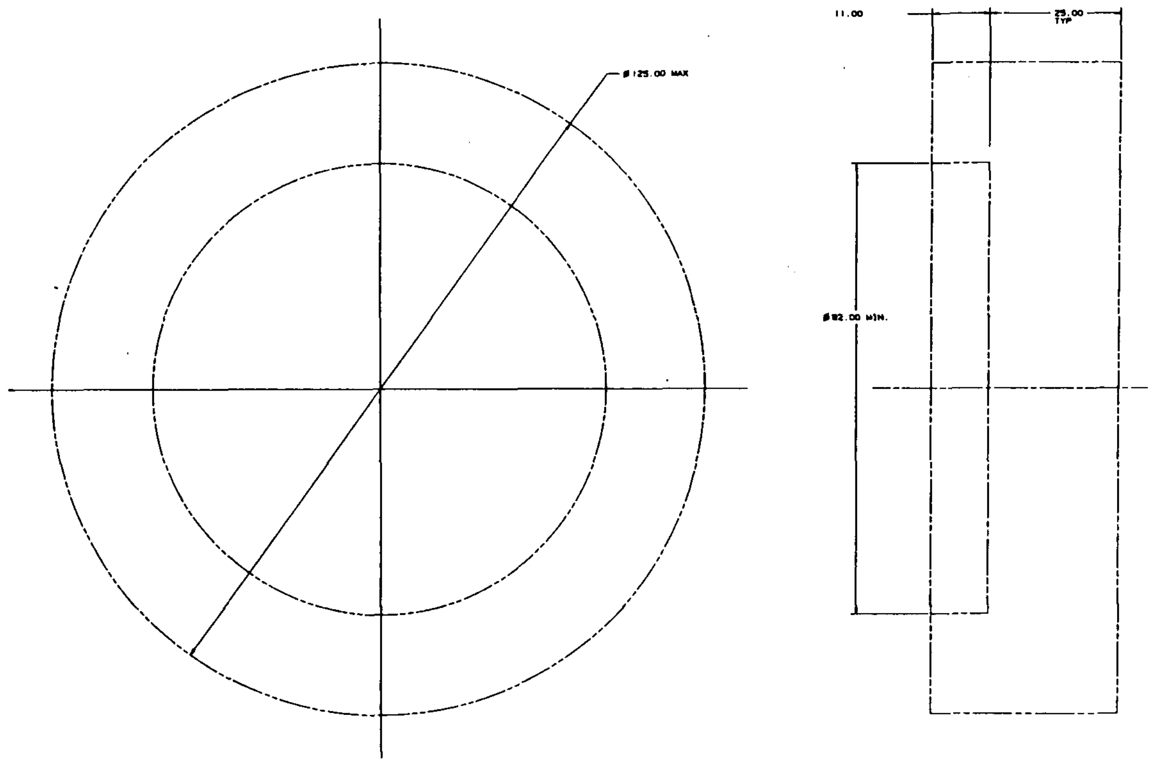
1/16

1192015 E 2

09-14-89

FOR PREVIOUS REVISIONS SEE MICROFILM IN RECORDS CENTER

REVISIONS			
NO.	DESCRIPTION	DATE	APPROVAL
2	REVISED AND REDRAWN	9/14/89	



NOTES:

1. ALL DIMENSIONS IN INCHES AT 68° F.
2. MATERIALS TO BE BALSA/RED WOOD, KEVLAR, AND STAINLESS STEEL. MATERIALS WILL BE SPECIFIED ON DETAIL DRAWING (LATER).
3. WEIGHT OF INDIVIDUAL IMPACT LIMITER TO BE 4,000 LBS. NOMINAL AND 4,500 LBS MAXIMUM.
4. HANDLING AND ATTACHMENT INTERFACES TO BE DEFINED LATER.

FOR ORIGINAL SIGNATURES SEE MICROFILM IN RECORDS CENTER

PRELIMINARY DESIGN BASELINE

BASELINE DRAWING FOR ANALYSIS ONLY

J. WOOD
A. BERA
E. MCGUINN
P. CHILDRESS

BR-100 CASK IMPACT LIMITER ENVELOPE

SCALE 1/8

1192009 E 2

09-14-89