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Conceptual Design of the Clinch River Breeder Reactor Spent-Fuel Shipping Cask

Edited by Ronald B. Pope and Jane M. Diggs

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Abstract

Details of a baseline conceptual design of a spent fuel shipping cask for the Clinch River Breeder Reactor (CRBR) are presented including an assessment of shielding, structural, thermal, fabrication and cask/plant interfacing problems. A basis for continued cask development and for new technological development is established. Alternates to the baseline design are briefly presented. Estimates of development schedules, cask utilization and cost schedules, and of personnel dose commitments during CRBR in-plant handling of the cask are also presented.

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Acronyms

There are a number of acronyms used throughout this report which are defined here for easy reference.

General

IDR – Interface Data Report
LMFBR – Liquid Metal Fast Breeder Reactor

Facilities

CRBRP – Clinch River Breeder Reactor Plant
HEF – Hot Experimental Facility
FFTF – Fast Flux Test Facility
CDS – Conceptual Design Study
LDP – Large Development Plant

In-Plant

CWA – Cask Washdown Area
RSB – Reactor Service Building
CS – Cask Shaft
CC – Cask Corridor
FHC – Fuel Handling Cell
IVTM – In-Vessel Transfer Machine

Cask

BL – Basket Lid
CIL – Cask Inner Lid
COL – Cask Outer Lid

Summary

A conceptual design study has been made of a spent fuel shipping cask for the Clinch River Breeder Reactor Plant (CRBRP). Consideration was given to how the cask would interface with the CRBRP, the rail transportation system, and the receiving facility, which was assumed to be the Hot Experimental Facility (HEF). Consideration was also given to areas where insufficient technology exists which limits the confidence level of the design (including seals, leak testing methods, thermal modeling, and the neutron shield concept) and was given to the uncertainties in the licensing and fabricating areas. In some areas (including seals, leak testing methods, thermal modeling, and neutron shielding), the efforts of meeting these interfaces have led beyond current, available technology. This coupled with licensing and fabrication uncertainties limits the confidence level of the design.

A baseline design and three alternate concepts of cask transportation systems were developed. These various concepts were needed to adequately address the uncertainties mentioned above. In all concepts it has been assumed that the spent fuel will be carried in individual, sealed canisters filled with liquid sodium as the primary coolant. The canisters may be mechanically sealed (baseline) or seal-welded (alternate). The sealed canisters could eventually be qualified as either normal form or special form. The advantages and disadvantages of these options must be considered further in any follow-on preliminary design.

The baseline design concept, denoted as B-F2 (see Figure 1-1), consists of seven fuel assemblies in seven canisters, each filled with sodium. The canisters are placed in a helium-filled, stainless-steel, sealed basket. The basket is placed in a thick-walled, ferritic steel cask body with the basket sealed to the cask body to allow helium to fill the gap between the basket and the cask; the cask body has a thick steel lid external to the basket lid which provides weather, impact, puncture and fire protection, but not containment. The cask body is equipped with water coolant channels to facilitate in-plant cooling during loading and cooldown prior to unloading. The cask body also has a partially volatile neutron shield with interstitial steel fins for heat transfer through the neutron shielding material and small external finlets for passive heat rejection to the environment during transport. Impact limiters may be required for transport. The cask would be carried on either a six-axle or an eight-axle railcar, covered with a combined sunshade/personnel barrier. The B-F2 notation indicates baseline (B), ferritic cask body (F), and two levels of containment (2),where the canisters and the basket constitute the two-containment systems.

The alternate designs are similar to the baseline except as follows:

1. The A-A2 concept has a monolithic austenitic cask body that incorporates the basket, thereby eliminating the gap between the basket and the cask body.
2. The A-A3 concept has an austenitic cask body separate from the basket, and the cask body has an inner lid to provide a third level of containment.
3. The A-F3 concept is identical to the A-A3 concept except the steel cask body is ferritic rather than austenitic.

For all cask designs, two lifting trunnion concepts have been developed, and a unique, completely redundant, lifting yoke has been designed.

Limited assessments of shielding, materials, structural, thermal, leak testing, cask operations, personnel doses during handling, and systems costs were made during the conceptual design study. Details of these assessments and their results are presented in the body of this report. These assessments indicate that

1. Approximately 419 mm (16.5 in.) of steel and 178 mm (7 in.) of neutron-shielding material are required to reduce the surface dose rate to 10 mrem/hr.
2. Many materials-related issues must be addressed before a cask can be developed that could be certified and capable of being fabricated.
3. No insurmountable problems were identified relative to structural dynamic response in impact and puncture environments, although further design analyses are needed.
4. The thermal analyses showed that heat transfer, to a great extent, controls the design. Because these analyses were based upon limited empirical data a low-confidence level exists in the design. Further data are needed to increase design confidence.
5. Extensive effort will be required in the future to properly select the seals, define sealing methods, develop and qualify leak testing

procedures, and quantify correlations between isotopic and more readily measurable volumetric leakage rates.

6. The cask operations study showed that, on the average, a cask can be "turned-around" within the CRBRP facility in approximately 66 working hours (i.e., in 4.1 days based on two 8-hr shifts per day).
7. A loading estimate showed that, during the in-plant operations for loading seven spent fuel assemblies, a maximum cumulative personnel dose of approximately 235 mrem can be expected.
8. The lifetime spent fuel transportation costs (excluding system development costs) were estimated to be approximately $27 million (1981 dollars) if the round-trip distance is 805 km (500 mi).

An assessment shows that a cask built according to the designs developed for CRBRP could be used to transport Fast Flux Test Facility (FFTF) spent fuel if the FFTF handling facility in-plant can be modified to accept the cask. With some modifications to the design, the concepts developed might also be used to ship Large Development Plant (LDP) fuel.

Finally, a study of the procedure and philosophy needed to produce a licensed cask showed that preliminary design and supportive technology development must be started in FY82 if a first production unit is to be available in FY90.

Conceptual Design of the Clinch River Breeder Reactor Spent Fuel Shipping Cask

Chapter 1. Introduction

The demonstration of technical and commercial viability of the Liquid Metal Fast Breeder Reactor (LMFBR) requires closure of the fuel cycle, including the reprocessing of spent fuel and the fabrication of new fuel from the recovered plutonium. In the United States, it is envisioned that the fuel reprocessing plant(s) will not be co-located with the LMFBR plants. Thus, transport of the spent fuel from the reactors to the reprocessor will be required.

Studies of methods for transporting LMFBR spent fuel have been underway for almost a decade in the United States. Initial efforts are reported in Reference 1. Later, a cask was conceived which would serve both the Fast Flux Test Facility (FFTF) and the Clinch River Breeder Reactor Plant (CRBRP) where an internal rotating basket was to be used to facilitate fuel loading at the FFTF, and Dowtherm, a liquid organic, was to be used as the primary coolant* (Reference 2). Work on this design was terminated in 1976 by the Energy Research and Development Administration (ERDA) because of significant questions relative to both the rotatable basket and the choice of coolant. An alternate cask concept was developed where attempts were made to optimize the design for the needs of both the FFTF and the CRBRP (Reference 3). Both of these designs (References 2 and 3) were severely constrained by insufficient technology combined with competing and restrictive design requirements for the two plants.

In FY80, a cask concept was developed for transporting spent fuel from a large, 1000 MWe, LMFBR plant which would result from the Department of Energy's Conceptual Design Study (CDS). This cask concept (Reference 4) was then scaled to provide an estimate of a similar configuration which would serve the CRBRP. The basic concept consisted of a spent fuel shipping cask having a monolithic steel structure with seven basket cavities. Each cavity would contain a fuel assembly in a sealed, sodium-filled, stainless-steel canister. The cask cavity would be backfilled before shipment with helium, or possibly nitrogen. Containment of the sodium would be provided by the canister, an inner cask lid, and an outer cask lid. Surrounding the steel cask body, longitudinal steel fins would extend through a solid neutron shield of borosilicone rubber. External heat rejection would be accomplished with spaced finlets welded to an outer steel shell encasing the neutron shield.

Other concepts, utilizing multiple levels of containment, have been developed for shipping spent fuel from large scale British, French, German, and Japanese LMFBR plants (see References 5 through 8).

In FY81, the Transportation Technology Center (TTC) at Sandia National Laboratories (SNL) was asked by the Clinch River Breeder Reactor Plant Project Office (CRBRP/PO) to initiate a detailed design effort to meet current needs of the CRBRP. The FY80 conceptual study results were used as the starting point for the FY81 effort. Specifically, milestones for the FY81 design activity were

1. Allow the TTC to concur with or provide recommendations on CRBRP Interface Control Document (ICD) CL54003 (Reference 9)**
2. Justify the need for canistering spent fuel assemblies before shipping
3. Define external, cask-cooling interfaces with the CRBRP

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*Pimary coolant is defined by the US Nuclear Regulatory Commission as "a gas, liquid or solid, or combination of them, in contact with the radioactive material, or, if the material is in special form, in contact with its capsule, and used to remove decay heat" (see Title 10, Chapter 1, Code of Federal Regulations, Part 71).

**Included as Appendix A.

4. Provide dimensional control interface drawings on
    a. The canister
    b. The removable plugs at the CRBRP Fuel Handling Cell (FHC)
    c. The cask transporter interfaces
5. Release the conceptual cask design.

The first two milestones were met early in FY81, and the latter three milestones are being satisfied by this report. The primary purpose of this report is to describe in detail the baseline conceptual design developed during the FY81 activity.

This report also presents

1. A summary of the basis for the design
2. Alternate concepts to the baseline concept that are responsive to economic, regulatory, and fabrication concerns
3 Design analyses in the shielding, materials, structural, and thermal areas
4. Definition and list of cask/plant interface requirements and projected Interface Data Report (IDR) phase submittal dates
5. An in-plant time and motion analysis defining cost schedules, a baseline cask turnaround time, and plant personnel exposure for cask handling
6. A brief assessment of the applicability of the CRBRP cask concept to other LMFBR plants
7. A discussion of cask design philosophy, projected development schedule, and a basis for new technological development.

The spent fuel cask shipping system concepts presented in detail in this report have common features (Figure 1-1). Working from the spent fuel assembly outward, these features include

1. Sealed stainless-steel canisters containing a spent fuel assembly and liquid sodium as a coolant
2. An austenitic (stainless-steel) basket which receives up to seven canisters and
    a. Can be sealed with the basket lid to provide a second-level containment
    b. Is bolted and sealed to the cask body to allow the gas filling the gap between the basket and cask to be controlled.*
3. A cask body of either austenitic or ferritic steel, with neutron shield, heat transmission and rejection fins, water-cooling channels, and lifting and tiedown trunnions
4. A basket lid (BL) providing closure of the second-level containment system
5. A cask inner lid (CIL) providing closure of the cask and a third-level containment, if needed**
6. A cask outer lid (COL) providing weather and puncture protection for the containment systems.

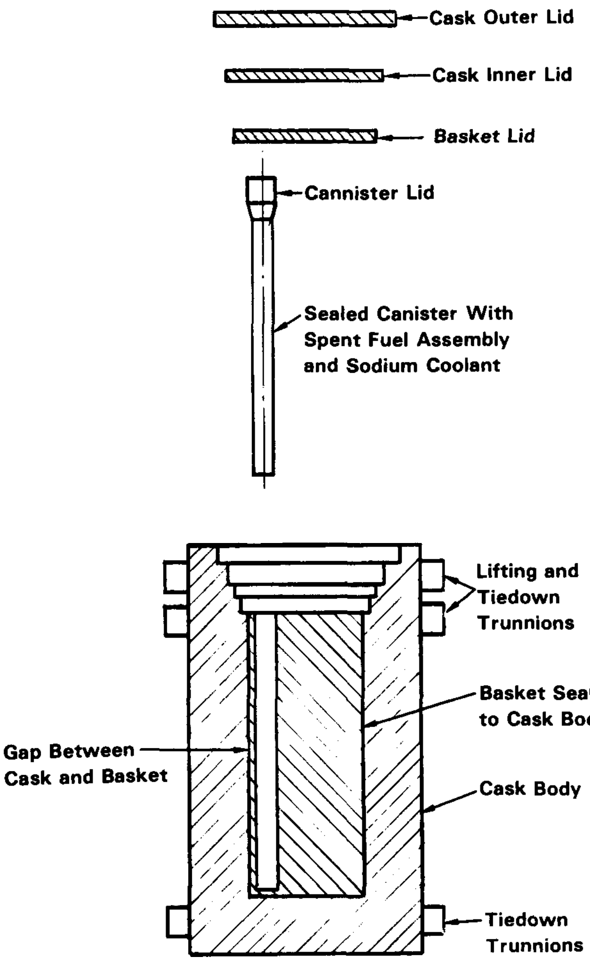

Figure 1-1 General Features of CRBRP Spent Fuel Shipping Cask System

The procedure for handling and loading the cask within CRBRP is illustrated in a simplified fashion in Figure 1-2. Details of this procedure are provided in the various sections of this report.

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*For one concept, the basket and cask body are monolithic, eliminating the gap between the two.

**The CIL is only included as one of the alternate designs. Baseline design does not include the CIL.

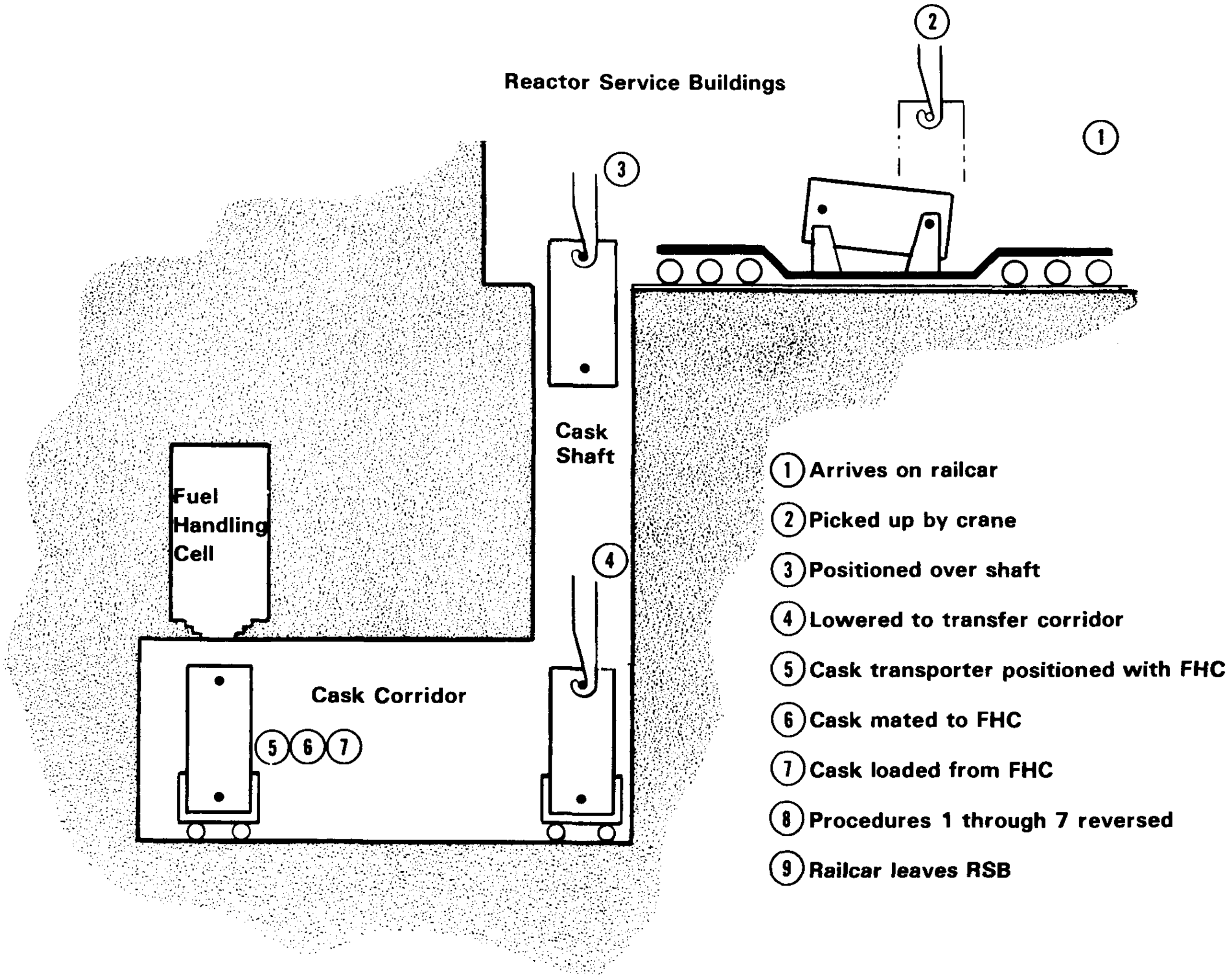

Figure 1-2 Simplified Plant Schematic and Path of Cask Through the Plant

Chapter 2. Design Requirements

The design of a spent fuel cask is governed by many, often competing, factors including regulatory requirements, plant requirements, transportation system requirements, economics, fabrication, and maintenance. The first three of these factors are discussed in this section. Other factors affecting cask design are discussed and assessed throughout the report.

2.1 Regulatory Requirements

The principal regulations that control the design of the CRBRP spent fuel shipping cask are the US Nuclear Regulatory Commission (NRC) Rules and Regulations (Reference 10) "Packaging of Radioactive Material for Transport and Transportation of Radioactive Materials Under Certain Conditions," Title 10, Code of Federal Regulations, Part 71 (denoted henceforth as 10CFR71). In addition, the NRC has a series of Regulatory Guides that applies to transport packagings such as shipping casks. Two that specifically apply are Regulatory Guide 7.4, "Leakage Tests on Packages for Shipment of Radioactive Materials," issued June 1975; and Regulatory Guide 7.8, "Load Combinations for the Structural Analysis of Shipping Casks," issued May 1977. The Regulatory Guides are "issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations to delineate techniques used by the staff in evaluating specific problems or postulated accidents or to provide guidance to applicants."

The NRC and the Department of Transportation (DOT) have joint jurisdiction of the transportation of high-level radioactive materials.* The NRC has jurisdiction over packaging (Type B package or cask) design and fabrication, and the DOT has jurisdiction over operations. The DOT regulations of significance are 49CFR171 through 178 (Reference 11).

In addition to existing regulations, proposed revisions to both 10CFR71 and 49CFR173 have been issued (References 12 and 13, respectively). Since the CRBRP spent fuel cask is to be used far into the future, consideration must be given during its design to proposed changes of controlling regulations.

For the shipment of DOE-controlled radioactive materials between DOE facilities, the shipping cask would normally be certified by DOE that it meets the requirements of both the NRC and DOT regulations. However, in the development of the conceptual cask design, it has been assumed NRC certification of the spent fuel shipping cask will also be required. This assumption must be made because Congress specified in Section 202 of the Energy Reorganization Act of 1974 that "the NRC shall have licensing authority ... relative to ... demonstration liquid metal fast breeder reactors when operated as part of the power generation facilities on an electric utility system, or when operated in any other manner for the purpose of demonstrating the suitability for commercial application of such a reactor."

Thus, the currently planned certification procedure will be to submit the Safety Analysis Report for Packaging (SARP) on the final cask design to DOE for their consideration. Once a DOE Certificate of Compliance has been issued on the cask, the DOE would submit the SARP (which may have been updated through the DOE certifying process) to NRC for their consideration. Additions, changes, and/or updates to the SARP or the cask design may be required for successful NRC certification.

The following paragraphs summarize some of the regulatory issues where existing regulations are not sufficiently specific relative to the CRBRP cask design, or are vague because precedents have not been established through past certification activities. These issues and uncertainties must be addressed through official channels before final cask design, or they may have significant impact during the regulatory review process. Failure to obtain official guidance from regulators early in the next phase of the design effort could lead to a design that may later prove to be uncertifiable.

2.1.1 Classification of Hazard

The DOT regulations (49CFR173.2) state that " . . . A hazardous material having more than one hazard . . . must be classed according to the following order . . .

1. Radioactive material

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*Memorandum of Understanding between DOT and NRC effective June 8, 1979.

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5. Flammable liquid

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.

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12. Combustible liquid"

This specifies that radioactive materials transportation regulations are controlling in the design of the cask.

However, there appears to be a conflict in the classification of hazard, specifically in the DOT regulations in the area of flammable solids where mixtures of sodium and radioactive materials are addressed.

The key sections of the DOT regulations (49CFR) are reproduced here for convenience, and critical phrases are italicized:

"173.202 *Sodium metal liquid alloy*, potassium metal liquid alloy, and sodium potassium liquid alloy.

"(b) Packaging of metallic liquid *alloys of sodium* or potassium *in combination with fissile or large quantities of radioactive material, is authorized as provided in 173.206(a)(10) and (11).*

"173.206 *Sodium* or potassium, metallic; sodium amide; sodium potassium alloys; sodium aluminum hydride; lithium metal; lithium silicon; lithium ferro silicon; lithium hydride; lithium borohydride; lithium aluminum hydride; lithium acetylide-ethylene diamine complex; aluminum hydride; cesium metal; rubidium metal; zirconium hydride, powdered.

"(a) *Metallic sodium* or potassium, sodium amide, sodium potassium alloys, sodium aluminum hydride, lithium metal, lithium silicon, lithium ferro silicon, lithium hydride, lithium borohydride, lithium aluminum hydride, lithium acetylide-ethylene diamine complex, aluminum hydride, cesium metal, rubidium metal, and powdered zirconium hydride must be packaged as follows:

"(10) *Tubes of stainless steel*, or other metals of equivalent strength and nonreactivity, *having sealed, welded end caps, and containing not more than 50 grams of metal. Authorized only for metallic sodium*, metallic lithium, metallic potassium, and sodium potassium alloy. *Each tube must be enclosed within a secondary sealed metallic tube and further enclosed within strong, tight outer packaging.*"

This may be interpreted that a "tube of stainless steel, having welded end caps" could only be used for transporting a spent fuel assembly with sodium, and then only if less than 50 g of sodium were contained in the tube. It is noteworthy, however, that these regulations are for flammable solids and that liquid sodium* does not qualify as either a flammable liquid, a combustible liquid, or a pyrophoric liquid (see 49CFR173.115).

Thus, the question is raised whether the DOT regulations preclude, automatically, using sodium as a coolant; or whether 49CFR173.2 (cited above) in conjunction with 49CFR173.396(c)(3)** would result in the shipment being classified entirely as "radioactive material," and as such the carriage of sodium is incidental to the overall movement of the materials and to the design and certification of the cask transportation system, and therefore the regulations of the NRC (10CFR71) are controlling.

2.1.2 Levels of Containment

The principal concerns relative to the use of liquid sodium as a coolant will probably be those of assuring that the sodium will be contained and assuring that water or air will not enter containment during normal transport and following exposure of the cask to severe, transportation accident-related environments. The environments to which a package must be exposed before certification are specified in 10CFR71, Appendix B. These "Hypothetical Accident Conditions," established by regulators and to be applied sequentially to Type B packages, are summarized below.

1. **FREE DROP** 9-m (30-ft) drop onto essentially unyielding horizontal surface (48 km/hr, 30 mph).
2. **PUNCTURE** 1-m (40-in.) free drop onto 0.15-m (6-in.)-diameter mild steel bar.

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*Sodium would be a liquid when used as a coolant with the high-heat output CRBRP spent fuel assemblies.

**49CFR173.396(c) reads, in part: "Fissile radioactive materials containing Type B quantities of radionuclides, in either normal form or special form, must be packaged as follows:

"c) Any other Type B packaging which also meets the standards for packaging for fissile radioactive materials in the Regulations of the U.S. Nuclear Regulatory Commission (10CFR71), and is approved by the U.S. Nuclear Regulatory Commission."

3. **THERMAL** 800°C (1475°F) thermal exposure for 30 min.
4. **IMMERSION** 1-m (40-in.) immersion in water for 8 hr.

One method of assuring containment and preventing water or air ingression is to provide more than one level of containment of the sodium in the cask transportation system. There is no single compelling technical or regulatory reason for providing more than one level of containment for the spent fuel assemblies in sodium. Rather, the need is established by a body of technical, regulatory, and institutional arguments that support a value judgment. Providing more than one level of containment for spent fuel with sodium coolant will lead to a shipping system which will be technically sound, fabricable, reliable, licensable (i.e., capable of receiving a certificate of compliance from the NRC), and most importantly more publicly acceptable.

It is proposed that the first level of containment be a sealed canister filled with one fuel assembly and the sodium coolant. One or more canisters will be placed in a cask transportation system and at least one more containment level will be provided by this system.

Some technical advantages of using the canister option are

1. Lightweight—A canister offers one method of containment that is a relatively lightweight unit in which to move the sodium and assembly.
2. Seal Makeup—The operations for providing the first level of containment, where the sealing surfaces are possibly contaminated with sodium, can be performed more easily on a small canister located in the FHC than on a large basket located in the cask below the floor of the FHC.
3. Seal Reliability—Sodium contained in canisters will keep contamination of the cask/basket sealing surfaces low. The only sodium that should come in contact with these surfaces is any left on the canister outer surface or any sodium vapor entrained in the FHC atmosphere. This will provide for cleaner sealing surfaces on the large diameter basket and cask seals, thereby enhancing their reliability.
4. Operational Advantage—If, after loading, a basket lid seal (two-level containment concept) or a cask lid seal (three-level containment concept) is found to be defective, unloading the cask with canisters is relatively easy. The seven canisters would be removed, and the cask taken away for repair. If the seven assemblies were sitting in cavities surrounded by only sodium that may have solidified in the bottom, the entire cask will require heating, and then both fuel assemblies and sodium coolant must be removed before the cask can be removed from the plant for maintenance.
5. Seal Welding—If it is determined that a welded seal is preferred for the first level of containment, remotely seal-welding a canister in the FHC presents little difficulty. Equipment for doing this currently exists (Reference 14). Welding of a large lid to the basket inside of the spent fuel shipping cask below the FHC would be very difficult if not impossible, and would be very expensive. Furthermore, verification of this first containment boundary will be a simpler procedure with single canisters than in dealing with the large basket. An exact method of verification in either case has not been finalized. However, the smaller, more accessible canister is preferred when verifying a seal-weld.
6. Maintenance—Damage to the sealing surface of a canister would mean a loss of one canister. Loss of sealing surface on a basket or cask would mean the entire basket must be removed and replaced before the cask can return to service.
7. Sodium Return—The canister provides a ready method of returning and handling sodium to the FHC. Heating a canister with sodium inside will be much easier and faster than heating a thermally massive cask containing solidified sodium.
8. Release Control—If a seal should fail on a canister, a limited sodium inventory would be available for release.

Some technical disadvantages of using canisters are

1. Additional Operations—More operations would result since additional sealing surfaces are required if canisters are used.
2. Thermal Resistance—The space between the canisters and the basket would need to be filled with a gas, preferably helium, for shipping. These filled gaps add a thermal resistance causing a higher normal operating clad temperature than would exist in a sodium-filled basket.

Concerning the regulatory arguments for more than one level of containment, the NRC has never issued a Certificate of Compliance for a cask with sodium as a coolant. Therefore a precedent has not been established for this case. However, when concerns over extra-severe hazards have been addressed in the past, the regulatory response has been to require multiple levels of containment. Two examples of this are cited here. First, it can be noted that a sealed tube "enclosed within a secondary sealed metallic tube and further enclosed with strong tight outer packaging" was required by DOT for metallic liquid alloys of sodium in combination with radioactive materials as discussed above [see 49CFR173.202 and 49CFR173.206(a) (10)]. Second, when questions arose relative to the shipment of plutonium, the regulators responded with the requirement that "plutonium in excess of twenty (20) curies per package shall be packaged in a separate inner container placed within outer packaging that meets the requirements of Subpart C for packaging of material in normal form. The separate inner container shall not release plutonium when the entire package is subjected to the normal and accident test conditions . . ." [See 10CFR71.42(b).]

The current regulations do not address the issue of water ingression, but the proposed revision to the regulations [see Reference 13; 10CFR71.32(f)] includes a statement which requires prevention of inleakage of water "to the maximum credible extent."

The ultimate successful transport of spent CRBRP fuel and of spent LMFBR fuel from follow-on plants may hinge upon the perception of regulators and other public bodies. It must be perceived that the shipment of the spent fuel is safe and conforms with all applicable regulations.

The Proposed Final Environmental Statement on the Liquid Metal Fast Breeder Reactor Program (Reference 15) issued in 1974, states in Section 4.5:

"It is economically desirable, however, to ship shorter-cooled fuel. Because short-cooled fuel has associated with it a substantial radioactive iodine inventory, any significant leakage could not be tolerated. Thus, short-cooled fuel shipments should not be made unless the cask in which it is shipped, and the procedures by which it is shipped, are adequate to ensure that essentially no radioactivity could be lost even if the cask were subject to extreme accident conditions.

"Research and development programs are currently being funded by the AEC to develop information to enable predictions of behavior under severe accident conditions. Significant additional funding is planned for future years to determine whether complete invulnerability can be achieved. Second-generation casks may use sodium as a primary coolant if current studies continue to support the belief that the cask cannot be breached by any extremely severe accident which can be reasonably postulated and if the design incorporates procedures that prevent improper assembly of the cask prior to its shipment."

Indeed, the research programs "developing information to enable predictions of behavior under severe accident conditions" has continued since the issuance of Reference 15, and as stated in Section 1.3 of Reference 15: "The safety of the transportation system is backed up by a continuing program of designing and testing packages under severe conditions to ensure that in the event of an accident, the likelihood of release of any radioactive material would be quite small."

A cask system which demonstrates multiple levels of containment by incorporating a canister will go far in demonstrating the ultimate safety of the system.

2.1.3 Special Form Canisters

One method for increasing the likelihood of NRC certification might be to qualify the canister and its contents as "Special Form." For this case, the current regulatory requirements imposed by 10CFR71, Subpart A, Section 71.4 (0) (2) are as follows:

"(0) "Special form" means any of the following physical forms of licensed material of any transport group:

"(2) The material is securely contained in a capsule having no dimension less than 0.5 millimeter or at least one dimension greater than five millimeters, which will retain its contents if subjected to the tests prescribed in Appendix D of this part; and which is constructed of materials which do not melt, sublime, or ignite in air at 1,475°F, and do not dissolve or convert into dispersible form to the extent of more than 0.005 percent by weight by immersion for 1 week in water at 68°F, or in air at 86°F."

It may be possible to qualify either mechanically sealed or seal-welded canisters as special form. The tests prescribed in 10CFR71, Appendix D are

"1. Free Drop—A free drop through a distance of 30 feet onto a flat essentially unyielding horizontal surface, striking the surface in such a position as to suffer maximum damage.

"2. Percussion—Impact of a flat circular end of a 1 inch diameter steel rod weighing 3 pounds, dropped through a distance of

40 inches. The capsule or material shall be placed on a sheet of lead, of hardness number 3.5 to 4.5 on the Vickers scale, and not more than 1 inch thick, supported by a smooth esssentially unyielding surface.

"3. Heating—Heating in air to a temperature of 1,475°F, and remaining at that temperature for a period of 10 minutes.

"4. Immersion—Immersion for 24 hours in water at room temperature. The water shall be at pH 6-pH 8, with a maximum conductivity of 10 μmhos per centimeter."

Under current regulations, if the canister, assembly, and contained sodium unit is qualified as "special form," the gas surrounding the canisters becomes the primary coolant.* In this case, the gas occupying this space and any radioactivity in the gas is the only containment concern. If the contamination level of the gas is below that specified in 10CFR71.35(a)(4), the closure seal can be considered a secondary seal. If the gas contains contamination above that specified in 10CFR71.35(a)(4), the leakage rate and leakage test for the basket seal must satisfy NRC Regulatory Guide 7.4** which accepts ANSI N14.5.

If the canister provides containment but does not qualify as "special form," the cask and/or basket must definitely serve as a "containment vessel" and must be leak-tested per USNRC Regulatory Guide 7.4 before each shipment. The special form canister option has not been addressed in this study.

2.1.4 Fracture Toughness

Although not currently a specific requirement in the NRC regulations, the consideration of fracture toughness of cask containment systems is now being required by NRC. In the supplementary information provided with the proposed regulations (Reference 13), it states that the International Atomic Energy Agency (IAEA) package requirement is "calling attention to the phenomenon of brittle fracture" because it is currently a subject "for discussion in existing and contemplated regulatory guides." Some initial guidelines have recently been provided by the NRC in Reference 16, and the impact that fracture toughness considerations have on the design are discussed more fully in Section 5.2.

2.1.5 Isotopic Release Limits

The current regulations require that "no loss or dispersal" of the radioactive contents of a packaging occur during normal transport. The requirement of "no loss or dispersal" in normal transport is being retained in the proposed NRC regulations (see Reference 12), but with an acceptance test sensitivity which is now keyed to an isotopic leak rate. Similar isotopic leak rate standards are being proposed for Type B packages under accident conditions. Furthermore, Reference 12 states that "present regulations restrict the loss to gases or contaminated coolant." However, "This restriction is deleted in the proposed revised regulations because the concept of an identifiable coolant is no longer included in the regulations."

2.2 Plant Interface Requirements

The CRBRP imposed requirements are summarized in Reference 9, which is also included in Appendix A of this report. Some of the pertinent requirements are discussed here.

The cask and railcar envelope must be less than 5.2 m x 6.7 m due to door dimensions. As noted in Section 2.3, the cask and transport vehicle must meet American Association of Railroads (AAR) Plate B requirements as well, which are more limiting than those of CRBR's ICD envelope. The hook-to-rail dimension will be 12.8 m (42 ft) in the Reactor Service Building (RSB) where crane capability extends 15 m (50 ft) from the end of the rail area. The crane capability is 104.4 tonnes (115 tons). The cask diameter must not exceed 2.44 m (96 in.) with a maximum allowable lid diameter of 1.6 m (63 in.). The RSB floor is limited to 3176 kg/m^2 (650 lbm/ft^2) load according to verbal guidance from Burns and Roe during FY81.

The assemblies have dimensions of 4.267 m (168 in.) long and 120.5 mm (4.745 in.) across hex flats for normal conditions. There may be 25.4 mm (1 in.) free bow, 30-deg twist, 2.2 mm (0.085 in.) radial growth, and 50.8 mm (2 in.) axial growth. The weights,

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*The definition of primary coolant is not to be included in the revised version of 10CFR71 currently proposed by NRC (Reference 13). In addition, the contamination level in 10CFR71.35(a)(4) would no longer exist, being replaced by a specified leakage rate. See proposed 10CFR71.32(h) and 10CFR71.33(a).

**The USNRC Regulatory Guide 7.4 "Leakage Tests on Packages for Shipment of Radioactive Materials," provides guidance to satisfy the requirements of 10CFR71 by establishing leakage rates and leakage tests in accordance with ANSI N14.5, "Draft American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials."

volumes, and surface areas of the assemblies are in Table 1 of Reference 9.

Thermal restrictions include a maximum heat load of 84 kW per cask containing a maximum of 12 assemblies. The highest decay power of an assembly is 7 kW. Temperature of the hottest fuel pin in normal handling and transport must be less than 538°C. In emergency conditions, this limit is raised to 816°C. Cask handling surfaces under normal conditions must not exceed 52°C, while cask support surfaces may reach 205°C in plant under off-normal conditions.

The source terms of assemblies used in determining cask shielding are those of 100-day cooled fuel. The cask shielding should limit the surface dose rate to 10 mrem/hr. This is a departure from transportation regulations which state 10 mrem/hr at 2 m from the surface. The personnel dosage shall be limited to quarterly radiation exposure of 125 mrem.

Some operational aspects of the plant interfaces require that the RSB crane be used to lift the cask from the near horizontal shipping configuration to the vertical. The cask must be washable while on the transport vehicle. Coolant and cover gases should be capable of being monitored before and after loading. The containment boundaries should be leak-testable before and after loading. The assemblies may be canistered.

Overall, the cask must support an average shipping rate of six assemblies per week with a 5-day in-plant turnaround.

This study also addressed the reprocessing facility's interfaces, although these interfaces did not have highest priority in design. These interfaces were defined in FY80 by HEF and SNL/TTC personnel during the meeting described in Reference 17. The cask weight should not exceed 113.5 tonnes and the surface dose rate must not exceed 200 mrem/hr. The cask handling surfaces should be capable of being cooled to under 60°C without immersion in water.

Some operational interfaces at HEF were also defined. Currently, only exterior cask surfaces are to be decontaminated. Seal replacement is the only cask maintenance planned at this time.

The canisters within the cask need not be specific to the fuel type, but all canister heads should be at the same level in the cask. Canisters should be inspected and identified upon unloading by either a binary notch system or visual identification marks. The canisters should have integral grapple sockets. The canisters may or may not be returned in the same cask as delivered, but all canisters should be returned in a shipping cask. The canister seal should not be leak-checked at the reprocessing facility.

The following interfaces with the repocessing facility may require some changes. The current HEF status is that the canisters should have reusable mechanical closures and seals. A recommended change would be the addition of seal maintenance since their reusability is questionable. Also in order to reduce the possibility of seal damage en route back to CRBR, it is recommended that the canisters be returned with different "return lids" with nonmetallic seals. The maintained "shipping lids" with new metal seals should be returned in plastic bags along with the cask. This concept of seal maintenance and separate return lids applies also to the basket lid.

The current HEF interface allows for no sodium purification, makeup, or removal from canisters unless there is failed-fuel. The recommended interface is that the reprocessing facility be responsible for sodium contamination levels and makeup. In fact, the sodium quantity should be checked following solidification with the canister oriented vertically, and the canister should then be returned to CRBR in that state.

In general, it is recommended that the HEF should be the maintenance facility for casks, canisters, and sodium.

2.3 Transportation System Requirements

Because the cask is to be transported by rail, the cask on the railcar with its tiedowns and combined personnel barrier/sunshield must not exceed the dimensions of the AAR Plate B envelope. Basically, this constrains the transported unit (railcar/cask/sunshield) to a height less than 4.16 m (13 ft 8 in.) and a width less than 3.25 m (10 ft 8 in.). In addition, if the transported weight exceeds 119.4 tonnes (131.5 tons), then a railcar with more than four axles will be required.

Chapter 3. Systems Design Concepts

The effort in developing the design concepts was directed toward meeting the requirements discussed in Chapter 2 while also considering fabrication and in-plant operations.

The cask system concepts developed in this program all utilize seven sealed canisters held in a sealed basket within a cask body. The canisters contain the spent fuel (or blanket, control, or shield assembly), and the sodium which is used as the primary coolant in the transportation system. In all cases, auxiliary cooling of the cask body is required for loading and in-plant handling at CRBRP. Passive cooling is utilized for transport. Auxiliary cooling is then required at the receiving site. The cask, loaded with the spent fuel in canisters, is transported on a railcar. A combined personnel barrier and sunshield is required for transport. In the initial conceptual design study, it has been assumed that impact limiters on the cask will not be required for transport. However, impact limiters have been sized in the event they are required.

In the following sections, baseline and alternate designs are presented for canisters, casks, lifting yokes, and railcar transport systems. Concepts are also presented for impact limiters and a personnel barrier.

3.1 Canister Concepts

Because of the concerns over the use of sodium, past design efforts have focused upon the canister design and testing. As a result, the confidence level associated with the canister concepts which follow is higher than for some other aspects of the cask concept.

Canister designs have been influenced by the following considerations. A decision was made early in the development program that an attempt would be made to design a canister that would survive, when loaded, a 9-m (30-ft) impact onto an unyielding target. If successful, this might allow the loaded canister to qualify as special form (see Section 2.1.3). An additional influence on the design is that temperatures can range from -40°C (-40°F) when the shipping system is empty to as high as 538°C (1000°F) when the shipping cask is fully loaded with seven canisters. All loaded canisters are intended to be shipped with sodium as the heat transfer medium. A canister is designed to ship any one of the following reactor components: fuel assemly, blanket assembly, primary control assembly, secondary control assembly, or a radial shield. These components all have a maximum envelope of 16.5 cm (6.5 in.) in diameter and 4.318 m (170.0 in.) in length. All canister loading and unloading must be accomplished in a hot cell. This necessitates designing a canister closure that can be remotely and expediently placed and made up.

Two canister concepts were developed. The baseline canister design is a mechanically sealed system, whereas the alternate canister design is a seal-welded system. The mechanically sealed canister offers the advantage of indefinite reusability, whereas the seal-welded canister may provide a more reliable containment boundary.

3.1.1 Baseline Canister Concept (Bolted Seal)

The mechanically sealed canister is shown in Figure 3-1. When loaded, the canister is designed to be lifted by using a grapple inserted into the lid. Whenever the lid is removed from the canister, the canister should have a lifting bail placed below the canister head area. This operation generally is performed in the FHC, or at the HEF, with the canister in the vertical orientation.

The design approach to satisfy the plant operating constraints follows. The canister body is constructed from 304 condition annealed stainless-steel round mechanical seamless tubing 177.8 mm (7 in.) in diameter x 0.63 cm (0.25 in.) wall x 3810 mm (150 in.) long. The canister bottom end is intended to be forged or deep drawn and consists of 304 stainless steel fully annealed after working. The outside diameter of the bottom end is 178.8 mm (7 in.) and is 38 mm

(15 in.) long. The wall has a 4-deg taper giving the side wall a varying thickness from 6.3 mm (0.25 in.) to 29.5 mm (1.16 in.). The bottom is 25.4 mm (1 in.) thick. The flange end can be forged or machined from seamless round mechanical tubing 241.3-mm (9.5-in.) outside diameter x 38.1-mm (1.5-in.) wall. The flange end may be finish-machined before welding. If heat generated in welding causes distorion of finished seal surfaces, the flange end may need to be made longer. The weld joint could then be moved from 177.8 mm (7 in.) to about 304.8 mm (12 in.). All welds shall be as specified in AWS A5.4 (69) with 100% radiograph inspection. All seal surfaces should be protected during all phases of manufacturing.

The sealing cap is also fabricated from 304 condition A stainless steel. This part may be fabricated from a billet or forging having a weight of about 32 kg (70 lb) and a physical size of 23.81 cm (9.375 in.) diameter x 15.24 cm (6.0 in.) long. An internal feature is incorporated into the cap to facilitate cap and canister lifting. This feature allows the use of the In-Vessel Transfer Machine (IVTM) grapple for canister handling (Drawing No. CA 53074). The empty canister weighs about 182 kg (400 lb).

Seal surfaces on the sealing cap and canister body need to be locally hardened to prevent galling and surface scratches during seal makeup (see Section 4.2.2). Hardfacing materials must be selected to withstand temperatures from -40°C (-40°F) to 538°C (1000°F) as well as the effects of the surrounding medium (sodium). Material selection must resist heat, abrasion, corrosion, impact, galling, oxidation, thermal shock, and metal-to-metal wear. Experimental testing conducted at elevated temperatures needs to be accomplished for appraisal of hardfacing and seal materials.

Mechanical closure and seal makeup is achieved by the use of eight swing bolts with captive nuts. The swing bolts are forged from steel and the thread form is rolled. Swing bolts are captive to the canister body by 1.27-cm(0.50-in.)-diameter pins pressed into the flange end of the canister. This and the fact that the nuts are captive to the swing bolts prevent any loss of parts during remote canister loading and unloading. Materials should be selected for use in a sodium environment and experimental testing conducted to assure proper operation.

3.1.2 Alternate Canister Concept (Seal-Welded)

An alternate design has been produced similar to the the baseline bolted canister. This design is a reusable seal-welded design shown in Figure 3-2. It appears that a canister of this concept can be used approximately 10 times. This design requires remote welding and a remote opening operation. After 10 usages, an entire new closure end could be welded to the lower portion of the canister body. This would allow for the reuse of a major portion of the canister body. The closure cap, however, would need to be discarded and a new one used. The welded canister concept has a major diameter of 20.95 cm (8.25 in.). The smaller canister diameter should create a smaller basket outside diameter with a resulting lower weight cask. Empty canister assemblies weigh about 175 kg (380 lb) for this design.

Figure 3-3 shows the method used for sealing the welded canister, where a mechanical seal is first activated by providing an axial force on the lid (the details of the mechanical seal in both the unseated and seated configuration are on the right side of Figure 3-3). The mechanical seals used in the canister cask concepts are discussed in Sections 4.3.4 and 4.5.

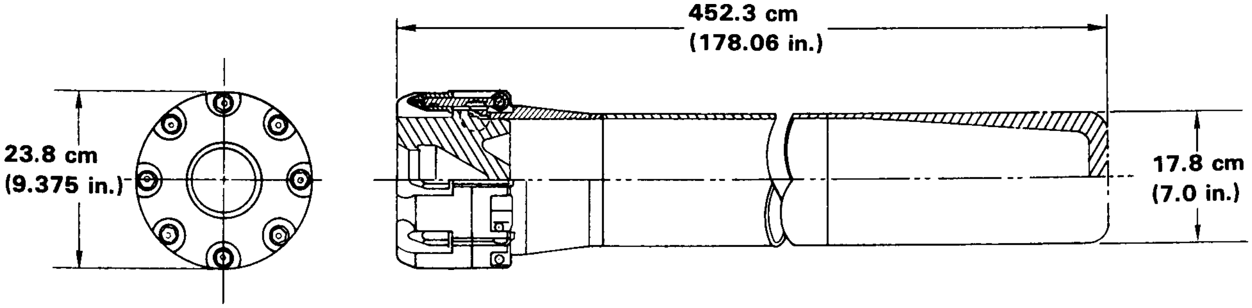


Figure 3-1 Canister Assembly-Baseline Design

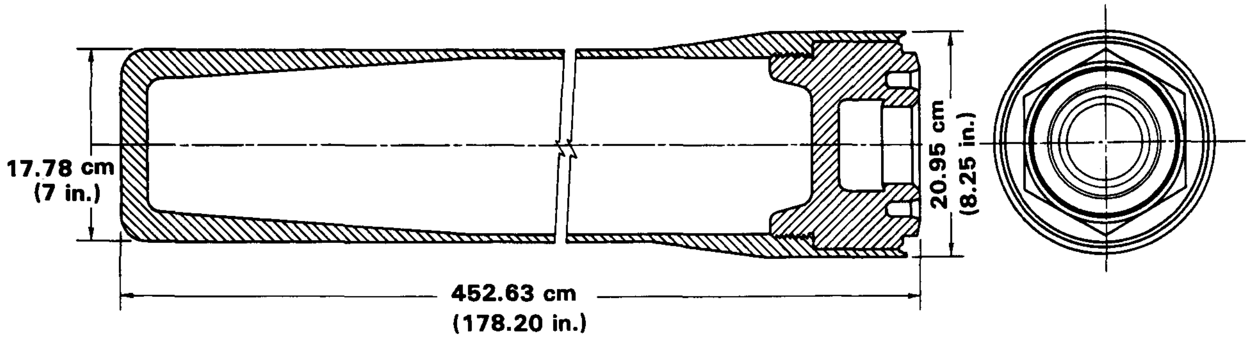


Figure 3-2 Seal-Welded CRBRP Spent Fuel Canister

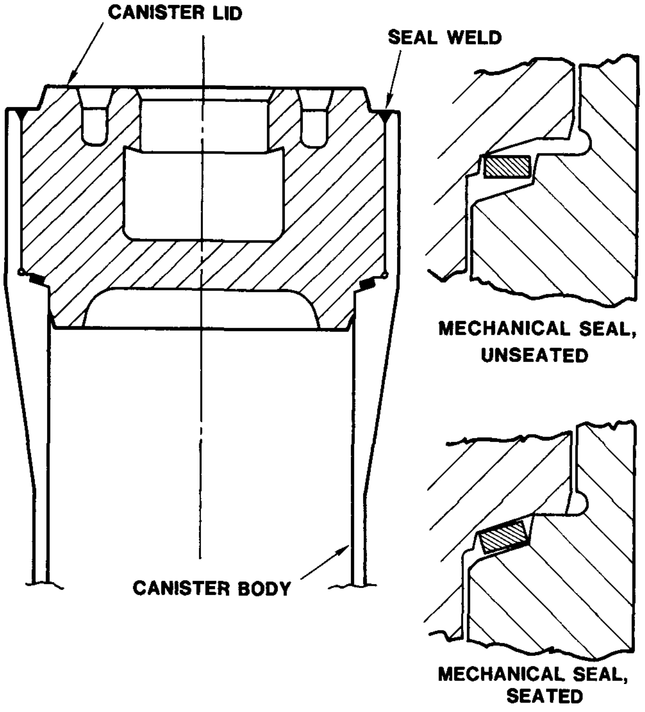


Figure 3-3 Reusable Seal-Welded LMFBR Spent Fuel Canister With Inner Seal

3.2 Cask Concepts

In the baseline design, the cask consists of a stainless-steel basket that is a containment system, bolted to a monolithic, heavy-section carbon steel cask body that provides shielding, impact, puncture, and fire protection. As such, the cask body serves as a protective "overpack," but not a containment vessel. The basket in combination with the cask body functions as the Type B packaging. Thus, the baseline design provides two levels of containment for the spent fuel: the canister and the basket. The baseline cask is denoted as B-F2, the B denoting baseline, the F denoting ferritic cask body, and the 2 denoting two levels of containment.

Alternate designs are shown, including monolithic cask body and basket structures, and a system providing three levels of containment where the cask body provides the third level of containment. These concepts are summarized in Table 3-1. The details of the cask designs, the reasons for their selection, and the advantages and disadvantages of each will be addressed in the following subsections.

Table 3-1 Cask Design Concepts

Concept	Cask Body	Basket	Levels of Containment in Shipping System
Baseline — F2 (B-F2)	Ferritic	Austenitic, separate from body	2
Alternate — A2 (A-A2)	Austenitic	Monolithic, with body	2
Alternate — A3 (A-A3)	Austenitic	Austenitic, separate from body	3
Alternate — F3 (A-F3)	Ferritic	Austenitic, separate from body	3

3.2.1 Baseline Cask Concept

The overall dimensions of the B-F2 cask, which meets the 10 mrem/hr at surface dose rate requirement, are 1.93 m (76 in.) in diameter excluding trunnions and 5.3 m (209 in.) in length.

The canisters are arranged in the basket with one canister in a center hole surrounded by a ring of six (see Figure 3-4). The canisters, each containing an assembly and liquid sodium, represent the first level of containment. The thin-walled basket, made of austenitic stainless steel, is sealed to afford the second level of containment. Containment is defined here consistent with the Reference 12 definition of "Containment System," which includes "the components of the packaging intended to retain the radioactive material during transport." In many of the drawings a proprietary seal made by Gamah Division of Stanley Aviation is shown. Whether this seal will meet the containment requirements has not been determined. The basket lid (Figure 3-5) contains 50.8 mm (2 in.) of depleted uranium for shielding purposes. The massive cask body of ferritic steel serves as an overpack to the system, providing impact, puncture, and thermal protection, as well as shielding, but not containment. Figure 3-6 provides an assembly view of the baseline cask with the basket, canisters, and lids. The cask lid affords puncture and weather protection.

The gap between the basket and the cask, assumed to be 2.54 mm (0.1 in.) on the radius, is filled with helium for heat transfer. The surfaces are coated at fabrication to give an emissivity of 0.8. This cavity is sealed at fabrication, but may require periodic checks to assure adequate helium. The cask body consists of a thick steel wall 0.4064 m (16 in.) surrounded by a neutron shield of borosilicone rubber with interstitial heat transfer fins. The fins extend through the rubber at 5- or 10-deg intervals (Figure 3-7) on the inside diameter. Located beneath each fin are channels that are used in cooling the cask during loading and unloading operation but are left dry during normal transport. Figure 3-8 shows the cooling channel pattern. The water coolant inlet is near the top of the lid end of the cask. Coolant flows through four ports from the top upward to a manifold and is distributed into the channels. It then flows down to an outlet manifold and discharges through four ports at the bottom. The flow is once-through. On all but four positions where 0.2921-m x 0.2921-m (11.5- x 11.5-in.) solid bosses serve as positioning points for the cask corrider transporter, and also near the cask ends, external surfaces of the side of the cask are finned. The fins are actually small finlets, each 76.2 x 101.6 mm (3 x 4 in.), and are staggered from their neighbors in an effort to reduce the orientation-dependence of heat rejection of the cask if conventional circumferential fins were used. The base of the cask body contains 101.6 mm (4 in.) depleted uranium for shielding. The current trunnion design consists of four trunnions near the lid end and two at the bottom. The four near the lid (not currently depicted in the figures) are arranged with two opposed 180 deg with the other two. This configuration differs from the standard 90-deg spacing of four trunnions on some present LWR casks.

3.2.2 Alternate Cask Concepts

Alternate cask concepts differ in materials used, levels of containment, and fabrication. A summary of concepts was provided in Table 3-1. The first alternative listed is the A-A2 concept, which is a monolithic structure of austenitic steel (i.e., the cask and basket are a single-structural unit). The monolithic structure offers the advantage that the basket/cavity gap is eliminated thereby improving heat transfer, simplifying final cask assembly, simplifying in-plant cask operations, and reducing fabrication costs. However, it may not be possible to fabricate this cask (see Section 4.2). If this alternative were made of ferritic [or possibly ductile cast iron (see Section 4.2)], the inner cask surfaces would need to be lined with stainless steel, a procedure which is considered state-of-the-art, but difficult to accomplish with small diameter openings. Figures 3-9 through 3-11 show some details of the monolithic alternate design. The effects on interfaces of these alternate designs are addressed in Chapter 6.

If two levels of containment prove to be insufficient, a third level of containment can be added by modifying the baseline design. The cask body could be converted from an overpack to a containment system. This would require an increase in the length of the cask. Two alternate designs are proposed here: the A-F3 and A-A3 concepts. The concepts are identical, with the exception of materials of construction. The A-F3 concept would house an austenitic basket in a ferritic cask body, whereas the A-A3 would have an austenitic basket and an austenitic cask body. Figure 3-12 shows interface dimensions for the A-A3/A-F3 cask concepts, and Figure 3-13 shows details of the cask body. The basket for the A-A3/A-F3 design is identical to the basket for the B-F2 baseline design (see Figure 3-4).

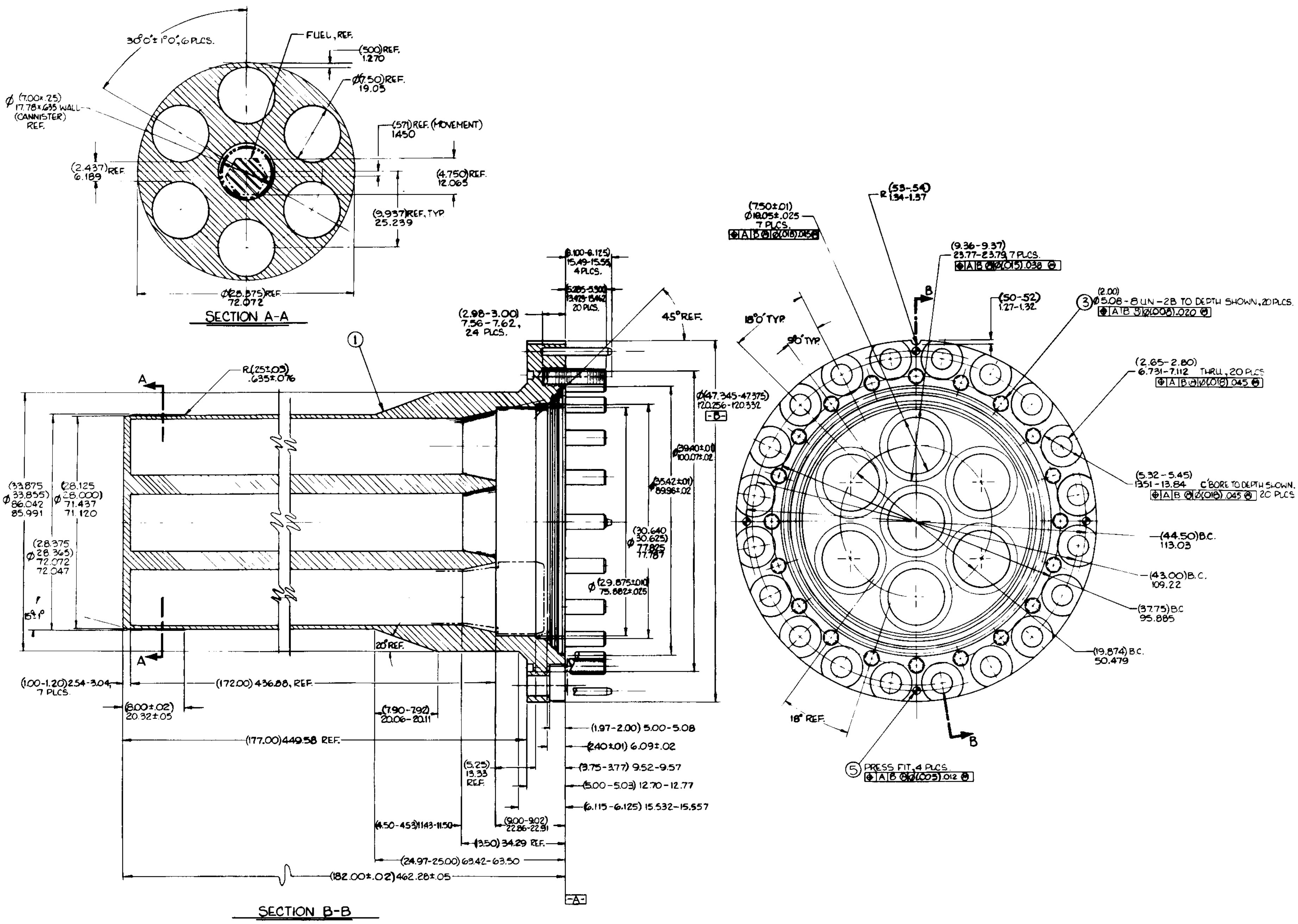


Figure 3-4 Basket Design

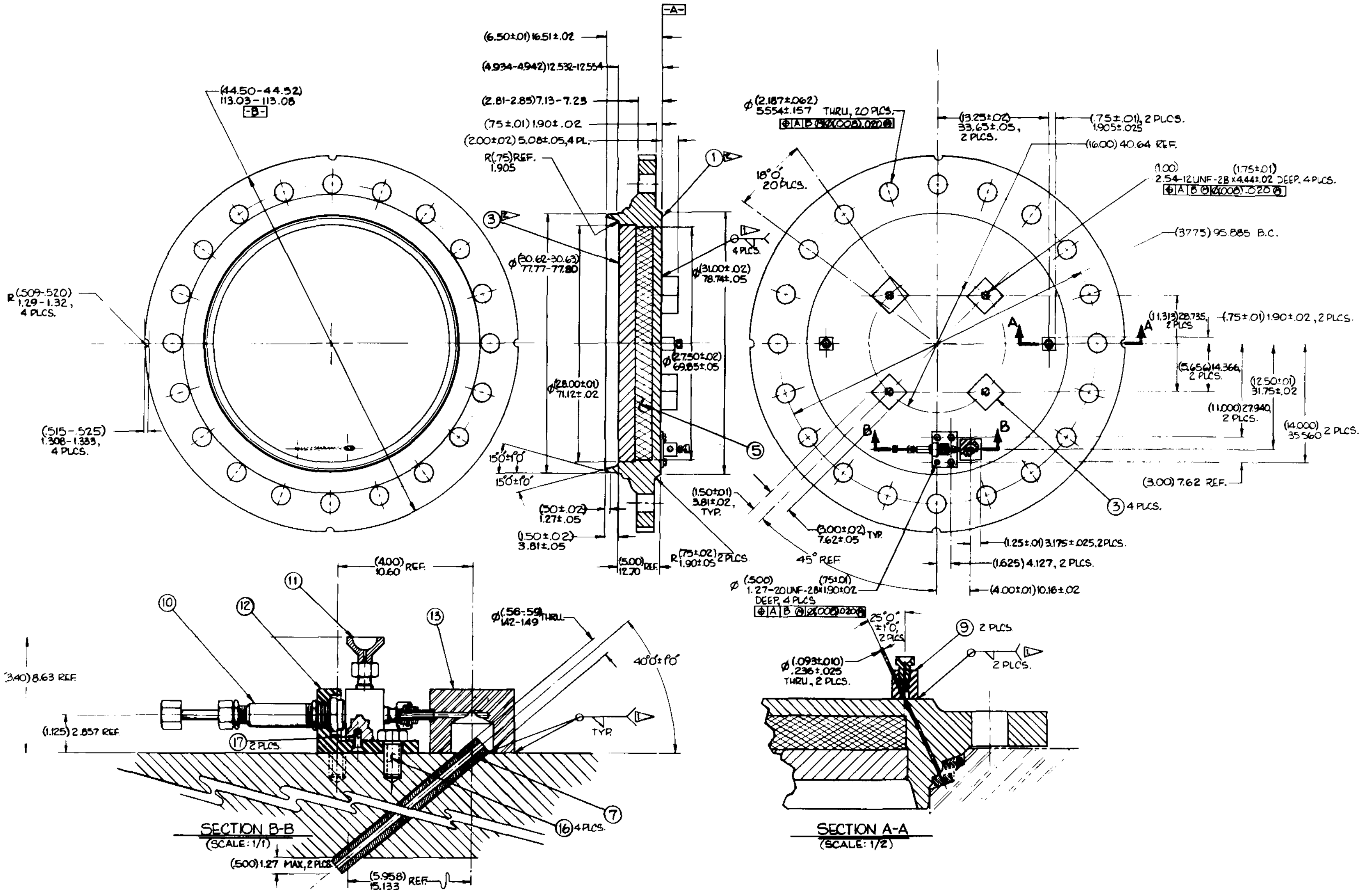


Figure 3-5 Basket Lid Design

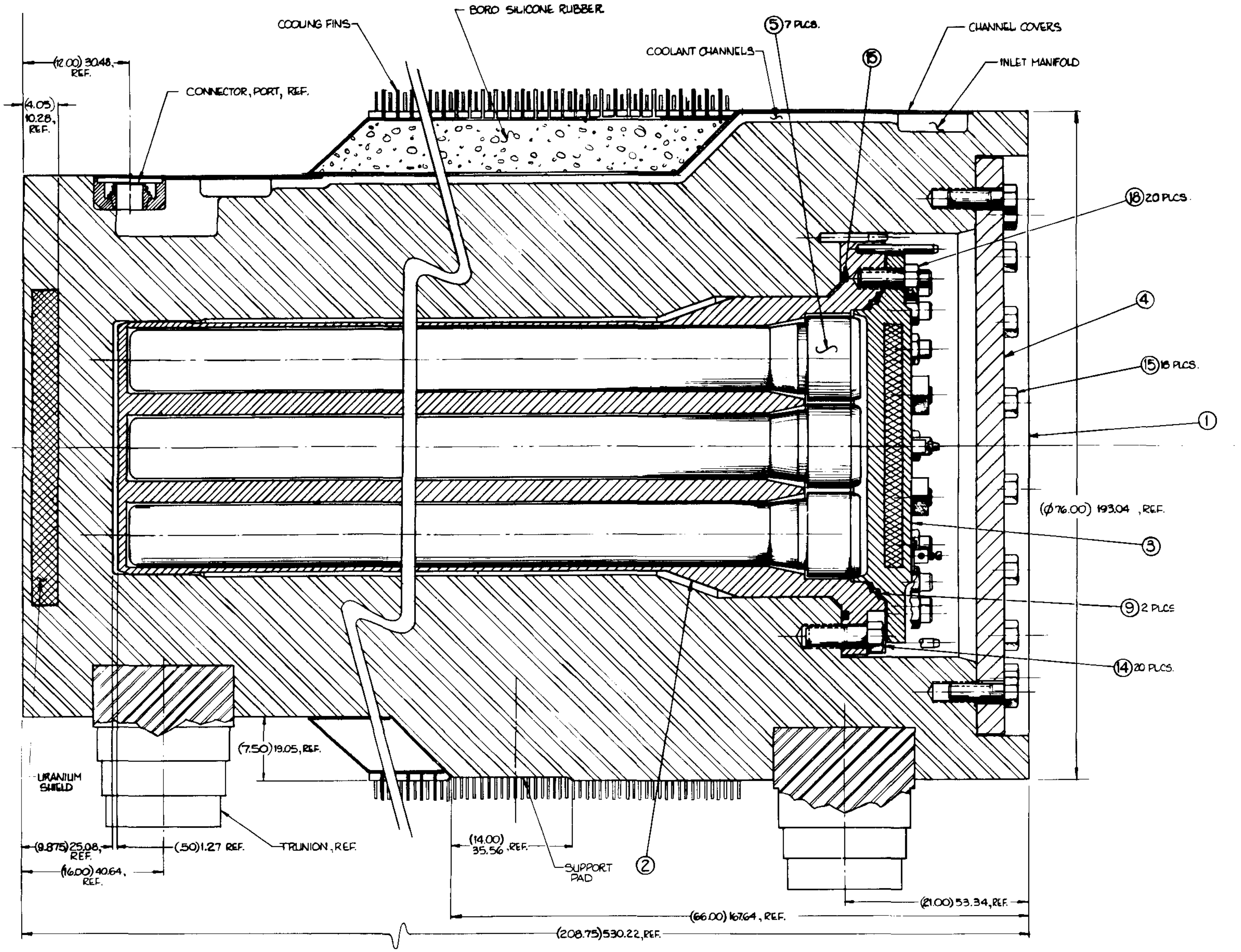


Figure 3-6 Cask Assembly—Two Levels of Containment, B-F2 Concept

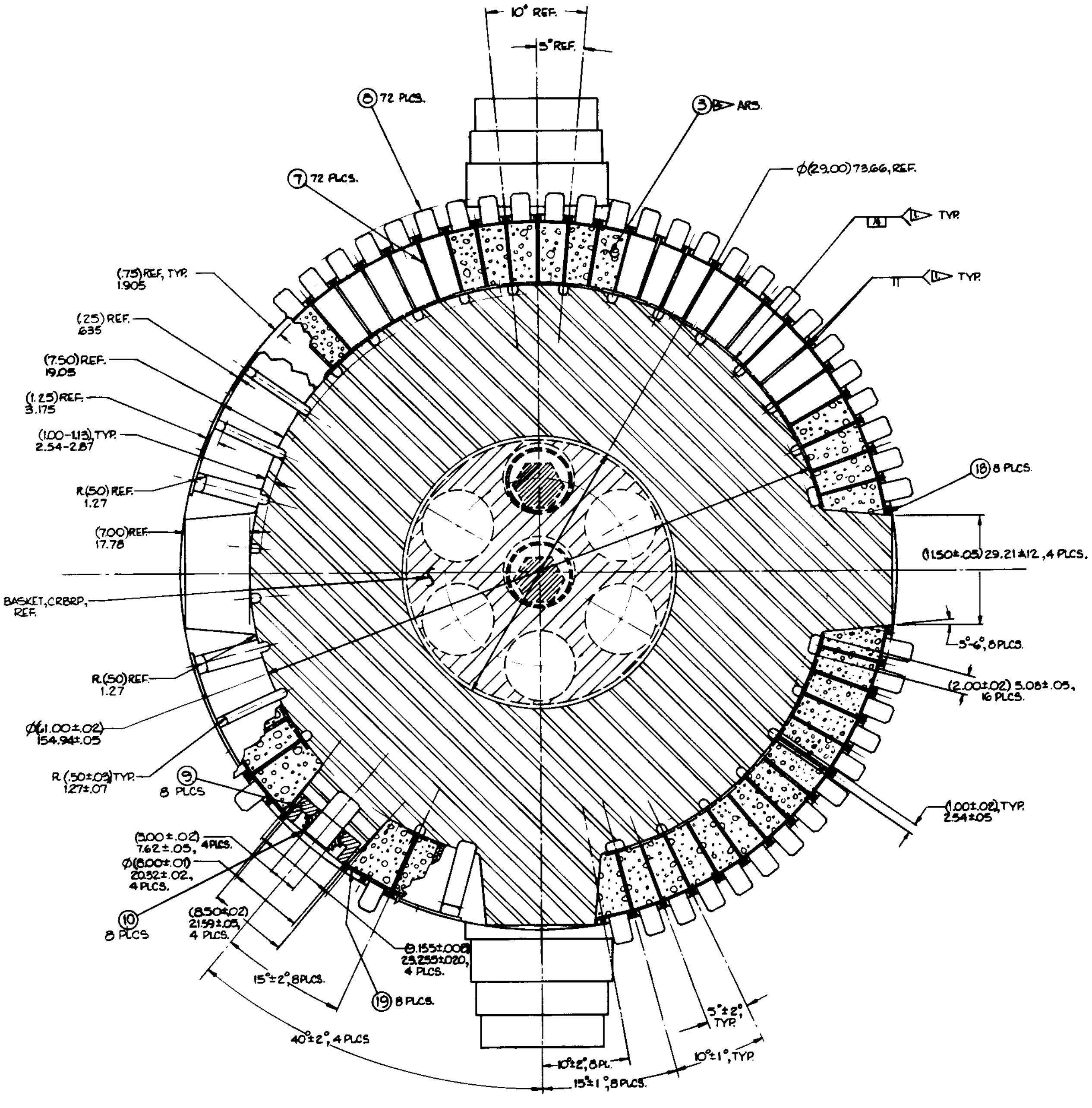


Figure 3-7 Cross Section of Cask Body Showing Neutron Shield and Fins

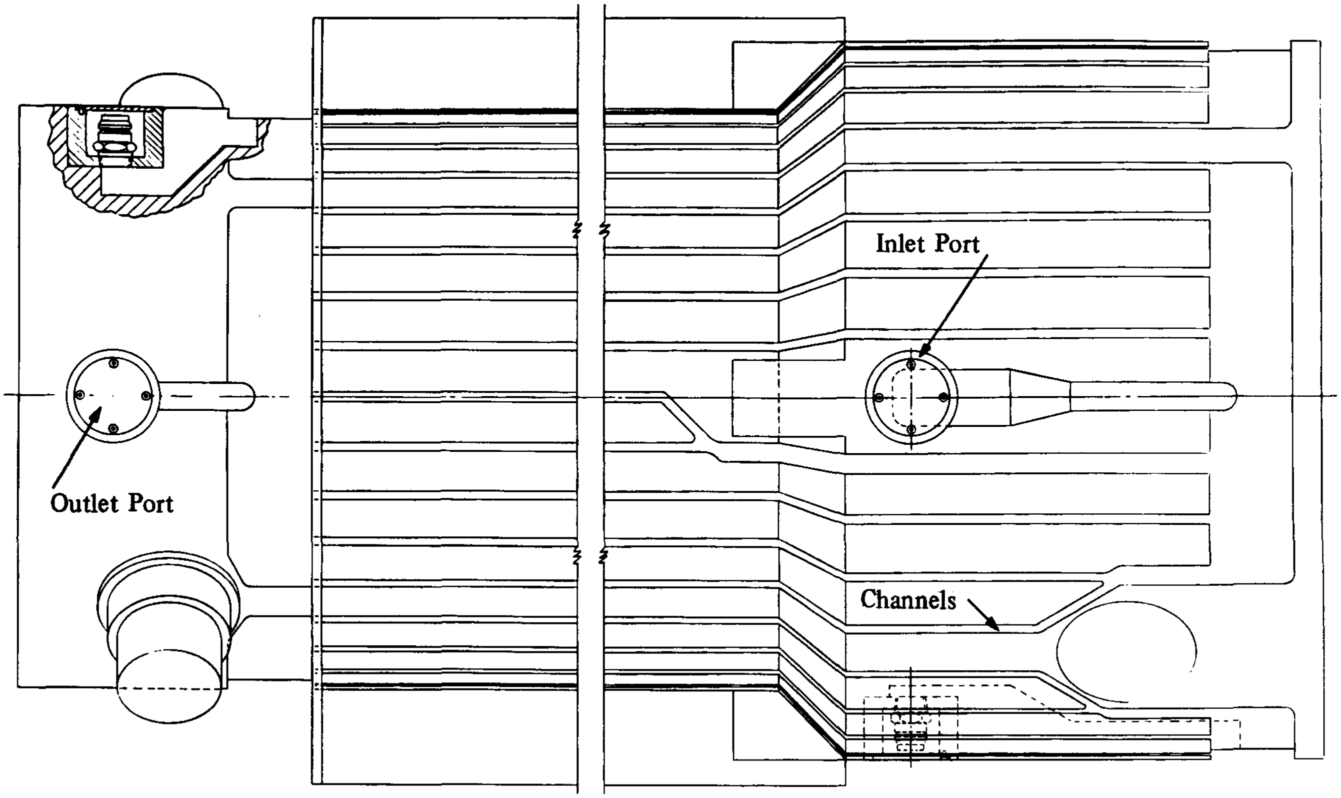


Figure 3-8 Cooling Channel Pattern

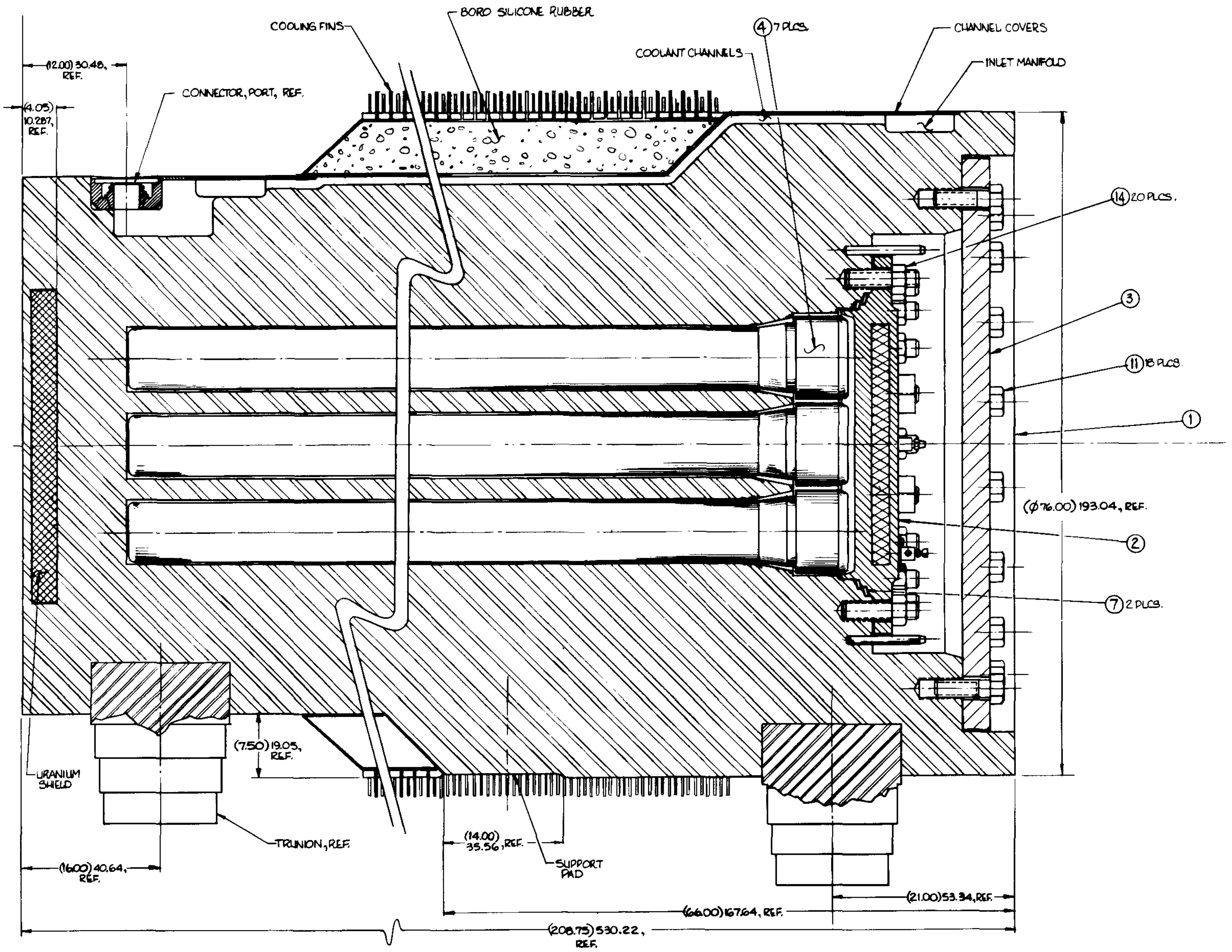


Figure 3-9 Cask Assembly—Monolithic Design, A-A2 Concept

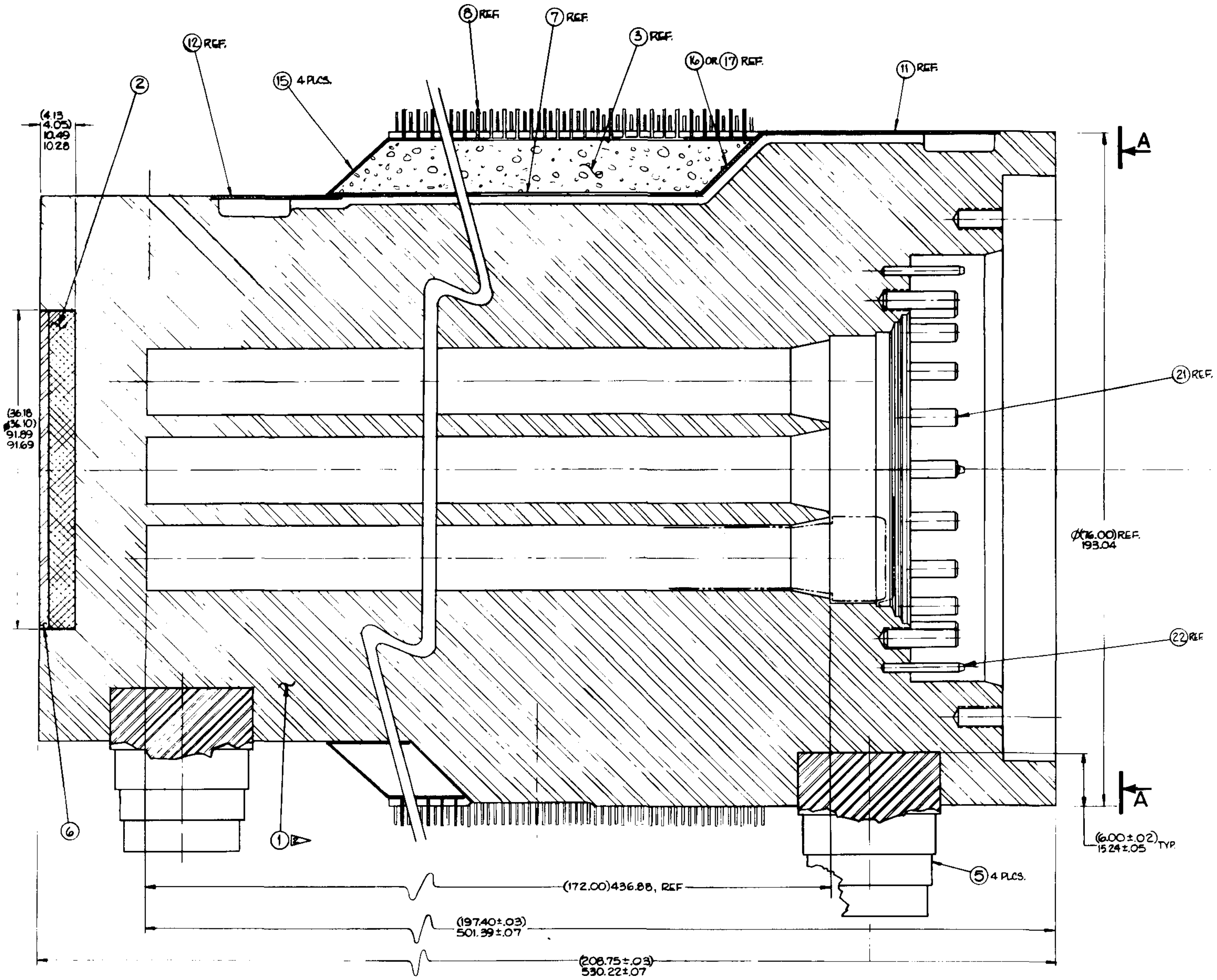
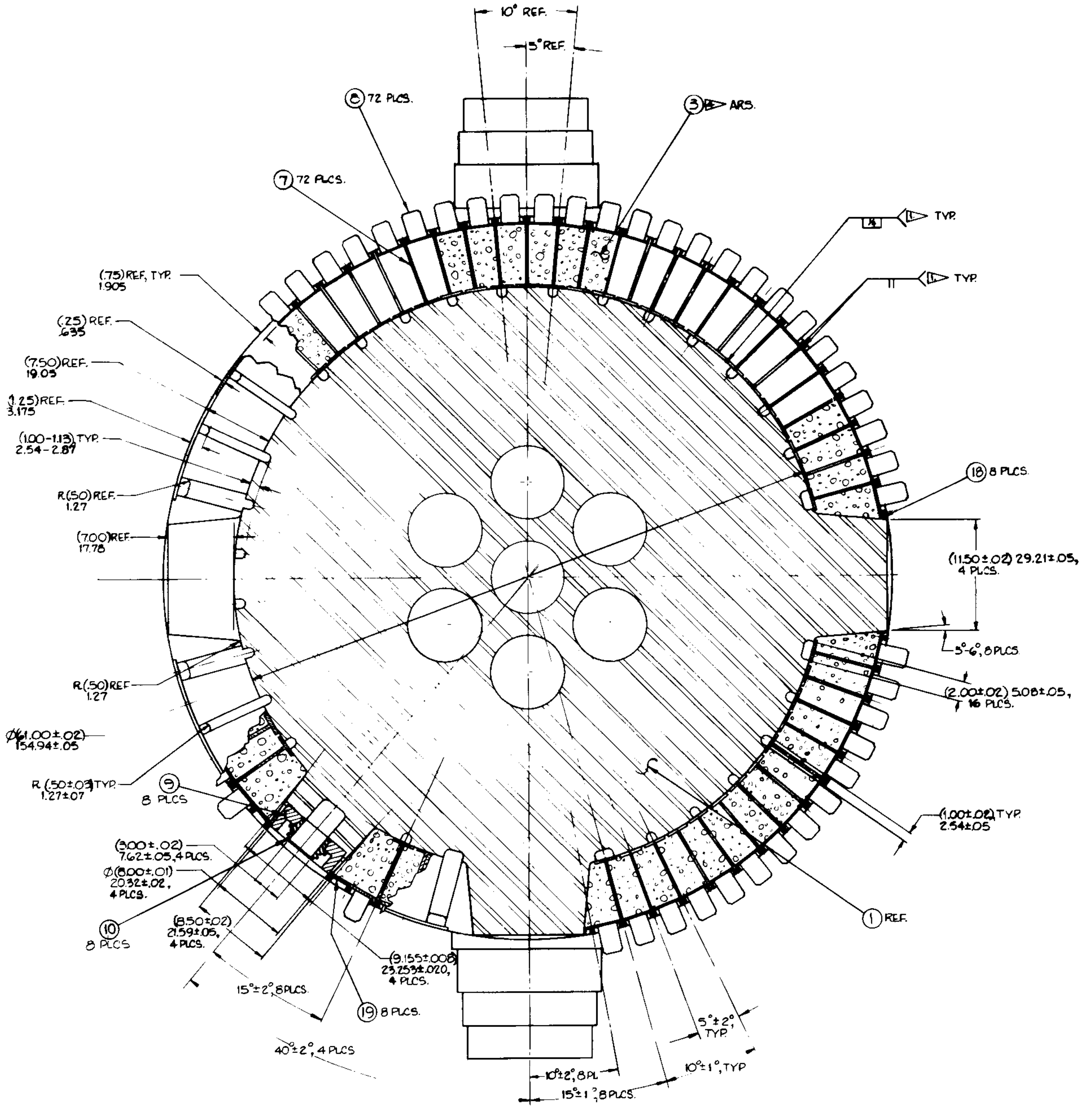


Figure 3-10 Monolithic Cask Body



SECTION B-B

Figure 3-11 Cask Design—Cross Section Monolithic Alternative

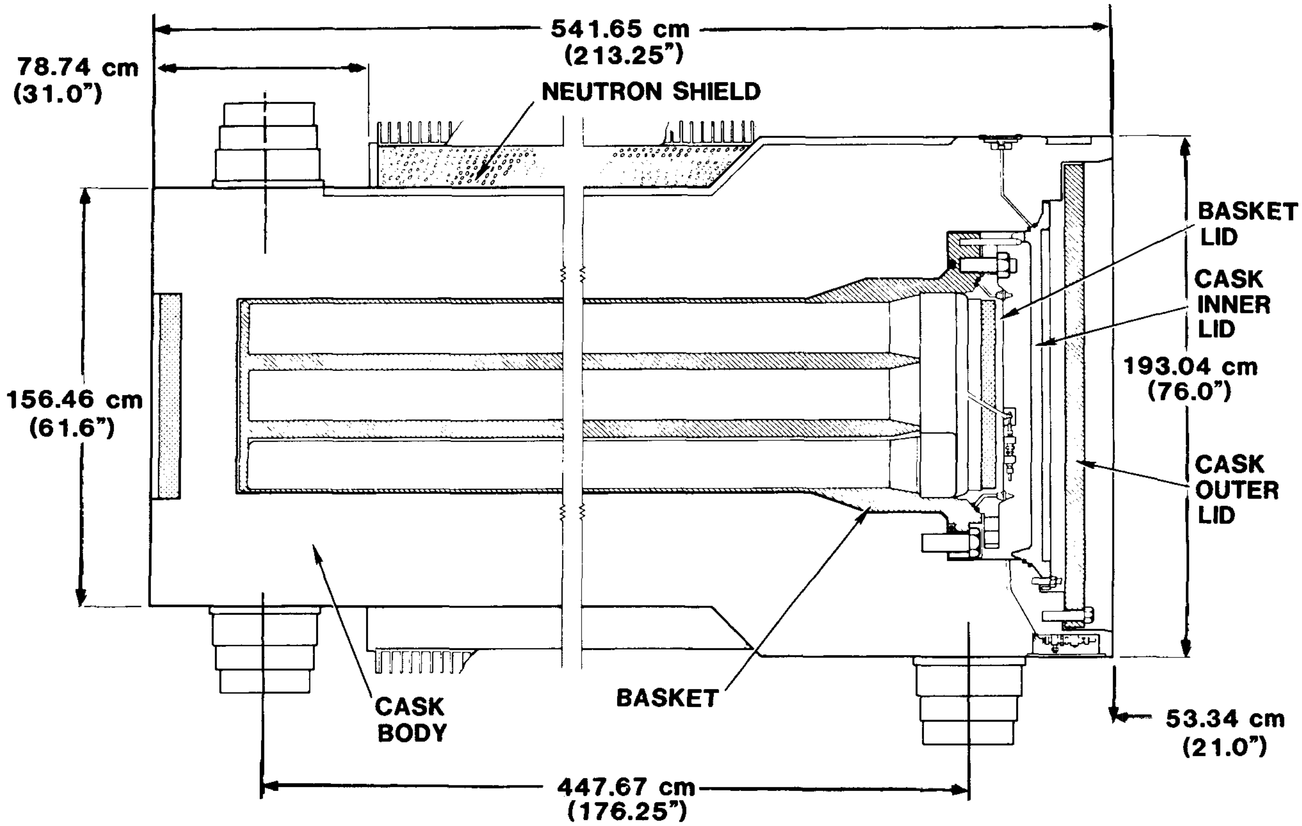


Figure 3-12 Interface Dimensions for Three-Level Containment Alternate Design, A-F3 and A-A3 Concepts

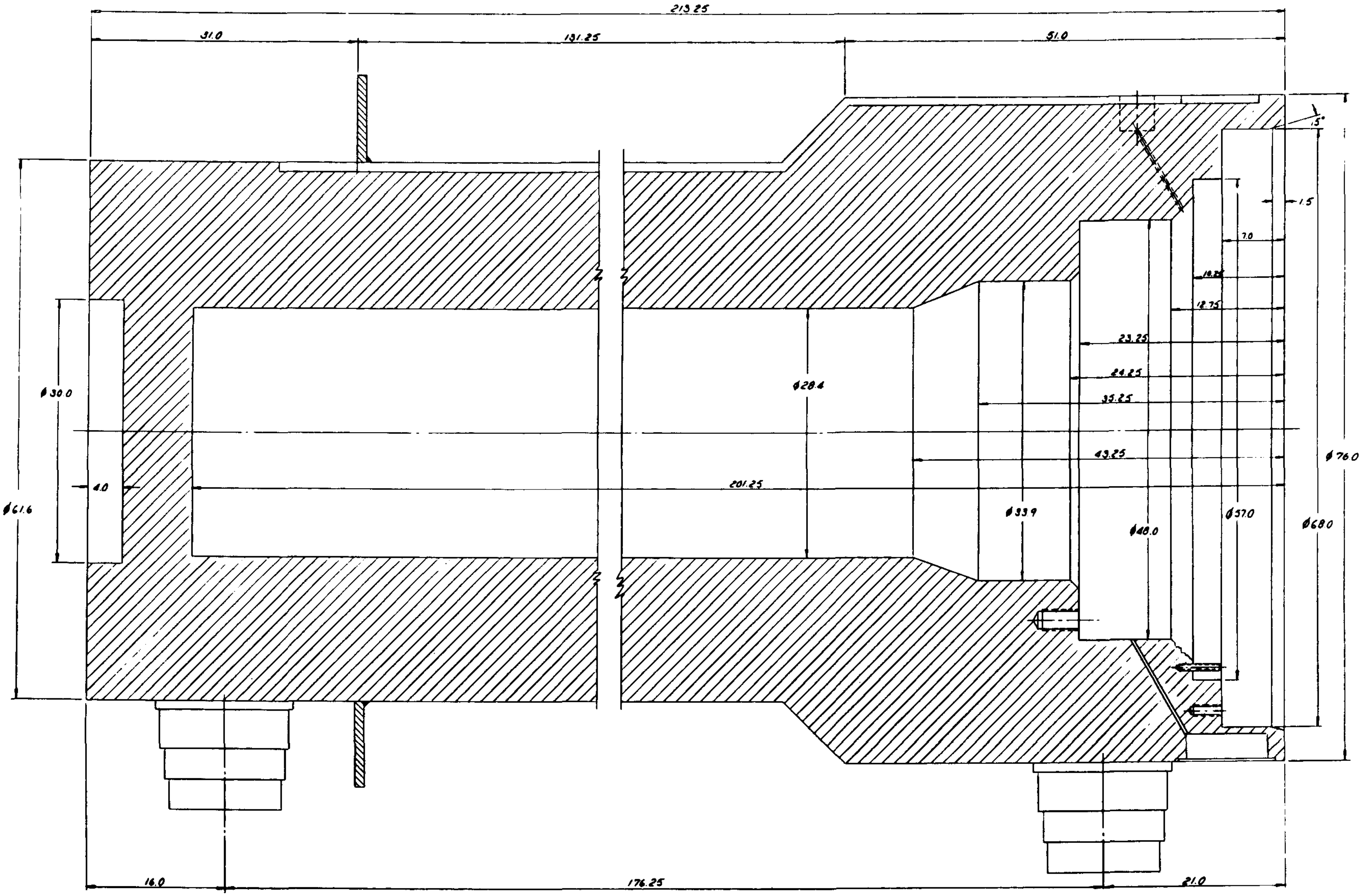


Figure 3-13 Cask Body Dimensions for Three-Level Containment Alternate Design

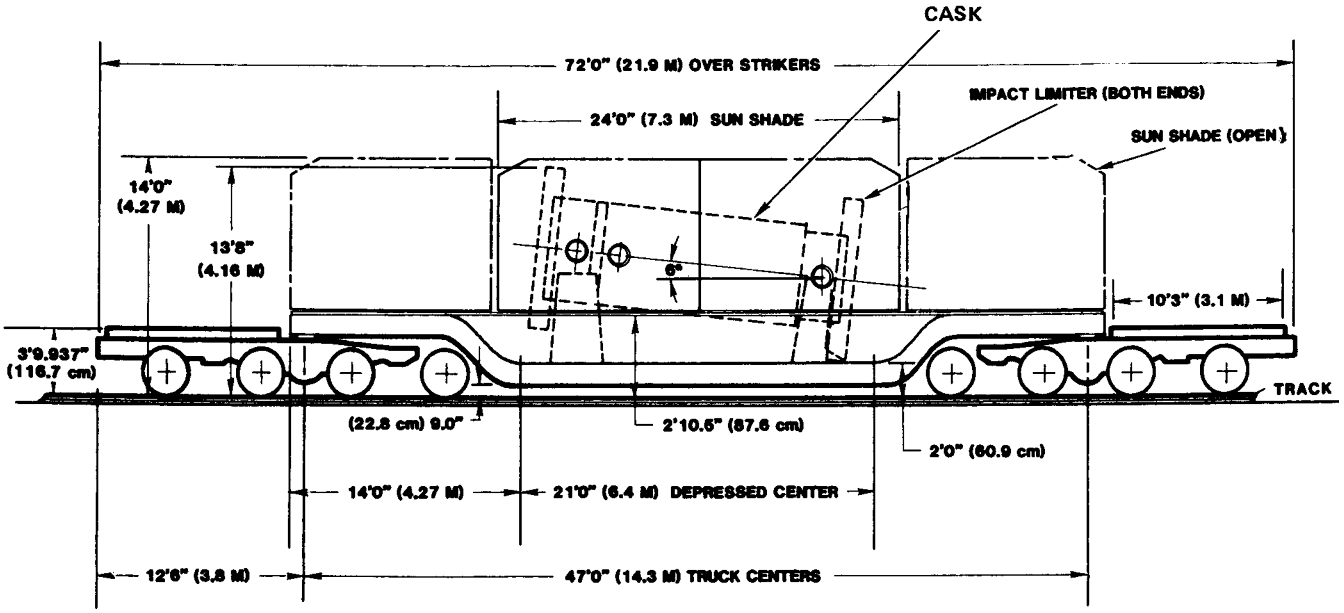
In addition to the added length of the A-A3/A-F3 design, with its coincident growth in weight, the third level of containment increases the complexity of in-plant handling procedures. Since the three containment levels result in the most complex handling procedure, and is most demanding on plant facilities, this concept was used for the time and motion study reported in Chapter 6.

3.3 Cask Ancillary Equipment

Included in this section are discussions on the choice of a railcar, and the cask tiedowns and trunnions. A possible lifting yoke for the cask to attach to the redundant RSB crane hook is also presented. A combination personnel barrier/sunshield is briefly discussed.

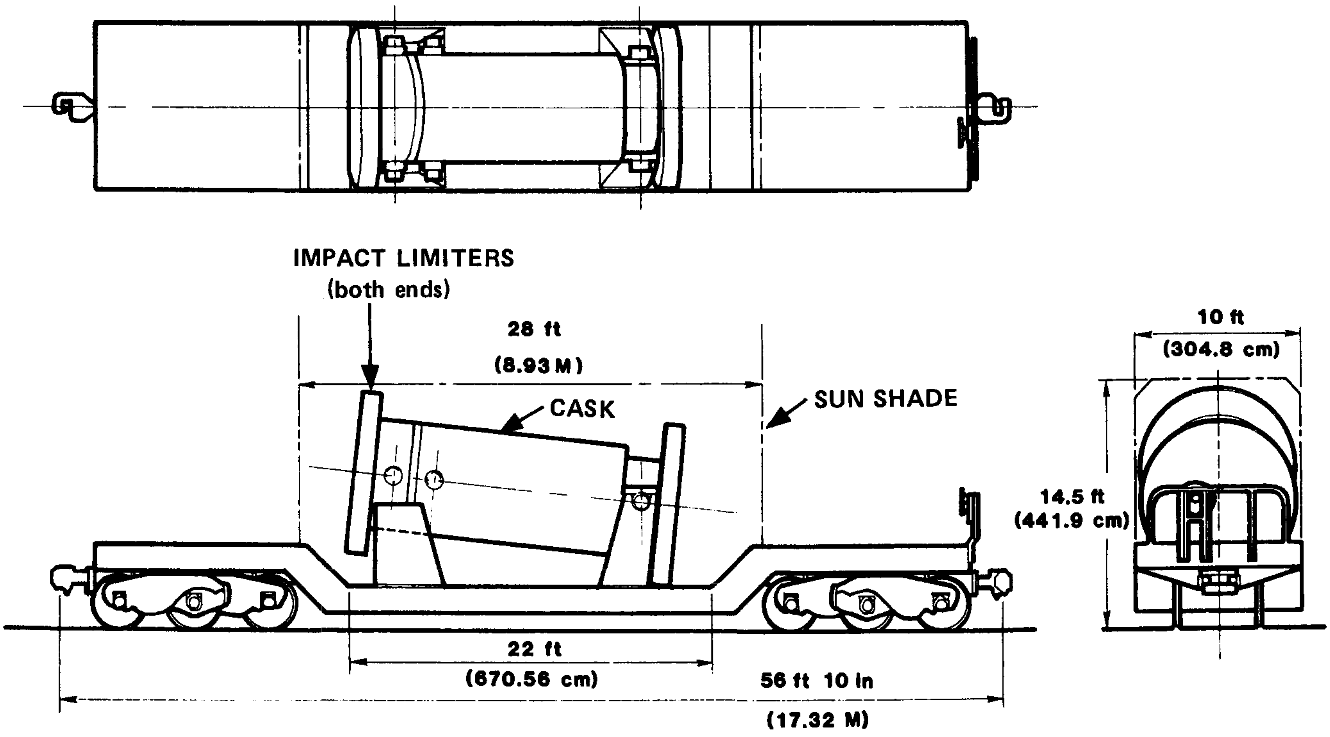
3.3.1 Railcar

The railcar that will be used to transport the spent fuel shipping cask has not yet been selected. The original design criterion for the railcar required that the transport vehicle be less than 18.3 m (60 ft.) long. However, this forces the use of a six-axle railcar and requires that the personnel barrier be removed from the vehicle during loading/unloading operations. These are both undesirable conditions since some railroads are opposed to six-axle cars and since additional space must be provided in the already cramped RSB to store the personnel barrier. It is therefore recommended that an eight-axle, drop-center, 22.9 m (75-ft) long railcar be used to alleviate these problems. This railcar is acceptable to the railroads and has sufficient room to allow the personnel barrier to remain on the vehicle during cask-handling operations. The transportation configuration with the eight-axle railcar is depicted in Figure 3-14. The alternate configuration, the six-axle railcar is shown schematically in Figure 3-15. In both figures, the cask is shown tilted 6 deg from the horizontal. The reason for this tilting of the cask is discussed in Section 4.4. Drop-center cars are recommended to assist in lowering the center-of-gravity of the system, decreasing the potential for rollover during transport.



150 TON DEPRESSED CENTER FLAT CAR		
G.R.L.	440,000 LBS	199,600 Kg
LT. WT.	121,600 LBS	55,160 Kg
LD. LMT.	318,400 LBS	144,425 Kg
DECK WIDTH	9'2"	2.8 M

Figure 3-14 Schematic of Eight-Axle Railcar With CRBRP Spent Fuel Shipping Cask



130 TON DEPRESSED CENTER FLAT CAR		
G.R.L.	366,400 LBS.	166,200 Kg
LT. WT.	106,400 LBS.	46,260 Kg
LD. LMT.	260,000 LBS.	117,930 Kg
DECK WIDTH	10 ft.	3.05 M

Figure 3-15 Schematic of Six-Axle Railcar With CRBRP Spent Fuel Shipping Cask

3.3.2 Tiedowns/Trunnions

Since a specific railcar was not selected, it was not possible to design the connection of the cask to the vehicle in any detail. Conceptually, the cask will be attached to the railcar by trunnions at its base and be supported by a cradle structure near its top or lid end as shown in Figure 3-15.

One possible design considered was that of concentric trunnions providing both load paths on two stepped pieces instead of four. One such set of trunnions that were sized are shown in Figure 3-16. This design is not intended to be the final configuration, but is based on what might be considered the worst-case criteria. The design was established to verify that trunnions can be designed and fabricated for the large loadings. As discussed earlier in this report, the proposed configuration would consist of two trunnions on each side of the cask at the front or lid end rather than the concentric design shown in Figure 3-16, and one on each side at the rear or bottom. The size and shape of the trunnions will depend on the final transportation and handling configurations of the cask. However, because of the results of initial calculations, no appreciable problems are expected in completing the final trunnion design.

3.3.3 Lift Fixtures

According to regulations, a cask must have a redundant-lift capability if it is to be handled within a nuclear reactor building. This requires that the lifting fixture for the cask provide two separate and distinct load paths from the body of the package to the redundant-lift points of the crane. The redundant crane hook for the RSB is shown in Figure 3-17 and the proposed lift fixture in Figure 3-18. The lift fixture has been initially sized according to the provisions of Reference 18. This requires that the fixture be designed to carry a load three times the static and dynamic load being handled without suffering any permanent deformation. The device is currently estimated to weigh approximately 9 tonnes (10 tons), but it is expected that this will be reduced appreciably upon completion of a detailed design analysis.

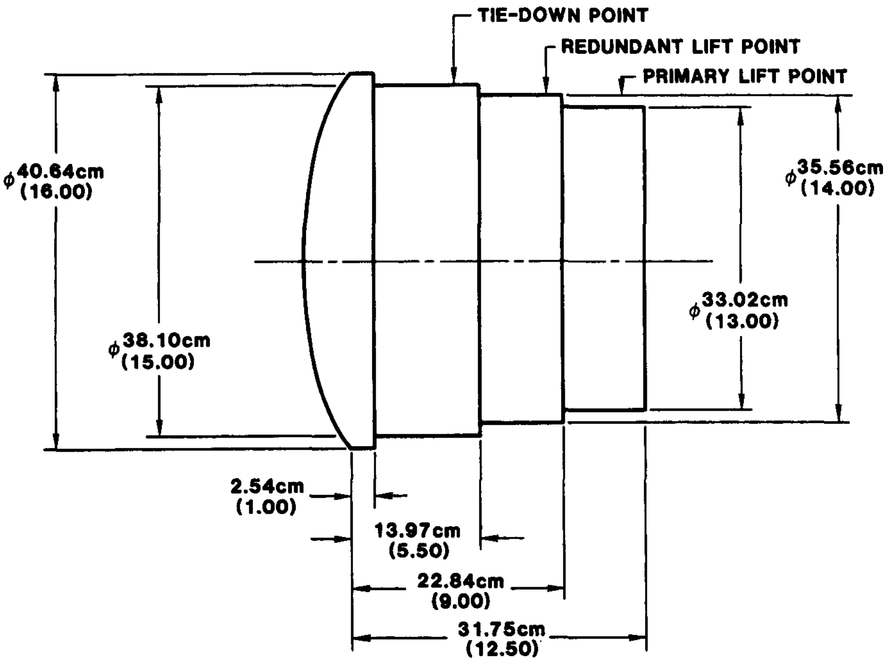


Figure 3-16 Trunnion-Sized To Accommodate Worst-Case Loading Criteria

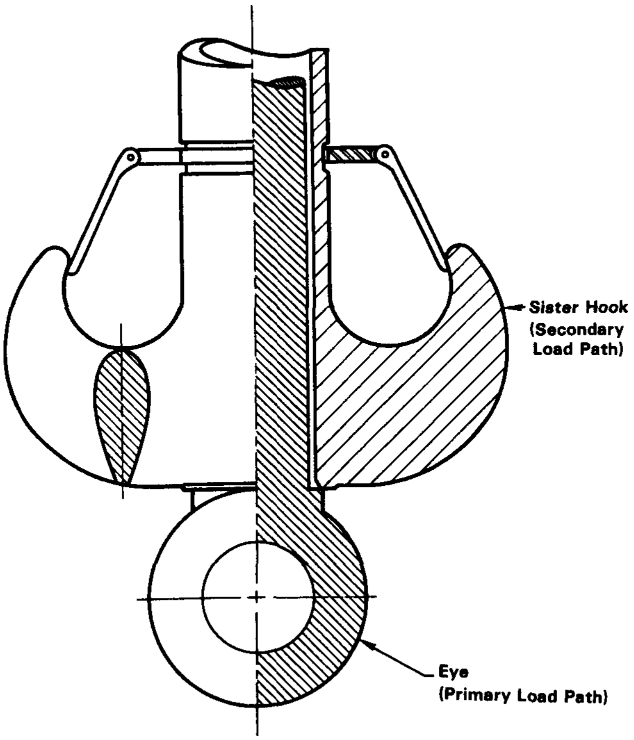


Figure 3-17 CRBRP Reactor Service Building Redundant Crane Hook

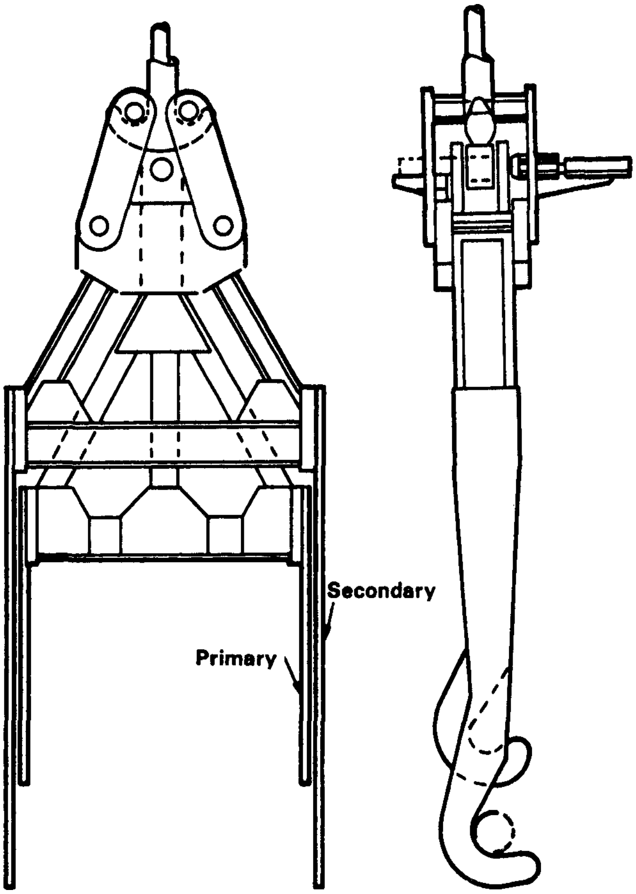


Figure 3-18 Redundant Lift Fixture for CRBRP Spent Fuel Shipping Cask

The manner in which the lift fixture operates is illustrated in Figure 3-19. The advantage of this design is that very little manual interaction is required to complete the redundant connection to the cask. The disadvantage is that the cask cannot be rotated to the horizontal position if the primary load path should fail. Thus, if failure occurs, the cask must be set down vertically in order to disengage and repair the lift fixture. This, in turn, would require that the cask either be placed in the transporter at the bottom of the transfer shaft or that provisions be made to set the cask down vertically in the RSB. It should also be noted that coolant must be provided if the loaded cask will be in the vertical position for an extended period of time.

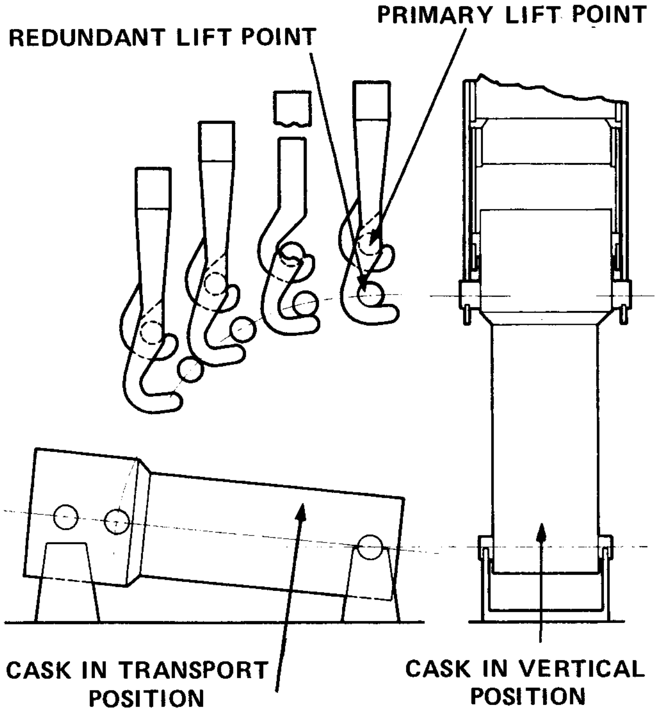


Figure 3-19 Method for Attaching the Redundant Lift Fixture to the CRBRP Spent Fuel Shipping Cask

One method of storing the yoke when not in use, either on the wall of the RSB or of the cask shaft, is shown in Figure 3-20.

3.3.4 Impact Limiters

Although the cask is being designed to survive the 9-m hypothetical accident drop test without impact limiters, later analyses and testing or fabrication problems may make this goal unobtainable. Therefore, "bulk" impact limiters have been sized to assure that the railcar and sunshade design can accommodate this feature, and that impact limiters were included in the operational assessment of Chapter 6. The limiters are shown schematically in Figure 3-21. They consist of stainless-steel shells filled with redwood bulk energy-absorbing materials and steel plate load spreaders. The redwood is grain-oriented to provide for adequate impact absorption for both side-on and end-on impacts. Further assessment of the design to accomodate other impact angles is required.

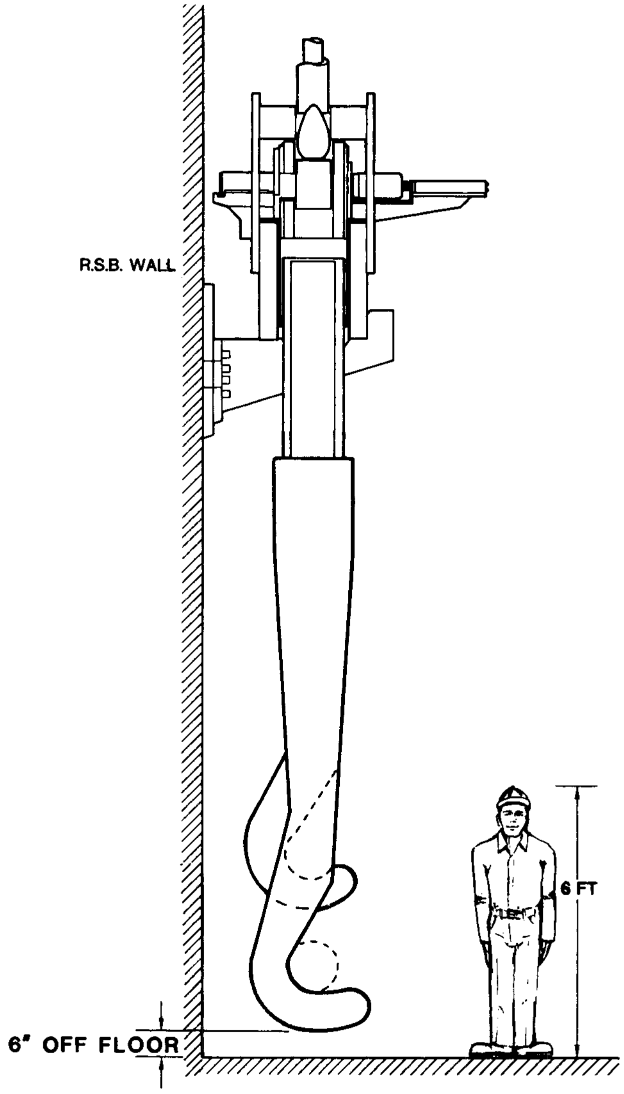


Figure 3-20 Side View of CRBRP Cask Lifting Yoke Stored on RSB Wall

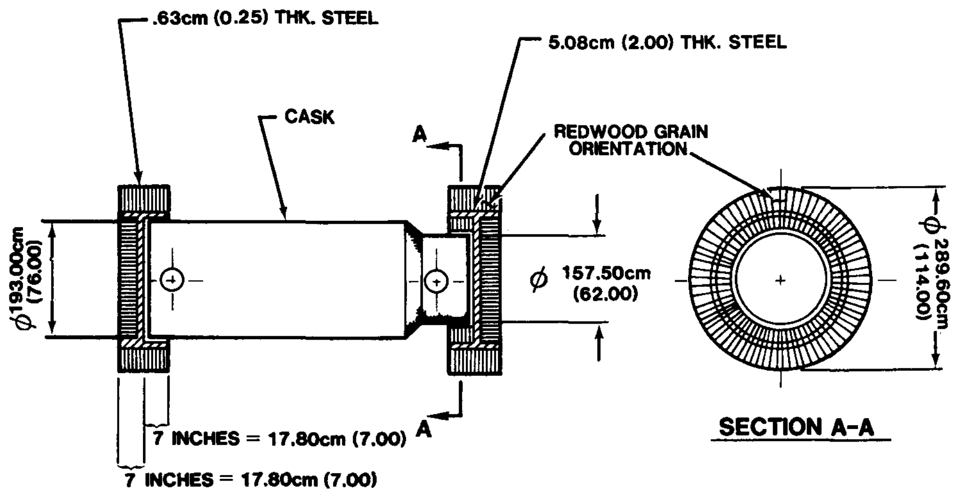


Figure 3-21 Schematic of Bulk Impact Limiters

3.3.5 Sunshade/Personnel Barrier

A lightweight but durable sunshade/personnel barrier will be required to prevent excessive heating during transport in hot weather (see Section 4.4.3), and to preclude access of personnel to the hot cask surfaces during transport. A schematic of a combined sunshade/personnel barrier for the eight-axle railcar is shown in Figure 3-22. The shade would be constructed of steel tubing, covered with steel sheet, and would weigh approximately 3110 kg (6860 lb.). As shown in Figure 3-14, the sunshade on the eight-axle railcars would roll away from the cask while being retained on the railcar. Similar sunshade designs on the four- or six-axle railcars would need to be lifted off the railcar before removing cask.

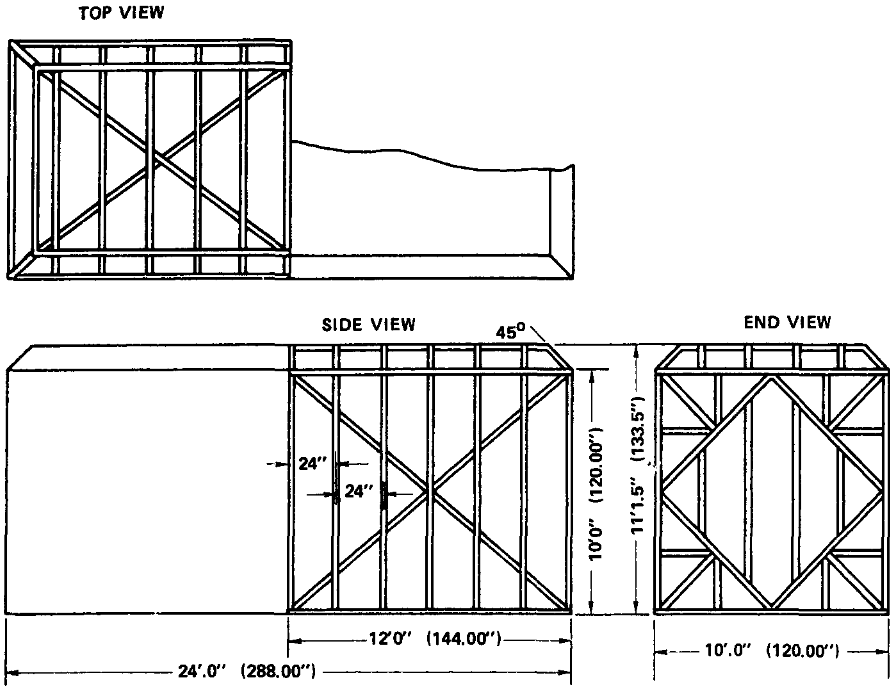


Figure 3-22 Schematic of Sunshade/Personnel Barrier

3.4 Systems Weights

The maximum weights to be lifted and transported were determined by using the A-A3/A-F3 concept. These weights are summarized in Table 3-2. If the B-F2 or A-F2 concepts were selected, the lifted and transported weights would be reduced by approximately 2.6 tonnes (2.9 tons). The lifted weight of the A-A3/A-F3 concept is 103.7 tonnes. The RSB crane capacity is 104.4 tonnes.

The weights of a cask system for a higher dose rate of 10 mrem/hr at 2 m (transportation regulation) rather than 10 mrem/hr at the surface were also estimated. These are summarized in Table 3-3. The loaded cask weight would be reduced by approximately 20 tonnes from the three-level containment cask weight. This would allow a four-axle railcar to be used with the lightweight cask.

Table 3-2 Maximum System Weights, A- A3 and A-F3 Cask Concepts

System Component	Kilograms	Pounds
Canister With Fuel and Sodium Unit Weight 431 kg (950 lb)	3,017	6,650
Basket	7,645	16,840
Basket Closure	863	1,900
Bolts	136	300
Basket Assy, including canister and closures Subtotal	11,661	25,690
Cask Body (steel)	71,800	158,153
Cask Outer Lid (3-in. thick)	1,390	3,063
Cask Inner Lid	613	1,350
Neutron Shield (borosilicone)	5,046	11,115
Steel Fins	4,109	9,050
Loaded Cask Weight	94,620*	208,400*
Lifting Yoke	9,080	20,000
Lifted Weight	103,699	228,400
Eight-Axle Railcar Weight	55,206	121,600
Total Shipment Weight*	149,800	330,000

*Totals rounded to four significant figures

Table 3-3 System Weights for Lightweight Design (10 mrem/hr at 2 m)

System Component	Kilograms	Pounds
Canister With Fuel and Sodium Unit Weight 431 kg (950 lb)	3,017	6,650
Basket	7,645	16,840
Basket Closure	863	1,900
Bolts	136	300
Basket Assy, including canister and closures Subtotal	11,661	25,690
Cask Body (steel)	52,582	115,820
Cask Outer Lid (3-in. thick)	1,390	3,063
Cask Inner Lid	613	1,350
Neutron Shield (borosilicone)	4,659	10,263
Steel Fins	3,269	7,200
Loaded Cask Weight	74,180*	163,400*
Lifting Yoke	9,080	20,000
Lifted Weight	83,260	183,400
Four-Axle Railcar Weight	18,432	40,600
Total Shipment Weight*	92,610	204,000

*Totals rounded to four significant figures

Chapter 4. Design Analysis and Assessment

The design analysis of the cask included the areas of shielding, structural, and thermal. Some qualitative assessments dealing with materials selection were also made. Also considered were leak-testing capabilities and possible methods for applying leak test equipment and procedure to the canister and cask.

The initial sizing of the cask was determined from shielding considerations. That cask was then used as a basis for thermal and structural analyses. As these analyses progressed and interface meetings were held, the cask design concepts underwent continuous changes, not all of which were immediately incorporated into the other studies.

The materials and seal assessments were completely parallel efforts to the other analyses. Considerations from all of the areas were incorporated into the baseline choice, however, because of time constraints not all analyses were performed on this choice.

4.1 Shielding Analyses

From a shielding point of view, it makes little difference whether the basket is removable and, therefore, the cask was treated as a monolithic structure with no radial gaps. Figure 4-1 shows schematically the cask design which was used in the initial shielding model. The closure and bottom shield design evolved as the analyses proceeded. Details of the initial (or original) closure and bottom end designs are shown in Figures 4-2 and 4-3.

The shielding analysis of the CRBRP spent fuel shipping cask conceptual design was composed of two distinct tasks. The first was a search for side wall thicknesses that yielded 10 mrem/hr at the surface of the cask, 10 mrem/hr at 2 m from the surface of the cask, and a dose rate at the surface of the cask halfway between the first two cases. This task was accomplished by treating the cask as a one-dimensional cylindrical object and using a one-dimensional, discrete ordinate code to do the calculations. The second task was the evaluation of the shielding at the ends of the proposed cask. For this task, the cask was reduced to a two-dimensional object, and the calculations were performed again with a discrete ordinate code.

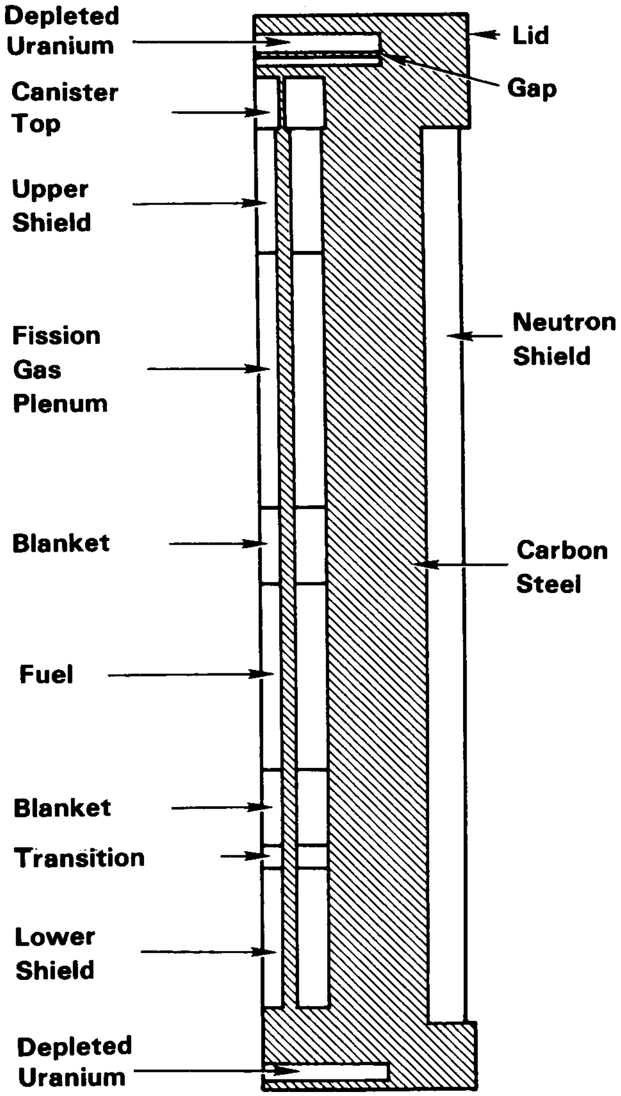


Figure 4-1 Schematic of Cask for Initial Shielding Calculations

4.1.1 One-Dimensional Analysis

The purpose of the one-dimensional shielding analysis was to determine the thicknesses of the carbon steel wall and of the neutron shield of the shipping cask (Figure 4-1) necessary to reduce the dose rate external to the cask to a specified value. In addition, the effect of varying the thickness of the coolant fins which pass through the neutron shield was to be assessed. This analysis was done by using the one-dimensional discrete ordinates code XSDRN from the SCALE system (Reference 19) developed for the transportation branch of NRC to do both criticality and shielding analysis of shipping packages.

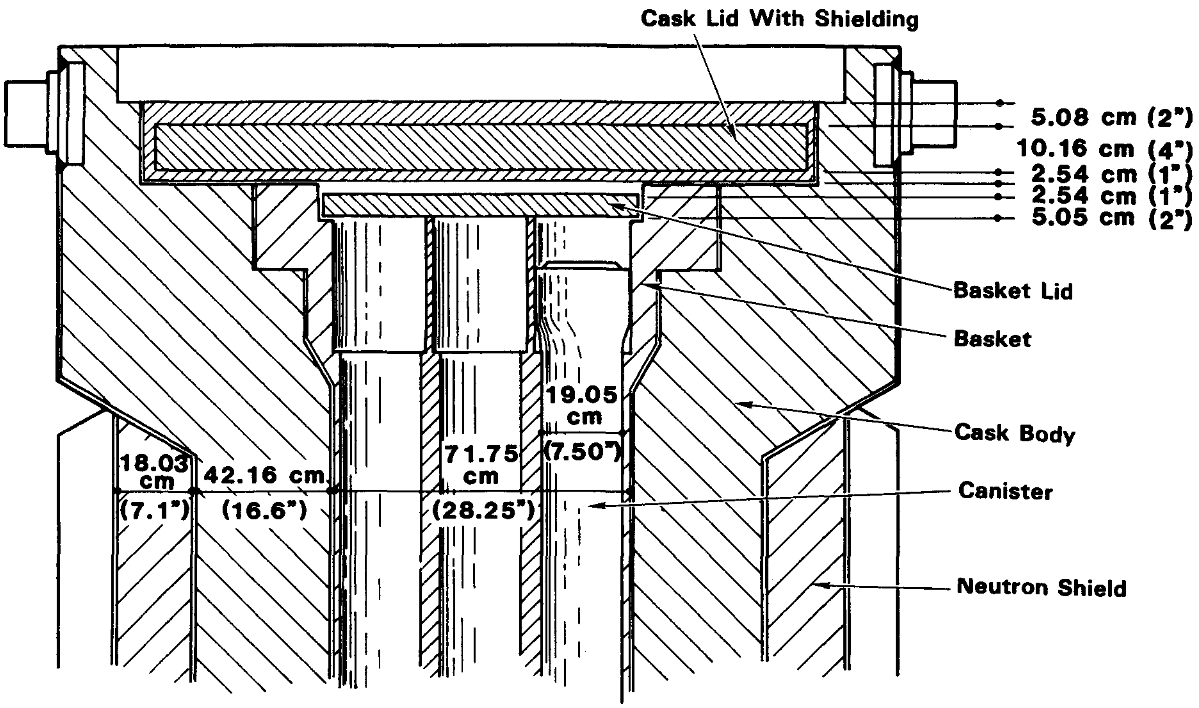


Figure 4-2 Schematic of Cask Closure End for Initial Shielding Calculations

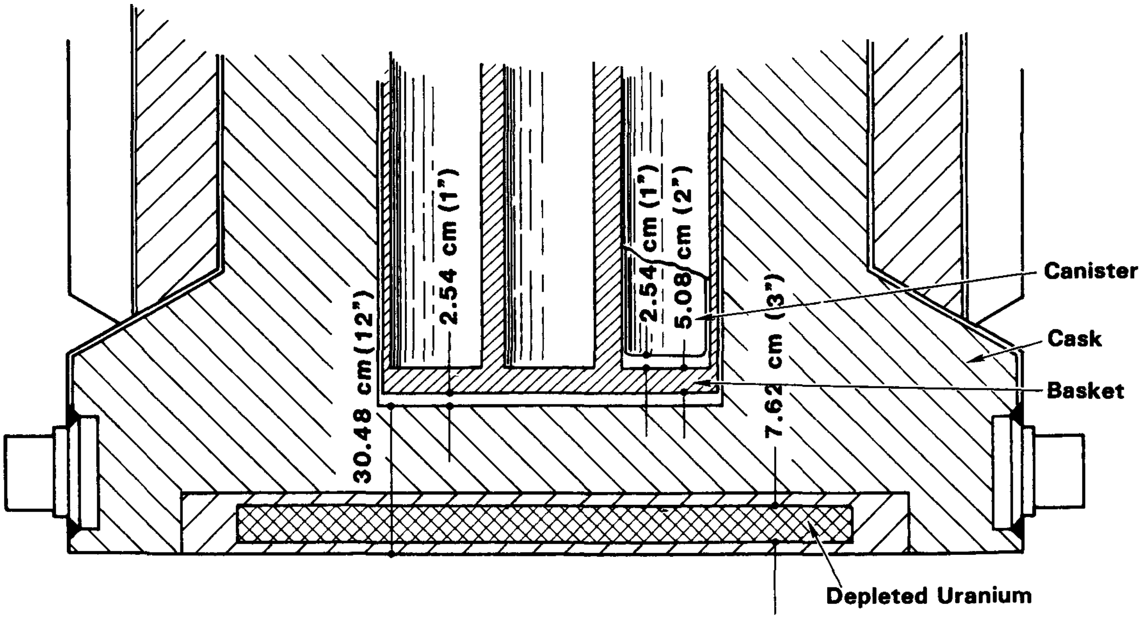


Figure 4-3 Schematic of Cask Bottom End for Initial Shielding Calculations

An S8 cylindrical quadrature (24 angles) was used along with about 90 spacial intervals. The cask was reduced to a one-dimensional object by treating it as an infinite cylinder whose composition was the same as at the center of the fuel region of the fuel assembly. The central fuel assembly was smeared over the central hole in the basket. This consisted of homogenizing the fuel pins, the sodium, and the canister over the volume of the hole. Similarly, the ring of six fuel assemblies was smeared into an annulus by homogenizing six smeared holes with the steel from the basket between the holes.

For the one-dimensional analysis, all steel components were assumed to be Type 316 stainless steel. The neutron shield was Type 236 borosilicone rubber (Reactor Experiments, Inc). The diameter of the basket was taken to be 0.7176 m (28.25 in.). All steel wall thicknesses for the cask were measured from this point.

To account for the actual height of the cask, a buckling correction of 150 cm was used in the calculations. This correction made a 0.25% change to the system losses, which indicates that axial losses were not very important in completing the side-wall calculations. The neutron source spectrum was assumed to be the same as the spontaneous fission spectrum for ^{252}Cf. The neutron source strength was interpolated from Table 7.1-3 of Reference 20 to a 7-kW assembly. The gamma-ray source was taken from Table 7.1-2 (Reference 21) at 80 days (data for 100 days not available) after shutdown, and was distributed into the gamma groups listed in the table. The fuel element composition used in smearing was taken from a WARD attachment to LRA-78-47 (Reference 22). The fuel element labeled AO302 at the end of cycle 4 (Table 4 of Reference 22) was used.

The cross sections used were a 27-neutron, 18-gamma-group set (Reference 23) developed for NRC. The cross-section set is based on ENDF/B version 4 data. The ANSI/ANS-6.1.1-1977 (N666) dose factors (Reference 24) were used to convert the flux values to doses.

Since it was not possible to explicitly represent the fins in a one- dimensional calculation, they were treated by homogenizing them with the neutron shield. The fins were taken to have a basic thickness of 4.76 mm (0.1875 in.). Calculations were then performed for no fins and one, two, and three times the basic thickness.

The results of the one-dimensional calculations are summarized in Table 4-1. Shield thicknesses noted in Case 1 give a dose rate at the surface of the cask of approximately 10 mrem/hr. Thicknesses noted in Case 2 give a dose rate of about 10 mrem/hr at 2 m from the surface of the cask. Case 3 gives a dose rate at the surface of the cask halfway between Cases 1 and 2. Shield thicknesses given in Case 4 represent an earlier (conceptual) cask design for which the shielding calculations were rechecked.

Table 4-1 Results of the One-Dimensional Analysis

	Thickness (mm)			Surface Dose Rate (mrem/hr)			2-Meter Dose Rate (mrem/hr)		
Case	Fin X=4.76	Neutron Shield	Gamma Shield	η	γ	Total	η	γ	Total
1	0X	180	422	2.0	7.2	9.2	0.6	2.2	2.8
	1X	180	422	2.7	5.8	8.5	0.8	1.8	2.6
	2X	180	422	3.7	5.1	8.8	1.1	1.5	2.6
	3X	180	422	5.2	4.6	9.8	1.5	1.4	2.9
2	0X	157	333	10.2	22.6	32.8	2.85	6.45	9.3
	1X	157	333	13.0	17.6	30.6	3.6	5.0	8.6
	2X	157	333	16.8	14.9	31.7	4.6	4.2	8.8
	3X	157	333	22.2	13.1	35.3	6.1	3.7	9.8
3	0X	165	366	5.9	13.4	19.3	1.7	3.9	5.6
	1X	165	366	7.6	10.8	18.4	2.2	3.1	5.3
	2X	165	366	10.0	9.5	19.5	2.8	2.7	5.5
	3X	165	366	13.5	8.6	22.1	3.8	2.5	6.3
4	—	203	305	3.3	27.7	31.0	0.9	8.1	9.0

The results show an increase in neutron dose rate with increasing fin thickness and a decrease in gamma dose rate. Both of these effects are probably overemphasized by homogenizing the fins into the neutron shield and do roughly compensate each other for the shield thicknesses considered. It is probably valid to conclude that for the shield and fin thicknesses covered in the table, the total dose will not vary significantly with fin thickness.

In evaluating the revised (Reference 21) gamma source, it was found that most of the gamma dose was coming from secondary gammas created by the neutrons, and only a small fraction was coming from the primary gamma source.

4.1.2 Two-Dimensional Analysis

The purpose of the two-dimensional analysis of the CRBRP spent fuel shipping cask conceptual design was to determine if the shielding at the ends of the cask was adequate to meet the design goal of 10 mrem/hr at the cask surfaces accessible to operating personnel. Sketches of the cask used for the initial two-dimensional analysis are shown in Figures 4-2 and 4-3. As in the one-dimensional analysis, the central fuel assembly was homogenized in the central hole, and the ring of six fuel elements was smeared into an annulus. In the two-dimensional model, the basket remained Type 316 stainless steel, but the cask body was modeled as carbon steel. The fuel elements were modeled in the axial direction as having a 0.686-m (27-in.) lower shield, a 0.1016-m (4-in.) lower transition region, a 0.3556-m (14-n.) lower blanket region, a 0.9144-m (36-in.) core zone, a 0.3556-m (14-in.) upper blanket region, 1.245-m (49-in.) fission gas plenum zone, and a 0.6096-m (24-in.) upper shield zone.

Above the upper shield zone, there is a canister top zone. This zone, composed of the top of the canister (including the lid), sodium, and the stainless-steel basket in the annulus, was homogenized for the calculation. On top of the canisters was placed a 0.0508-m (2-in.) basket lid of steel. Then there was a 0.0254-m (1-in.) gap, and the inner cask lid, consisting of 0.0254 m (1 in.) of steel, 0.1016 m (4 in.) of depleted uranium, and another 0.0508 m (2 in.) of steel.

At the bottom of the cask, there was 0.0762 m (3 in.) of stainless steel representing the bottom of the canister plus the bottom of the basket. The cask bottom was assumed to consist of 0.2032 m (8 in.) of steel, 0.0762 m (3 in.) of depleted uranium, and another 0.0254 m (1 in.) of steel. In the radial direction, the cask had a basket of 0.7176 m (28.25 in.) outer diameter, a cask body of 0.422 m (16.6 in.) of carbon steel, and 0.1905 m (7.5 in.) of neutron shield.

The calculations were made by using the DOT-IV (Reference 25) two-dimensional discrete ordinates code. An S8 cylindrical quadrature (48 angles) was used along with P3 scattering moments. An axial mesh of 222 intervals was used with a radial mesh of 54 intervals. The cross sections employed were derived from the set used in the one-dimensional analysis by collapsing the 13 thermal neutron groups to 1 group and collapsing together the bottom 2 gamma groups. This resulted in a cross-section set with 15 neutron groups and 17 gamma groups.

The source for the initial calculations was taken from the same tables as for the one-dimensional calculations. Neutron and gamma sources for the axial blanket regions were given in tables and were also included in this calculation.

The results of this calculation are given in Table 4-2 and show that very little radiation from the fuel reaches the ends of the cask.

Table 4-2 Results of a Two-Dimensional Analysis With Source in the Fuel and Axial Blanket Only

	Dose Rate (mrem/hr)		
Position	η	γ	Total
Top of cask			
Top of inner cask lid	0.018	$<2 \times 10^{-4}$	0.018
Middle of uranium in lid	0.08	$<5 \times 10^{-4}$	0.08
Bottom of uranium in lid	0.20	1.5×10^{-3}	0.20
Top of basket lid	0.22	1.8×10^{-3}	0.22
Top of canister	0.34	3.0×10^{-3}	0.34
Bottom of cask			
9-in. steel, 3-in. uranium	2.7	2.0×10^{-2}	2.7
Side of cask			
Midsection	1.4	5.7	7.1

One possible error in the above calculations could occur from treating the fission product source as the only source. As a result, the next step was to add the activation source for the stainless steel in the fuel element. The CRBR staff supplied an equilibrium source activating the elements in stainless steel in the various zones of fuel element. It was necessary to modify this source in order to account for the cooling period before shipment and to correct the ^{60}Co source for the finite irradiation period. This activation source was then added to the fission product source and two calculations were made: the original model was rerun and the model was also rerun where both slabs of depleted uranium were replaced with steel. The results of these two calculations are presented in Tables 4-3 and 4-4.

Table 4-3 Original Model Plus Stainless Steel Activation Source

Position	Dose Rate (mrem/hr) η	γ	Total
Bottom of cask	2.72	1.05	3.79
Side of cask	1.44	5.69	7.13
Bottom of inner cask lid	0.23	2667.00	2667.00
Center of uranium in lid	0.10	18.00	18.00
Top of inner cask lid	0.01	0.04	0.05

Table 4-4 Original Model Plus Stainless Steel Activation Source and Depleted Uranium Replaced by Steel

Position	Dose Rate (mrem/hr) η	γ	Total
Bottom of cask	3.67	33.0	36.70
Side of cask	1.44	5.69	7.13
Bottom of inner cask lid	0.23	2650.00	2650.00
Middle of inner cask lid	0.12	184.00	184.00
Top of inner cask lid	0.02	4.30	4.32

Plots of the dose rate contours corresponding to Table 4-3 are given in Figures 4-4 through 4-8 and those corresponding to Table 4-4 are given in Figures 4-9 through 4-13. The dose contours in these plots are given in rem/hr rather than mrem/hr.

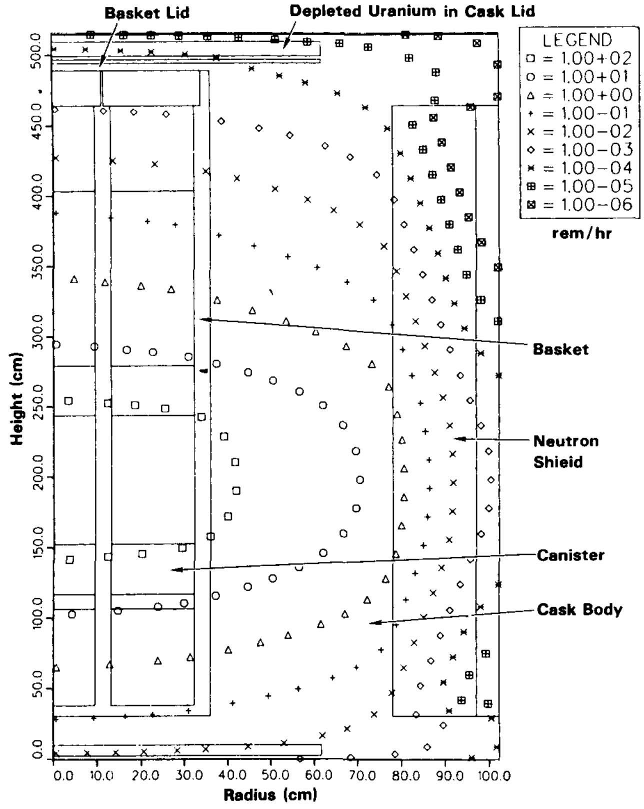


Figure 4-4 Neutron Dose Uranium End Shields (Activation source included)

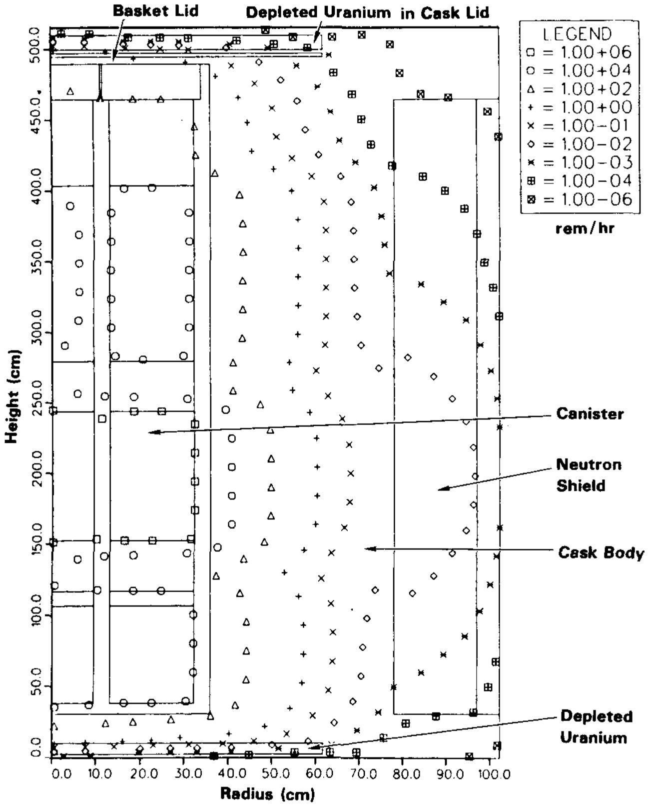


Figure 4-5 Gamma Dose Uranium End Shields (Activation source included)

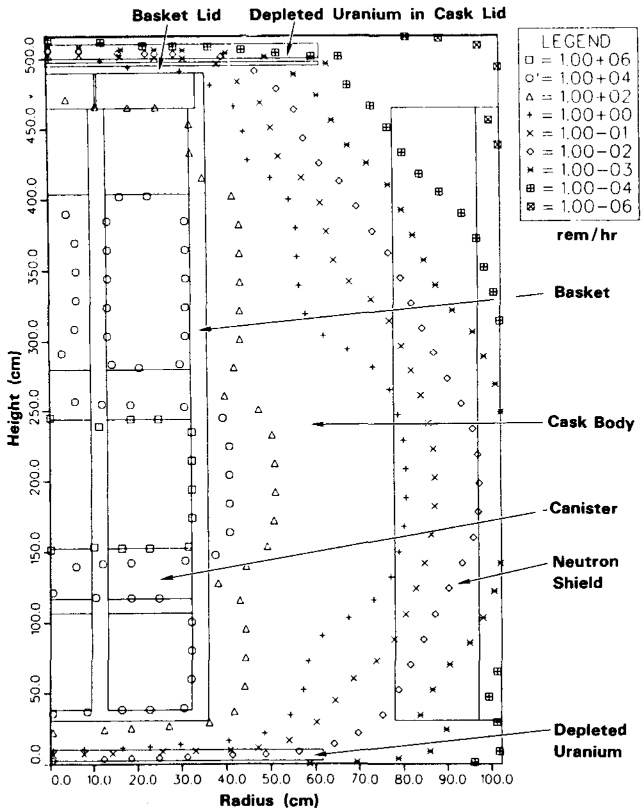


Figure 4-6 Total Dose Uranium End Shields (Activation source included)

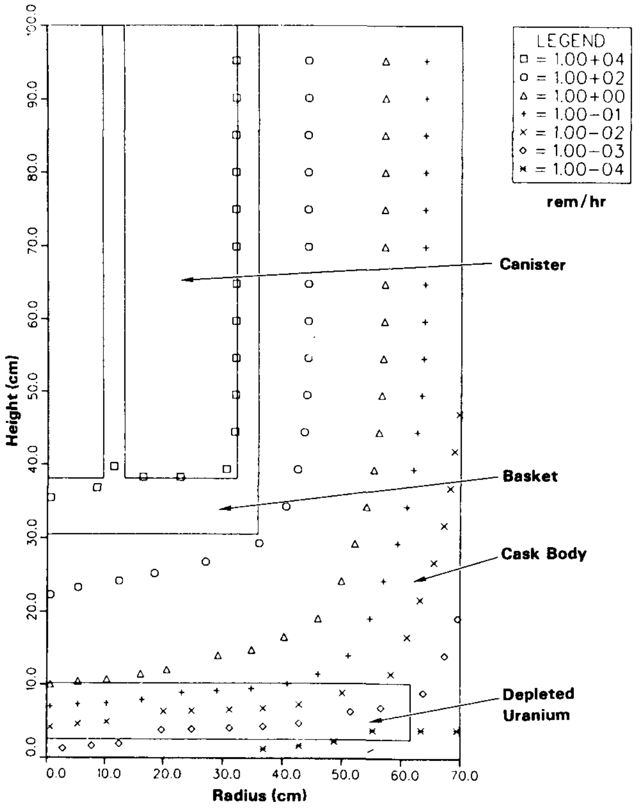


Figure 4-7 Gamma Dose Uranium End Shields, Bottom (Activation source included)

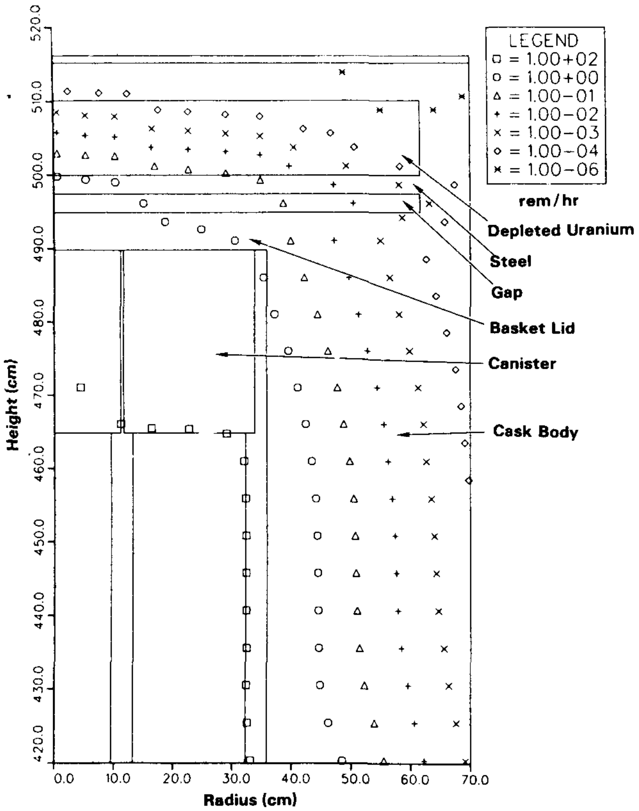


Figure 4-8 Gamma Dose Uranium End Shields, Top (Activation source included)

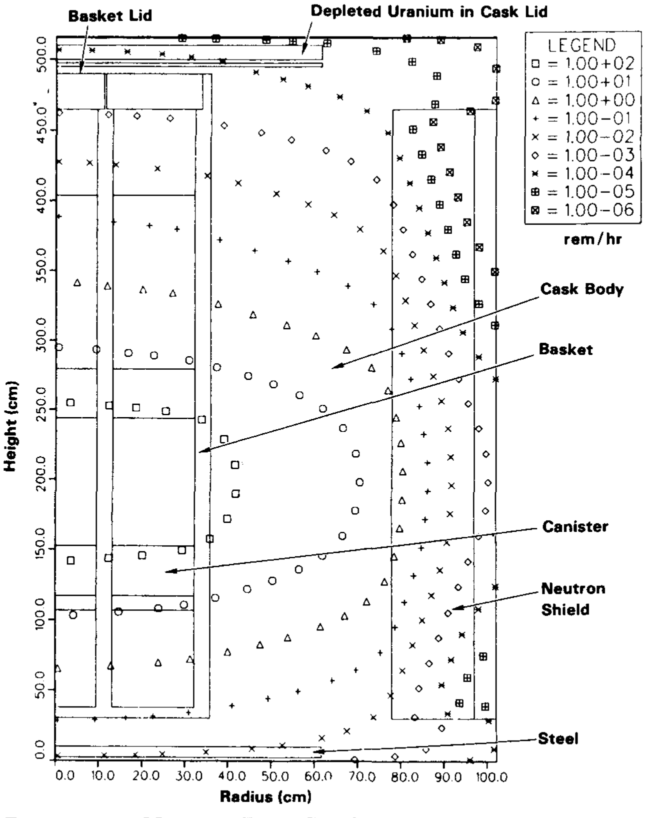


Figure 4-9 Neutron Dose Steel End Shields (Activation source included)

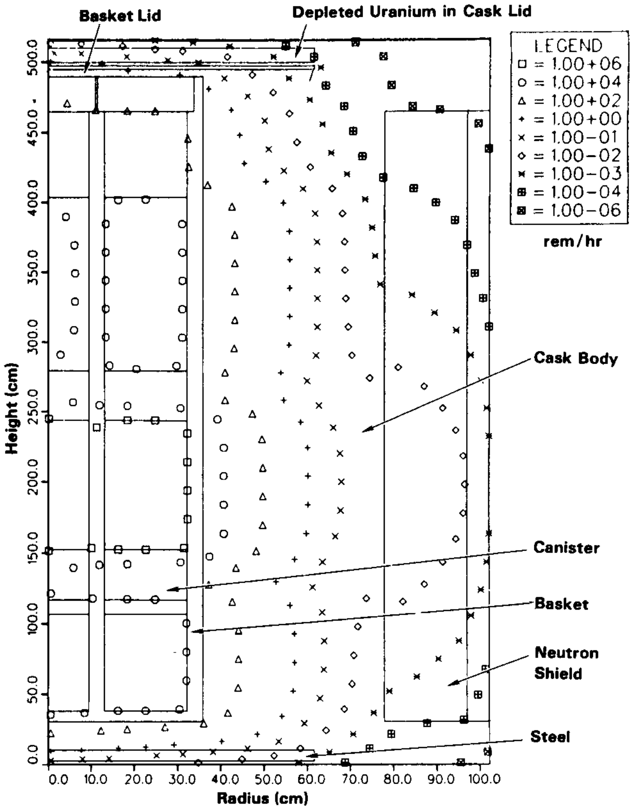


Figure 4-10 Gamma Dose Steel End Shields (Activation source included)

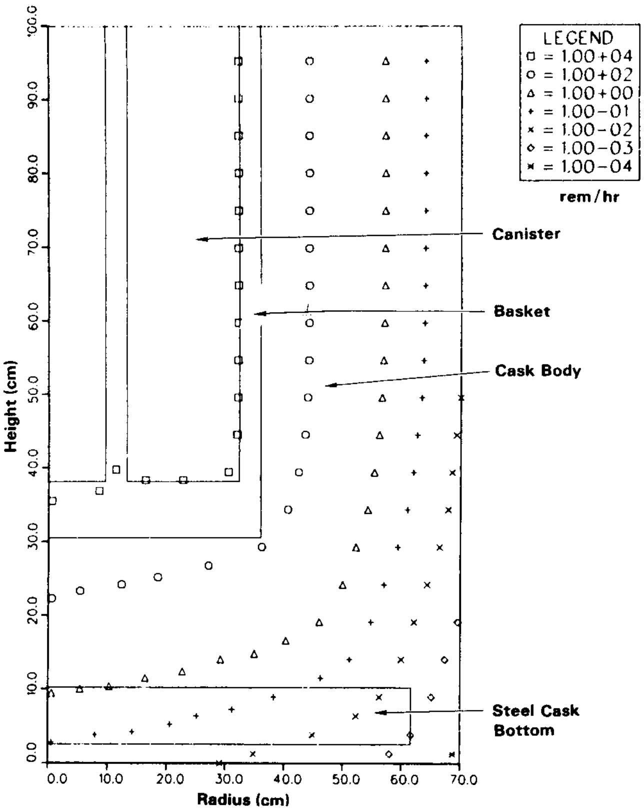


Figure 4-12 Gamma Dose Steel End, Bottom (Activation source included)

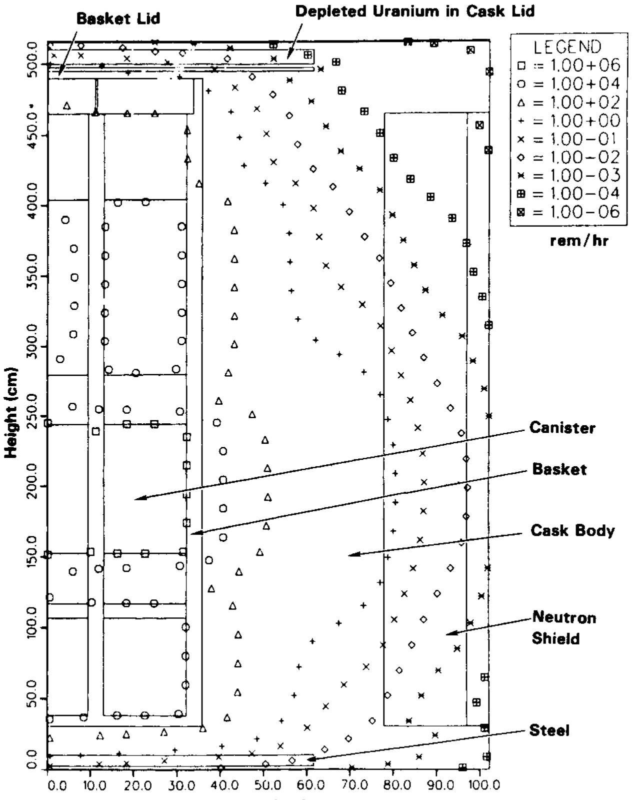


Figure 4-11 Total Dose Steel End Shields (Activation source included)

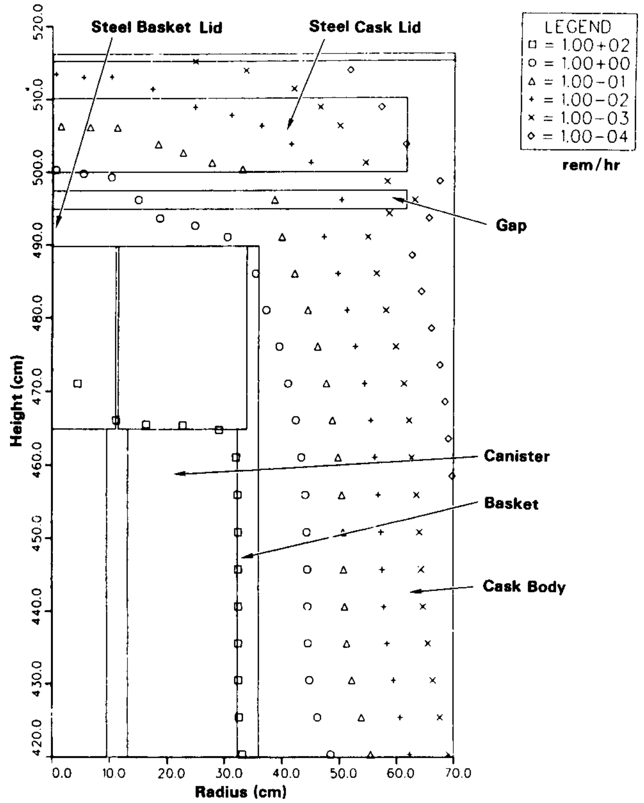


Figure 4-13 Gamma Dose Steel End, Top (Activation source included)

With these results available, it was decided to try to bring the dose rate at the surface of the basket lid (i.e., the bottom of the inner cask lid) down to 10 mrem/hr so that the cask inner lid could be removed with personnel present. This change required a complete remodeling of the lid section of the cask to add depleted uranium to the basket lid and removing it from the inner cask lid as well as adding more steel. The design of this top closure configuration is shown in Figure 4-14. At the same time, an additional gamma source was added in the canister top zone by assuming two fuel pins per fuel assembly failed and available fission product gases migrated to just below the canister lids.

The results of this calculation are given in Table 4-5 with plots given as Figures 4-15 and 4-19. In establishing this model, it was discovered that the gap outside the neutron shield on the edge of the cask had mistakenly contained neutron shield instead of void in the previous two-dimensional calculations. As can be seen from the results in Tables 4-1 and 4-5, putting in the void improves the agreement between the one- and two-dimensional calculations (from 7.1 to 9.5 mrem/hr for the two-dimensional compared with 9.2 mrem/hr for the one-dimensional case).

Table 4-5 New Basket Lid Model Plus Fission Product Gas Source, Stainless Steel Activation Source, and Correct Side-Wall Model

Position	Dose Rate (mrem/hr)		
	η	γ	Total
Bottom of cask	2.74	0.05	2.79
Side of cask	0.88	8.61	9.49
Middle of uranium in basket lid	0.24	128.87	129.00
Top of uranium in basket lid	0.15	3.54	3.69
Top of basket lid	0.10	0.62	0.72

In conclusion, there appears to be no problem in meeting the design goal of 10 mrem/hr at the surface of the cask.

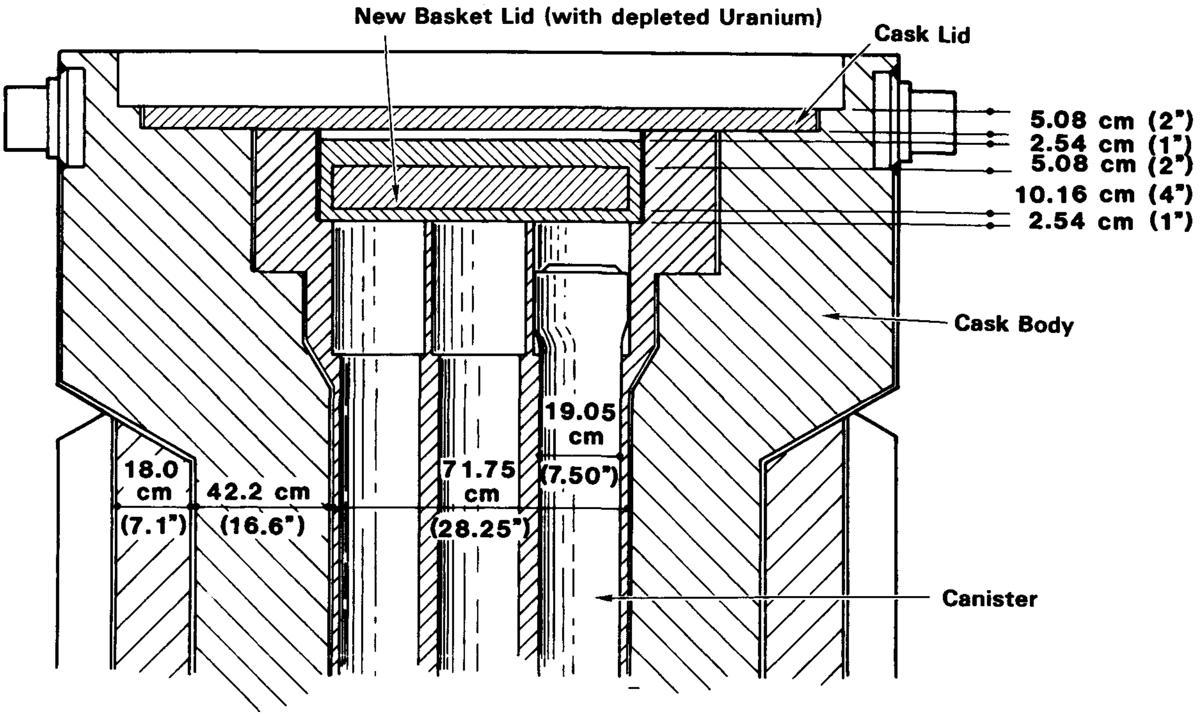


Figure 4-14 Cask Top Model for Shielding Calculations With Depleted Uranium in Basket Lid

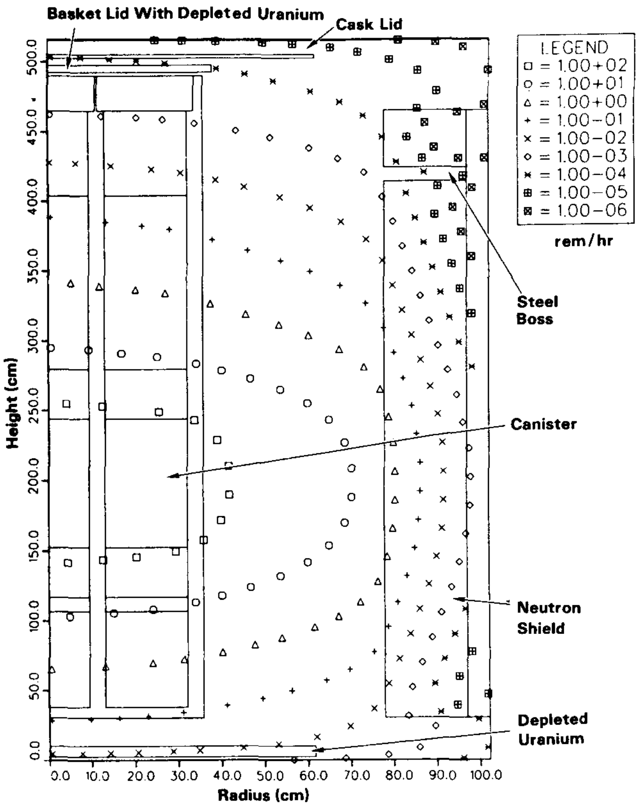


Figure 4-15 Neutron Dose, New Basket Lid

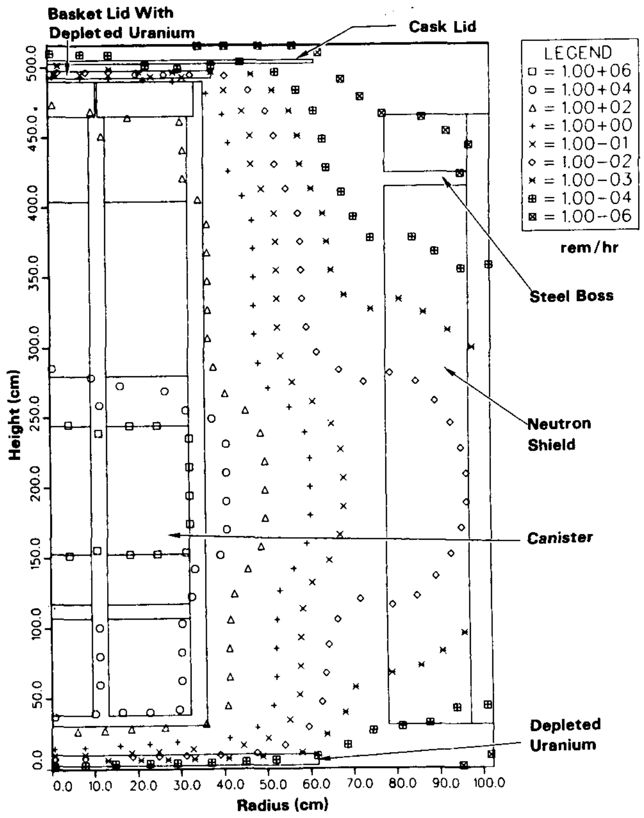


Figure 4-16 Gamma Dose, New Basket Lid

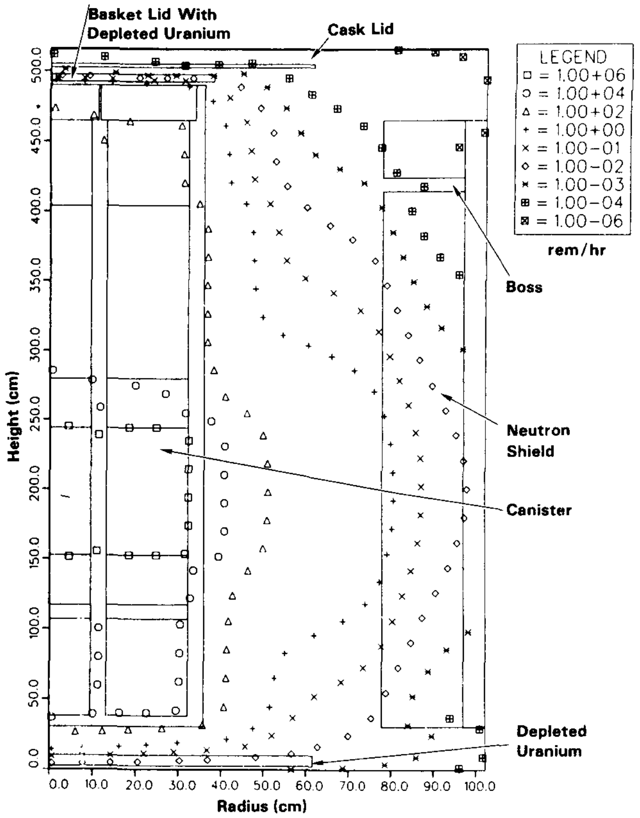


Figure 4-17 Total Dose, New Basket Lid

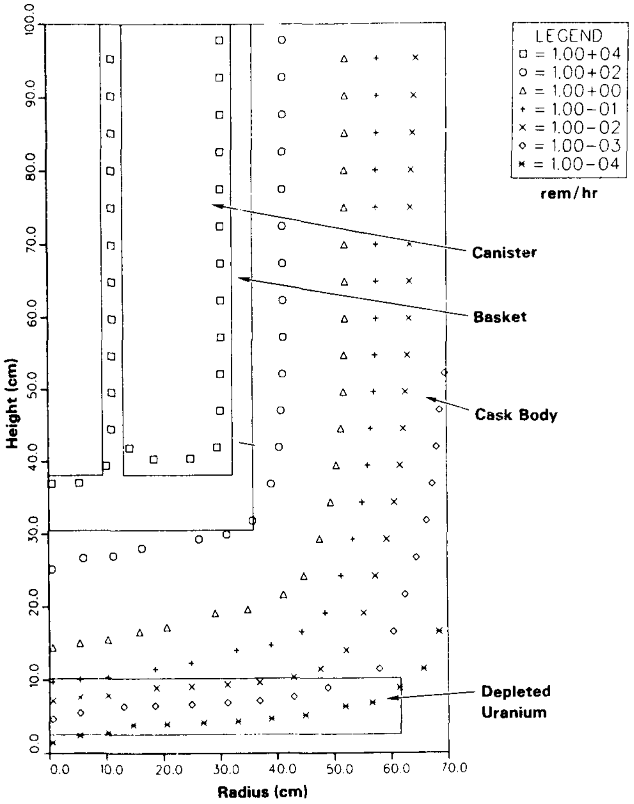


Figure 4-18 Gamma Dose, New Basket Lid, Bottom

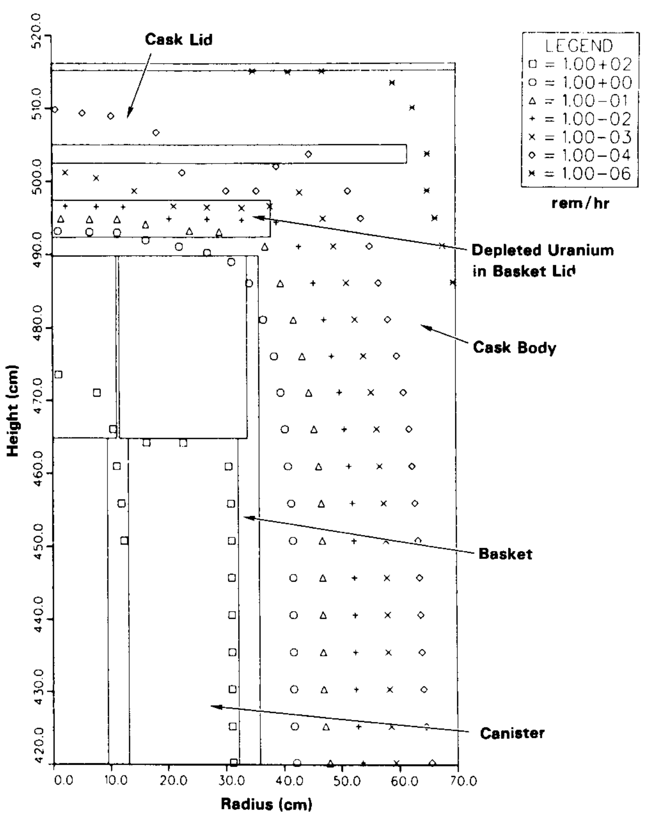


Figure 4-19 Gamma Dose, New Basket Lid, Top

4.2 Materials Assessment

The following subsections provide an assessment of the materials-related problems associated with the design, licensing, fabrication, and use of the CRBRP spent fuel shipping cask and canisters. It will be shown that candidate materials for the CRBRP cask include ferritic and austenitic (stainless) steels. Current state-of-the-art ferritic steels in heavy sections may not meet the fracture resistance toughness guidelines proposed by the NRC (Reference 16). Austenitic stainless steels however, can be readily used to meet fracture toughness requirements. Domestic manufacturers claim the ability to manufacture a monolithic cask, although they have no experience in fabricating a forging of the required dimensions from an austenitic steel. There are a number of problems related to material usages in the CRBRP cask that should be more fully investigated. These include welding in heavy sections, through thickness properties (including fracture toughness, strength, microstructure, and segregation), nil-ductility transition temperature (T_{NDT}) of the thick-walled structural sections, fracture toughness, and related properties of heavy sections of ferritic steels. Additionally, further work on design by analysis concepts are needed in order to qualify a broader range of more readily available, less costly (and critical) materials for use in nuclear transportation units.

4.2.1 Containment System

Information pertaining to material selection for the CRBRP cask is contained in this subsection. Candidate materials for the basket and cask body can be divided into austenitic (stainless) steels and ferritic steels. Material selection is based on several factors which include brittle fracture/toughness, material considerations, manufacturing capabilities, weld-ability, galling potential, inspectability, and other properties.

Alloys used in the thick-walled casks proposed for the CRBRP must possess adequate toughness to prevent initiation and catastrophic growth of cracks during either normal operations or accident conditions. Specific factors characteristic of shipping cask service which may aggravate toughness requirements include: (1) low temperature operation [(-29°C (-20°F) to -40°C (-40°F)], as specified in Reference 26, (2) possible dynamic loadings; (3) difficulty in inspecting for flaws; and (4) very thick wall sections. The heavy sections [defined herein as wall-thicknesses in excess of 200 mm (8 in.)] cause high mechanical constraints and make it difficult to control microstructural uniformity across the section. Because of manufacturing limitations, such heavy sections do not allow sufficient forging deformation to produce a uniform and fine-grain size or to reduce macrosegregation (present from ingot solidification). Cooling rate differences during subsequent heat treatment may also produce a non-uniform microstructure across the thickness. Each of these variations affect strength and toughness and must be measured to satisfy design allowances.

Based on current NRC recommendations (Reference 16) relative to fracture resistance/ toughness, it appears as though a ferritic steel cannot be used if the cask body is to serve as a containment system. However, if the cask body is to function as an "overpack," protecting the containment system and providing shielding, use of ferritics—or even newly developing ductile cast irons—may be possible. For the containment systems, only austenitic stainless steels meet the fracture guidelines.

Current NRC requirements for the fracture toughness of shipping cask structural alloys are not well-defined. The packaging rules given in 10CFR71 (Reference 10) are augmented by Regulatory Guide

7.6 (Reference 27). These documents outline suggested structural design procedures and reference material properties from Subsection NA of Section III of the ASME Boiler and Pressure Vessel Code (Reference 28). Regulatory Guide 7.6 utilizes only linear elastic stress analysis and does not consider brittle fracture. It simply states that designs of recently licensed shipping casks were made of austenitic stainless steel which is ductile at low temperatures (i.e., does not undergo a ductile-to-brittle transition with decreasing temperature). Austenitic stainless steels have been credited with possessing adequate low temperature toughness although no detailed fracture analysis has been required.

Recommendations for the design of shipping containers using ferritic steels have recently been published in a report by Holman and Langland of Lawrence Livermore National Laboratory (LLNL) (Reference 16) under contract to the NRC. This report only addresses design for material up to 100 mm (4 in.) thick. Requirements for heavy sections [up to 420 mm (16.5 in.) for the CRBRP cask designs] will probably be more restrictive. The design recommendations in the LLNL report should be considered in light of the severe limitations they place on alloy selection even for thinner sections. Application of the philosophy developed the LLNL report to heavier sections similar to those planned for the CRBRP cask would result in strict limitations on materials which could be used.

The LLNL philosophy, which is based on previous work by Pellini (Reference 29), seeks to prevent brittle failure at low temperatures in dynamic loading and in the presence of large pre-existing flaws by requiring sufficient alloy toughness to prevent crack propagation. An alloy's dynamic fracture toughness is related to the more easily measured nil-ductility transition temperature (T_{NDT}) for ductile-to-brittle fracture. T_{NDT} is measured by using either a drop-weight tear test, or a Charpy impact test. The T_{NDT} is arbitrarily defined as lying in the temperature range where fracture characteristics are changing rapidly from primarily fibrous (ductile) to primarily crystalline (brittle). T_{NDT} can be defined by the fracture appearance, or by some particular value on the energy absorbed vs temperature curve. Schematics of impact tests vs temperature for iron alloys are shown in Figure 4-20. The LLNL philosophy places the burden of brittle fracture prevention on the material through its ability to blunt a growing crack.

Other philosophies can be used to design casks by determining critical crack sizes, locations, and orientations by analysis of the overall design. This design philosophy requires the exclusion of critical flaws whether they occur because of pre-existing sites, or are generated during use (by slow crack growth), or during accident conditions. Extensive material properties must be determined and nondestructive examination (NDE) inspection intervals must be specified. This philosophy seeks to have the design analysis carry the burden of preventing brittle failure.

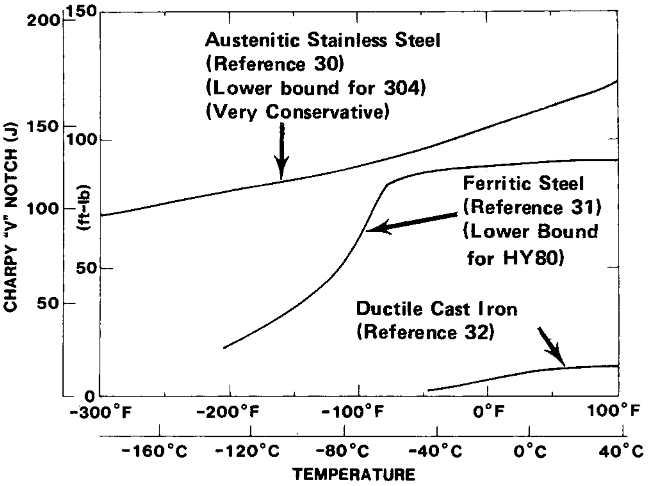


Figure 4-20 Example of Energy Absorbed vs Temperature Curves Used in Determining T_{NDT}

In the LLNL design philosophy, a required T_{NDT} is specified for a particular alloy which is a function of thickness, stress level, and lowest operating temperature. Using the LLNL method, a 100-mm (4-in.) section at -29°C (-20°F) under a stress of 20% of the dynamic stress would require a T_{NDT} no greater than -62°C (-80°F). Using this philosophy, thicker sections or higher stresses would certainly drive the T_{NDT} below -75°C (-103°F). As a practical consequence, this design treatment probably eliminates all ferritic steels that can be produced in heavy sections. For example, nozzle belt forgings produced by the Japanese (Reference 33) out of an alloy similar to A508 class 2 ferritic steel, in a 530-mm (21-in.) thickness show a T_{NDT} of about -30°C (-22°F), which is well above the -75°C (-103°F) requirement. Ferritic steels such as HY80 (A543) that have a transition temperature below -75°C (-103°F) are plate alloys that are not produced in thicknesses greater than 150 mm (6 in.).

If the recommendations proposed by LLNL for ferritic steels are adopted by NRC, it appears that an austenitic stainless alloy would be required for fabrication of thick-walled cask structures. Use of ferritic steels would require modification of the design recommendations in the LLNL report. These modifications could include more specific and rigorous structural and fracture mechanics analyses of each design. Additionally, well-qualified, nondestructive examination procedures would have to be applied in order to ensure that the flaw sizes in the fabricated piece do not exceed those used in the fracture analysis.

Although American Society of Mechanical Engineers (ASME) codes exist which provide guidance to reactor fabricators, similar codes do not exist for shipping container fabricators. As a result, concerned personnel in the industry, including TTC personnel, initiated an effort to develop an ASME code. In September 1979, an Ad Hoc Committee drafted a paper outlining the scope of the committee and what they wanted to achieve. This draft was then submitted to the ASME Nuclear and Standards Committee which gave approval for the committee to proceed under ASME auspices.

The scope of the committee on containment systems for nuclear spent fuel and high-level waste transport packagings (NUPACK) is to develop, maintain, and coordinate codes and standards for the construction and in-service requirements for containment systems for nuclear spent fuel and high-level waste transport packaging. Construction includes general requirements, materials, design, fabrication, examination, testing, inspection, overpressure protection, and certification. The in-service aspects are comprised of general requirements, examination, testing, inspection, modifications, and repairs and replacements. Those items required as pressure barriers limiting the release of radioactive material to acceptable levels during transport are included in the containment systems. However, a new code establishing the guidance needed will not be forthcoming in the near future.

Domestic steel fabricators (although they have no actual experience in forming similar stainless-steel components) feel that a monolithic cask could be manufactured with existing facilities. Welding qualification (particularly with stainless steels) would be very difficult, and thus designs with through-thickness welds should be avoided. On the basis of information gathered by SNL to date, it is felt that a monolithic cask machined from a forged austenitic stainless-steel ingot could be fabricated and qualified for the CRBRP cask.

Previous reports prepared by Exxon Nuclear (Reference 34) and General Atomic (Reference 35) indicated that there are significant limitations on the part of the fabricators to produce ferritic or austenitic casks in the size (external dimensions, wall thickness, and total tonnage) required for the CRBRP cask. However, SNL personnel have made informal contact with some leading manufacturers* who have indicated that in terms of materials availability and manufacturing capability, the cask could be fabricated from either an austenitic stainless steel or a ferritic such as A508 or A543. Each of these manufacturers indicated that they could potentially make a forging of the necessary size [about 1.83 m (6 ft) in diameter by 5.49 m (18 ft) long] with existing facilities. However, the concensus was that these manufacturers would be more confident in making such a container from a ferritic rather than an austenitic alloy.

The preferred process (as far as the manufacturers are concerned) would be to make a hollow cylinder by forging to the appropriate dimensions and then to weld the bottom end in place (refer to the subsequent discussion on heavy section welding). A second process which may be possible would be to fabricate a monolithic cask (i.e., without welding). This process would involve first casting a large ingot [perhaps as large as 306,000 kg (675,000 lb)], upset-forging the ingot to a solid cylinder, and then machining the inner diameter. This second process choice would be more costly than the first one described above because of the difficulty of removing the machining chips, but would provide a more reliable, higher quality end product, especially for austenitics.

Some reservations about making the CRBRP-type cask from an austenitic stainless steel were expressed by each of the manufacturers. These reservations arise from limitations in actual production experience (and normal plant operation), forging capacities, and possible welding requirements. Manufacturers have experience in forming as well as welding large sections of ferritics such as A508. However, their experience is limited in fabrication of thick sections from austenitic stainless steels. For many manufacturers, the melting of large tonnages of stainless steels is not common practice. Several furnaces would have to be "ganged" together to produce the required amount of material. Most of these furnaces are not normally used to produce stainless steels, and thus several "wash" heats would be needed to insure that the final ingot would be within the required chemistry specifications. Inclusion of these "wash" heats would significantly increase the fabrication cost of the cask.

It appears that more detailed contacts with the manufacturers will be necessary to determine existing fabrication uncertainties, particularly in light of the limitations listed in References 34 and 35.

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*Behtlehem Steel, US Steel, and National Forge

It appears that both austenitic and ferritic steels can be welded in heavy sections, but considerable welding development and qualification would be necessary. Welding of such heavy wall sections may potentially be accomplished by submerged arc, metal inert gas, or electroslag welding. However, no fully detailed welding procedures for such heavy sections have ever been established, qualified, or tested. Such an experimental welding program has been proposed by SNL/TTC as part of the generic TTC program. However, funding limitations have kept the research from being initiated. Metallurgical and mechanical variations are expected between the bulk material and the weld zone. Extensive experimental and developmental evaluation of the welding techniques and the resulting weld would be required to characterize welds in heavy sections. Heavy section welding is not current state-of-the-art and would thus require significant development.

Full inspection of the heavy section welds in austenitic stainless-steel may be extremely difficult if not impossible. Inspection for weld-induced cracking is generally done by an ultrasonic method—such techniques could not be used in extremely thick stainless materials because of their inherent high attenuation of ultrasonic waves; the much lower attenuation through a ferritic may make ultrasonic inspection possible.

Were a ferritic steel to be used for the cask, a stainless-steel liner of some sort may be required. If the liner is overlayed, cracking of the ferritic may occur. This phenomena has been found in overlays in nuclear reactors. Use of stainless-steel overlays on ferritic materials would be expected to seriously degrade their inspectability by ultrasonics.

4.2.2 Galling Problems

When stainless steel is used for bolting applications, a significant potential for galling exists. Galling is the process in which excessive friction develops between two mating surfaces and results in localized welding. Spalling can subsequently occur (with attendant surface roughening), and in extreme cases the two surfaces can be permanently joined together. Many stainless steels are particularly susceptible to galling. To avoid galling, special austenitic materials should be used. Two that are recommended are Inconel 718 and MP35N. Alloy MP35N (a high cobalt-containing alloy) is the more resistant to galling, particularly if threaded surfaces are silver-plated. The MP35N would be about twice as expensive as the Inconel 718 [i.e., $1000 per 6.4 x 12.7-cm-long bolt (2.5- x 5-in.-long) compared to $500 for Inconel 718]. Compositions and tensile properties for these materials are shown in Table 4-6.

Table 4-6 Composition and Tensile Properties for Inconel 718 and MP35N

Austenitic Material	Composition (%)	Tensile Strength [kPa (ksi)]
Iconel 718	Cr — 19.0 Ni — 52.0 Mo — 3.0 Nb — 5.1 Fe — 18.5	1030 (150)
MP35N	Co — 35.0 Ni — 35.0 Cr — 20.0 Mo — 10.0	1380 (200)

If the entire cask is made from a stainless steel, there is a large potential for galling between the cask and the canister (or basket and canister) to occur when the canister is either inserted or extracted. Machined tolerances must be close in order to provide narrow gaps for maximizing heat transfer; as the gaps are decreased, the likelihood for galling increases. At least a small amount of distortion can be expected because of nonuniform heating and cooling and this will exacerbate galling problems.

Galling problems with metal seals and between the canister and the cask (or basket) may be eliminated by hardfacing. Hardfacing is the process of laying down (by welding, flame spraying, or vapor deposition) a layer, edge, or point of metal onto a part in order to increase its resistance to abrasion, erosion, corrosion, heat, or some combination of these. Cobalt-based alloys are generally rated as the most versatile of the available hardfacing materials, and have good resistance to corrosion, abrasion, galling, oxidation, thermal shock, heat, and erosion. Two such cobalt-based alloys that should be considered for hardfacing in the CRBRP cask are Stellite 6 and Stellite 21.

4.2.3 Neutron Shield

A study was initiated in 1977 at SNL to evaluate the feasibility of fabricating neutron shields for shipping casks by using commercially available materials that would retain at least part of their shielding capability following exposure to an 800°C (1475°F), 30-min thermal test. The results of the first phase of this developmental program are outlined in Reference 36.

The neutron shield concept utilizes interstitially located layers of a neutron shielding material and metallic heat transfer fins. Materials that can be preformed to specific shapes and inserted into neutron shield cavities, and materials that can be "injected" into the cavities and solidified in place were studied. Only materials that are commercially available in the United States were considered. In Phase I of the program it was assumed that the heat transfer fins could not allow a "neutron window" through the shield and therefore the design concept provided for four distinct bends in the fins as they pass through the shield area to prevent neutron streaming.

Other criteria for selecting candidate materials, in addition to the fabrication procedures described above, included cost, neutron shielding effectiveness, and thermal stability of the material in both long-term temperature environments up to 225°C and short-term exposure to high temperatures. Initially the literature was reviewed and potential suppliers contacted for information not available in their literature. This "screening" process was continued by selecting candidate materials and examining their thermal stability using thermogravimetric analysis (TGA). As a result, three candidate materials were selected for the first phase of a more detailed evaluation: (1) borosilicone rubber 236, a product of Reactor Experiments, Inc; (2) borosilicone rubber, BISCO NS-I, a product of Brand Industrial Services, Inc (BISCO); and (3) borated beechwood, Permali JN, a product of the Permali International Group.

Problems associated with fabrication were specifically addressed early in the program. For simplified fabrication procedures, it was desirable to locate a suitable material that could be injected into existing cavities in the cask structure and have it solidify in-situ. This fabrication procedure would allow the designer to easily provide a protective outer metal cover over the neutron shield, which would prevent significant contamination uptake during in-plant handling and could also serve as a barrier to oxygen during fire exposure. At the time of initial material selection, only the NS-I material could be injected into a cavity and cured in place. However, as noted below, it has now been demonstrated that the borosilicone 236 material can also be fabricated in place.

The results of the Phase I tests demonstrated that this neutron-shielding concept is a viable design option for spent fuel shipping casks. The tests showed that the borosilicone 236 shield is far superior to the other shield materials considered. Repeated TGA, aging and fire tests demonstrated the reliability of the data developed during the Phase I testing. Following exposure of test samples of the borosilicone 236 material to a 1/2-hr thermal test similar to that required by 10CFR71 (Reference 10), the sample retained a significant portion of its neutron shielding capability—the neutron attenuation factor was reduced from 17 to approximately 12 (see Reference 36 for details).

In view of the success achieved in the first phase of testing with the borosilicone 236 material, a Phase II test program was initiated in FY80 as part of the generic program at the SNL/TTC. Test samples were fabricated of steel, some having bent internal fins and others having straight-through fins. Small holes were left in the outer surface of the samples, three holes per cavity, and borosilicone 236 was successfully injected through these holes and solidified in the cavities. Fusible nylon plugs were inserted in the holes to provide weather and contamination protection for the neutron-shielding material. The test samples had small external heat rejection fins (finlets) 76 mm high, 55 mm wide, and 6 mm thick (3 x 2 x 0.25 in.).

The goals of the second phase effort were

1. To demonstrate that the material can be formed in place inside of fabricated cavities
2. To demonstrate that the fabricated shield will withstand long-term high-temperature heat soak without significant degradation
3. To measure the effective thermal resistance of the neutron shield layer
4. To assess the effect of bent fins vs straight fins inside the neutron-shield cavities on neutron shielding capability
5. To determine the feasibility of fabricating the internal fins from steel rather than copper
6. To assess the heat rejection performance of small "finlets" on the external surface of the shield as compared with large lateral or circumferential fins
7. To assess the behavior of the material in an enclosed cavity when exposed to the thermal test environment.

As indicated previously, the first goal has been successfully demonstrated. Long-term thermal aging was initiated in late FY8l, and problems of a yet-to-be-determined nature were encountered. The thermal aging process was terminated and an assessment of the problem was initiated. However, the Phase II testing was terminated at the end of FY81 because of funding constraints.

For the purpose of the cask concepts described in this report, it was assumed that the thermal aging problem can be solved, and that the use of borosilicone 236 as a neutron shield is viable.

4.2.4 Other Material Problems

There are other material-related issues that should be considered for the CRBRP cask. A potential problem for a cask made from stainless steel would be stress-corrosion cracking (SCC) induced by the combination of residual and the presence of even small amounts of chlorides. SCC would be accelerated by the relatively high temperatures (above 100°C) on the outer surface of the cask. Residual stresses could result from welding (such as the welding of cooling fins) or handling (loading and shipping). Sufficient chlorides to induce cracking in the presence of stress are available from road salts or near-ocean environments.

Ferritic steels in either a tempered martensitic or bainitic condition are often susceptible to a form of embrittlement that occurs in the 350° to 500°C range. This form of embrittlement is associated with the segregation of impurities to grain boundaries. Such embrittlement can degrade the impact toughness of ferritics such as A508 or A543/HY80 to a value near that of plain carbon steels. Embrittlement of this type may require only a few hours at temperature for low-alloy ferritics. Reducing impurity levels and increasing grain boundary area (reduce the grain size by mechanical working for example) are effective ways of avoiding this embrittlement. The size of the CRBRP cask may make these control methods difficult to employ.

Temperatures at the outer wall of the canisters are currently projected to be above 450°C. This is in the creep range for stainless steels. Regulatory Guide 7.6 (Reference 27) specifically does not consider design for creep in its recommendations. The stress design allowances are based on materials data from Section III of the ASME Code (Reference 28) which gives data only to 425°C for austenitic stainless steels. A potential design rule problem thus exists, and it may be necessary to incorporate some procedures and criteria from elevated temperature design codes (Reference 37).

4.3 Structural Analyses

The structural analyses to date can be divided into three main areas: sizing of components, basket lid seal analysis, and the hypothetical punch of the cask outer lid. The parameters for the analyses come from the accident conditions provided by Reference 10. The geometrical orientation of the cask or alternate concept which would create the maximum detrimental effects was used for each analysis. In addition, a three-dimensional corner drop analysis was initiated, but not completed.

The structural calculations to size the necessary bolts for an end-impact accident have been completed. These include the BL bolts and the basket retention bolts. The analysis of the BL shows that the seals may release in an end impact, but possible changes of the system could be explored to alleviate this problem. A more accurate representation of the canisters hitting the BL could be incorporated into the model. The analysis of the COL shows that the lid will survive the punch accident. Further analysis should be done to detail the connection of the COL to the cask. The analysis should be done for the corner drop, and should be done with an appropriate three-dimensional code.

4.3.1 Sizing Calculations

The sizing of the basket retention bolts and the BL bolts was the first analysis, and the end drop of 9 m (30 ft) onto an unyielding surface was seen to be the worst case for these components. The computer code SHELL SHOCK (Reference 38) was used to determine the loads on the lid and basket bolts. This code has dynamic and axisymetric capabilities.

The model used a cask body of 304 stainless steel and had the mass of the canisters distributed on the BL. A sample of the accelerations caused by the canisters on the lid is shown in Figure 4-21. The analysis showed that an average of 520 g of deceleration was seen by the BL and 385 g was seen by the basket bolts. These accelerations provided the design load for the bolts in the two locations. A total of 20 bolts, 63.5 mm (2.5 in.) in diameter were required for the BL, and 30 bolts, 50.8 mm (2.0 in.) in diameter were required for the basket.

The load necessary to make up the seals on the canisters was checked and found not to be critical.

4.3.2 Basket Lid Seal Analysis

The BL was analysed to determine seal effectiveness during the end-on impact. Failure would occur if the bending deformation of the lid was sufficient to separate the seal from the seal surface. Using the forces from the SHELL SHOCK analysis for the sizing calculations, an axisymetric model of the BL was developed. HONDO II (Reference 39), a dynamic, axisymetric large deformation, finite element computer code was used for the analysis.

The BL design consisted of a 304 stainless-steel body with a depleted uranium insert for shielding.

The analytical model of the BL used a sliding interface between the steel and the uranium. Figure 4-22 shows the finite element mesh used for the analysis in the undeformed state. Figure 4-23 shows the deformed finite element model at maximum deformation. The depleted uranium insert is recognizable in the deformed mesh as the center layer that deformed as a unit discrete from the steel casing.

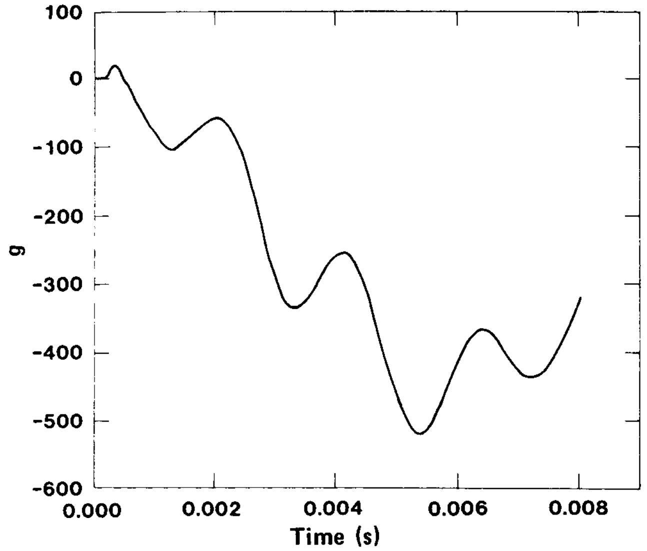

Figure 4-21 Axial Acceleration of Basket Lid in End Impact, 9-m (30-ft) Drop

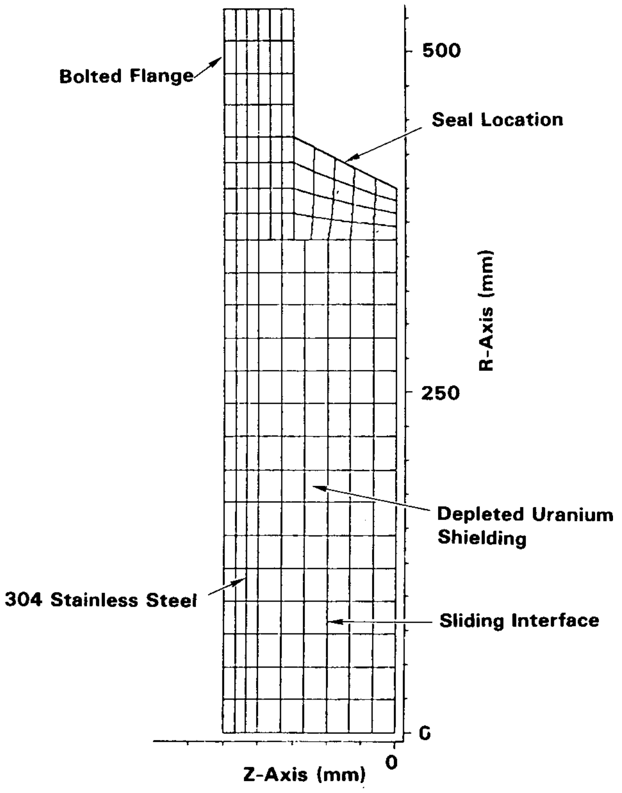

Figure 4-22 Undeformed Mesh of Basket Lid, Room Temperature

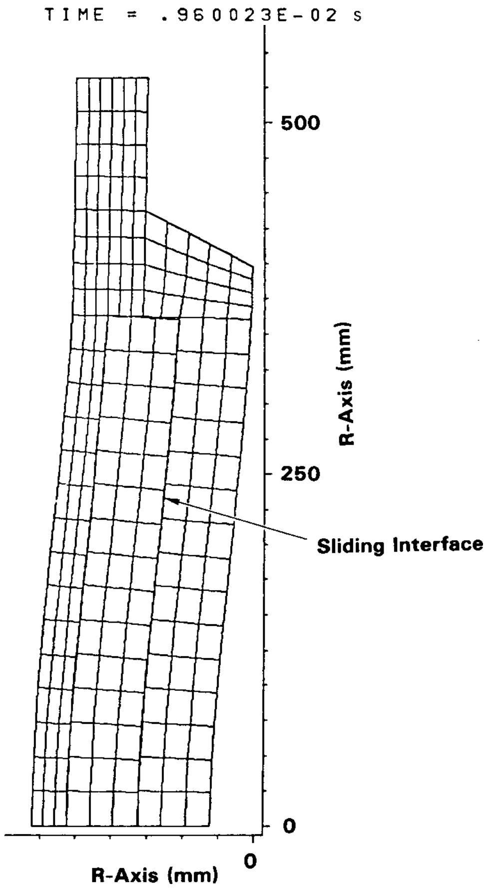

Figure 4-23 Maximum Deformation of Basket Lid Mesh for End Drop Analysis

The centerline deflection of the BL was 32.8 mm (1.29 in.) and the seal area deflection was 3.0 mm (0.12 in.). This seal deflection is approximately twice the allowable for the type of seal proposed. This means that with the current configuration, the BL will release and then possibly reseat during the end-on impact. This could be remedied by inserting some form of energy absorber between the canisters and the BL, thus reducing the peak accelerations felt by the BL during the accident. This change should be investigated in future design efforts.

4.3.3 End Punch Analysis

The purpose of the end punch analysis was to determine if the COL would survive the hypothetical puncture test of 10CF71 (Reference 10). The COL is not sealed so the only criteria for the analysis is that the COL protect the inner components of the cask. The computer code HONDO II was used again and an axisymetric model was created. The initial velocity of the cask was the controlling parameter for the analysis.

Figure 4-24 shows the finite element mesh used. The COL and shoulder of the cask were modeled as they exist in the design, and the large rectangular region has the density to give the model the same mass as the cask. This insures that the model has the same total energy as the cask system. Figure 4-25 shows the finite element model at maximum deformation.

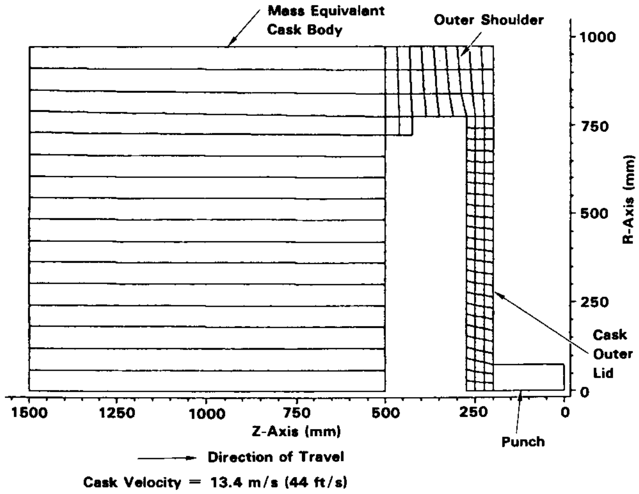

Figure 4-24 Undeformed Mesh for Punch Analysis

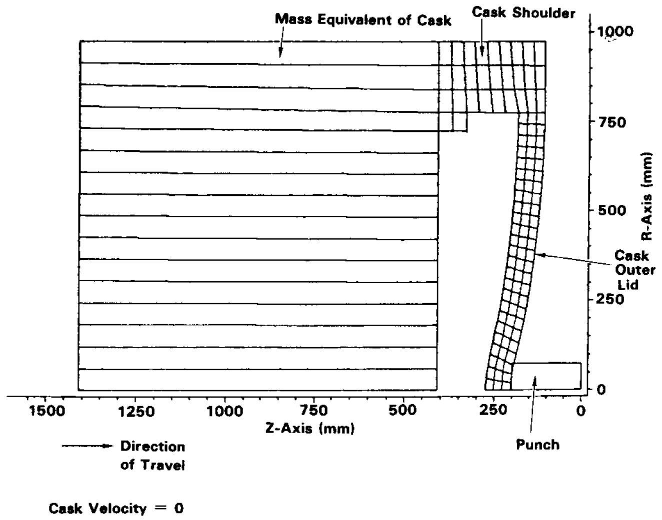

Figure 4-25 Deformed Mesh of Cask for Punch Analysis

The analysis shows that the maximum centerline deflection of the COL was 93.2 mm (3.67 in.). The COL undergoes large deformation but the stresses are not unreasonable as the yield zone is localized around the punch and the COL will survive the accident.

4.3.4 Canister Assessment

Canister analysis and testing is described in detail in Reference 40.

A summary of the test work, which was performed as part of a generic SNL/TTC activity prior to the FY81 conceptual design study, follows. Prototypes similar to the mechanically sealed, bolted lid canister described in Section 3.1 were built for testing, using a Haskell K® seal. Also built were fuel subassembly mockups that had the mass, moment-of-interia, and center-of-gravity location approximately equal to those of a real subassembly. Analyses indicated that, for the 9.1-m (30-ft) free drop which is the first test for qualification of the canisters as special form, the coolant (liquid sodium) property of concern was the acoustic impedance (product of density and acoustic velocity). This was matched with a mixture of glycerine and methanol.

Free drop tests were conducted at ambient temperature onto the SNL Old Cable Site Hard Target. One canister was dropped in two different attitudes successively, 0 and 45 deg (closed end down). Another canister was dropped at 90 deg (side-on).

In each case, the canister body was bent and swollen but there was no apparent cracking, buckling, or tearing. The mechanical seals leaked after the test, so this particular brand of seal should be removed from further consideration. Figures 4-26 through 4-30 show test photographs.

4.3.5 Trunnion Analysis

As mentioned earlier, detailed design of the cask tiedown to the railcar was not completed due to lack of information on the specific railcar to be used. However, the trunnions for the cask were sized to ensure that fabrication was possible and that the completion of a final trunnion design would present no appreciable problems.

The tiedown loadings caused by railcar coupling were determined by using a method developed by the Military Traffic Management Command Transportation Engineering Agency (MTMCTEA), Department of the Army (Reference 41). The assumptions used in applying this method are listed below.

1. Hammer car (transport vehicle) empty weight—36,320 kg (80,000 lbm)
2. Anvil car (vehicle at rest) loaded weight—119,400 kg (263,000 lbm)
3. Impact velocity—19.3 km/hr (12 mph)
4. Cask weight—95,340 kg (210,000 lbm)
5. Standard couplers on both cars.

Applying this method with a safety factor of 2 results in g-loadings of 11.8, 4.7, and 2.4 in the longitudinal, vertical, and transverse directions respectively.

While these loadings agree with regulations (Reference 10) in magnitude, they do not agree in direction. In view of the discrepancy, the trunnions were designed according to the more realistic loadings and then checked to verify that they satisfied the regulations as well. The trunnions sized were shown in Figure 3-16. Again, the concentric design is not the current conceived design.

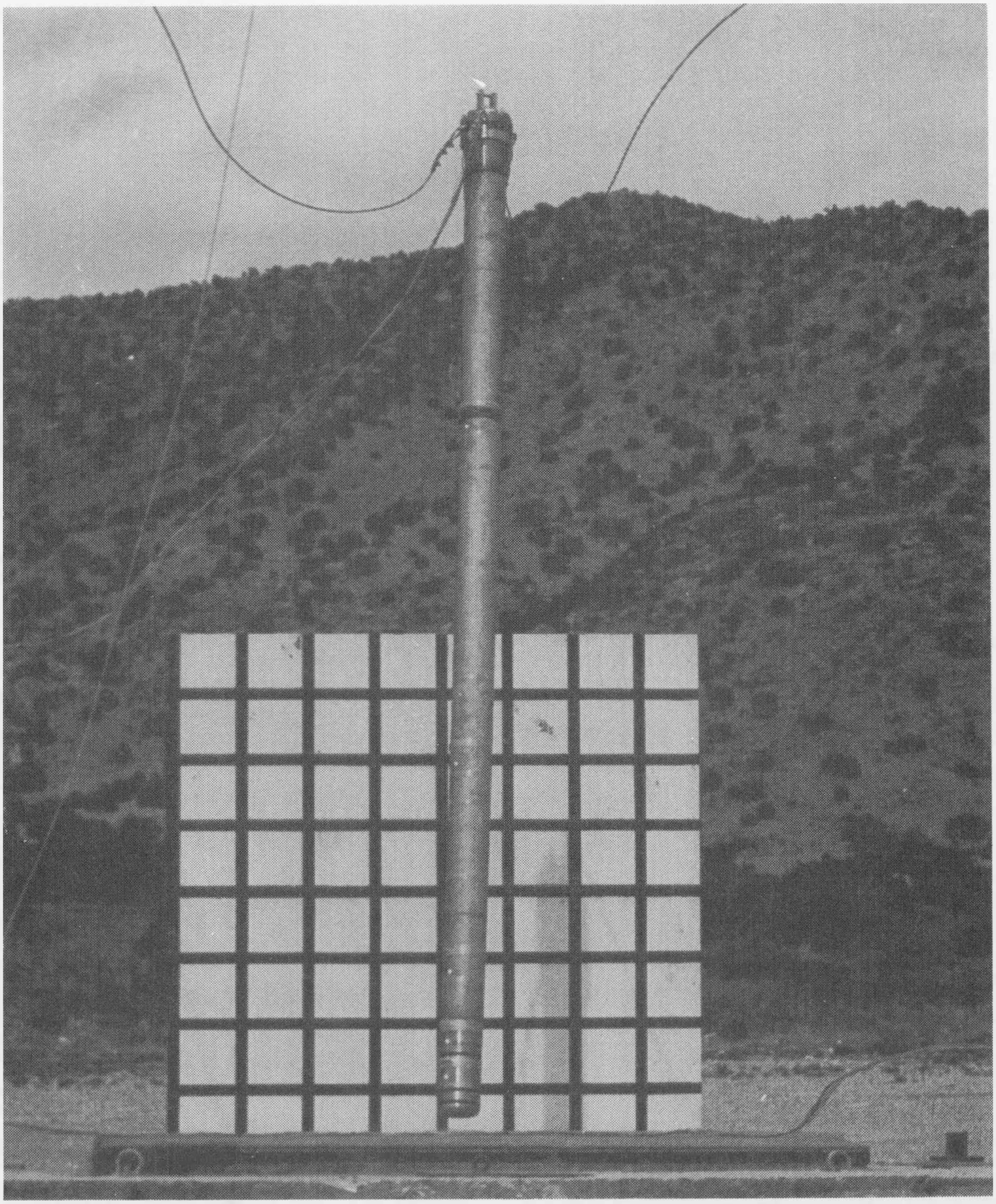

Figure 4-26 Canister With Surrogate Fuel and Coolant During Rebound, End-On Impact

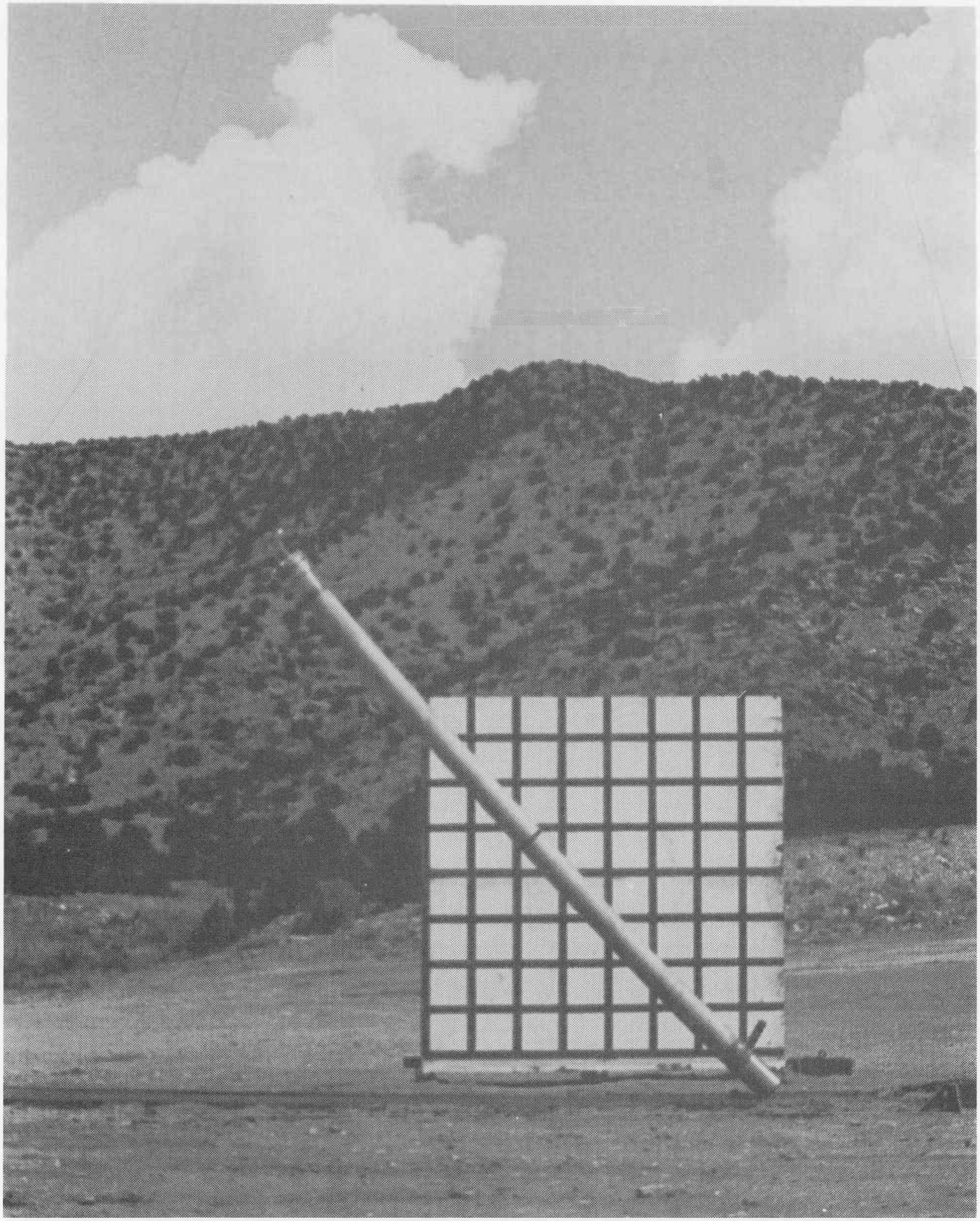

Figure 4-27 Canister With Surrogate Fuel and Coolant at 45-Degree Impact

Figure 4-28 Canister After Two End-On Impact Tests

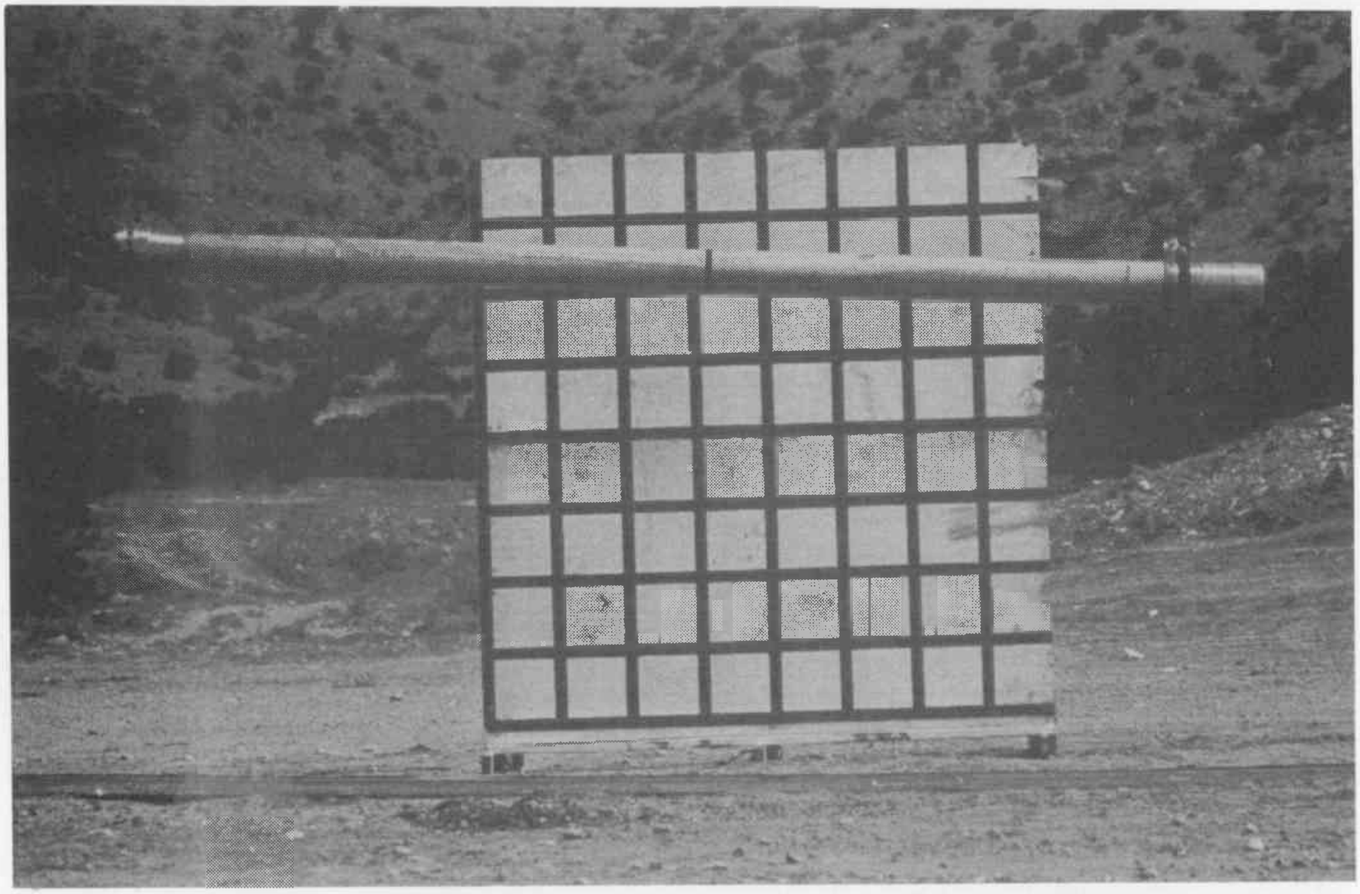

Figure 4-29 Canister in Free Fall Before Side-On Impact

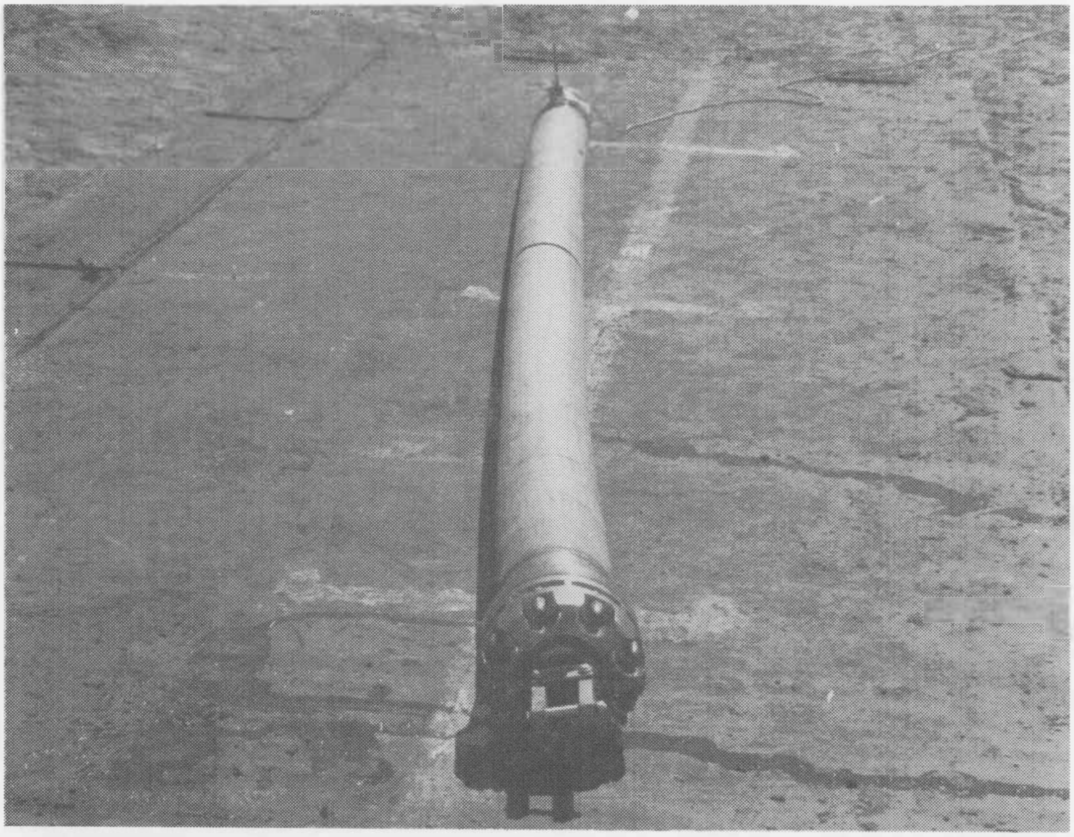

Figure 4-30 Canister After Side-On Impact

4.3.6 Lift Fixture Analysis

The lift fixture for the CRBRP spent fuel shipping cask shown in Figure 3-18 was designed according to the provisions of NUREG-0554 (Reference 18). It is specified therein that the fixture must be "designed or selected to support a load of three times the load (static and dynamic) being handled without permanent deformation." In the case of the CRBRP cask, the static load was taken as a conservative estimate of the cask weight or 95,450 kg (210,000 lb). Then, assuming that the slack in the secondary lift system was negligible, the total load (static and dynamic) was found by doubling the static load. The design load was then established as being three times the total load or 572,700 kg (1,260,000 lb). The lift frame members were next sized by assuming that the fixture was a truss work (with pinned joints) and would be constructed of mild steel that has a yield strength of 250 MPa (36,000 psi). Since it was the intent of this design effort to establish a 40% confidence level in the lift fixture, there was no need to complete a detailed analysis of all the welds and joints at this point. However, it is believed that the fixture is currently over-designed and an appreciable reduction in weight will result from a complete detailed analysis.

4.3.7 Impact Limiter Analysis

By dissipating the impact energy in a 9-m drop test through elastic and plastic body deformation, the conceptual cask design philosophy assures that impact limiters would not be required. The advantages of this philosophy are that

1. The diameter of cask system for shipping is small
2. Heat rejection from cask ends during shipment is possible
3. The number of handling operations is decreased.

Disadvantages of this philosophy are that

1. Elastic/plastic design criteria for cask body are not state-of-art
2. Higher g-loads to cask and contents occur and higher stress levels result when impact limiters are not used.

As the cask design progresses, it may be found that impact limiters will be desirable or even required for obtaining a certificate of compliance. In order to assess the effect impact limiters would have on cask weight and dimensions, the size of removable bulk impact limiters was estimated. Bulk impact limiters generally would be geometrically larger than fin-type limiters, but, through proper design, their performance can be made independent of impact orientation. For the purpose of the initial analyses, it was assumed that

1. One impact limiter would be used at each end of the cask (see Figure 3-21)
2. End-on and side-on impacts would control the general features and size requirements of the impact limiters
3. Grain-oriented redwood would be used as the impact limiting material as was done in Reference 42
4. The kinetic energy of the cask system must be less than or, as a limit, equal to, permanent deformational energy of bulk material involved in the impact
5. The deformational energy capability of steel encasing the bulk material was ignored
6. The deformation of bulk limiter material is uniaxial and one-dimensional
7. Only deformational energy to "lockup" of the bulk material was considered (beyond "lockup", large forces are transmitted through the material to the protected package)
8. Since the specific deformational energy is temperature-dependent, the lowest value over the expected service temperatures was used.

The method used for determining the volume of redwood involved in each impact is shown schematically in Figure 4-31 for the end-on impacts (both top and bottom) and in Figure 4-32 for the side-on impact. Load spreaders 50 mm (2 in.) thick were assumed (Figure 4-31) to extend the load to the proper diameter for the bottom end impact, and to the proper length for the side-on impact. Detailed sizing calculations were not made of the load spreaders.

The results of the scoping calculations are summarized in Table 4-7. The energy-absorbing properties of redwood were obtained from Reference 42. For the side-on impact, an angularity correction of cos 45 deg was used in the energy-absorbing term to account for the portions of the impact limiter volume involved in crush-up where the redwood grain is not perpendicular to the impacted surface. A similar angularity correction was used in Reference 42.

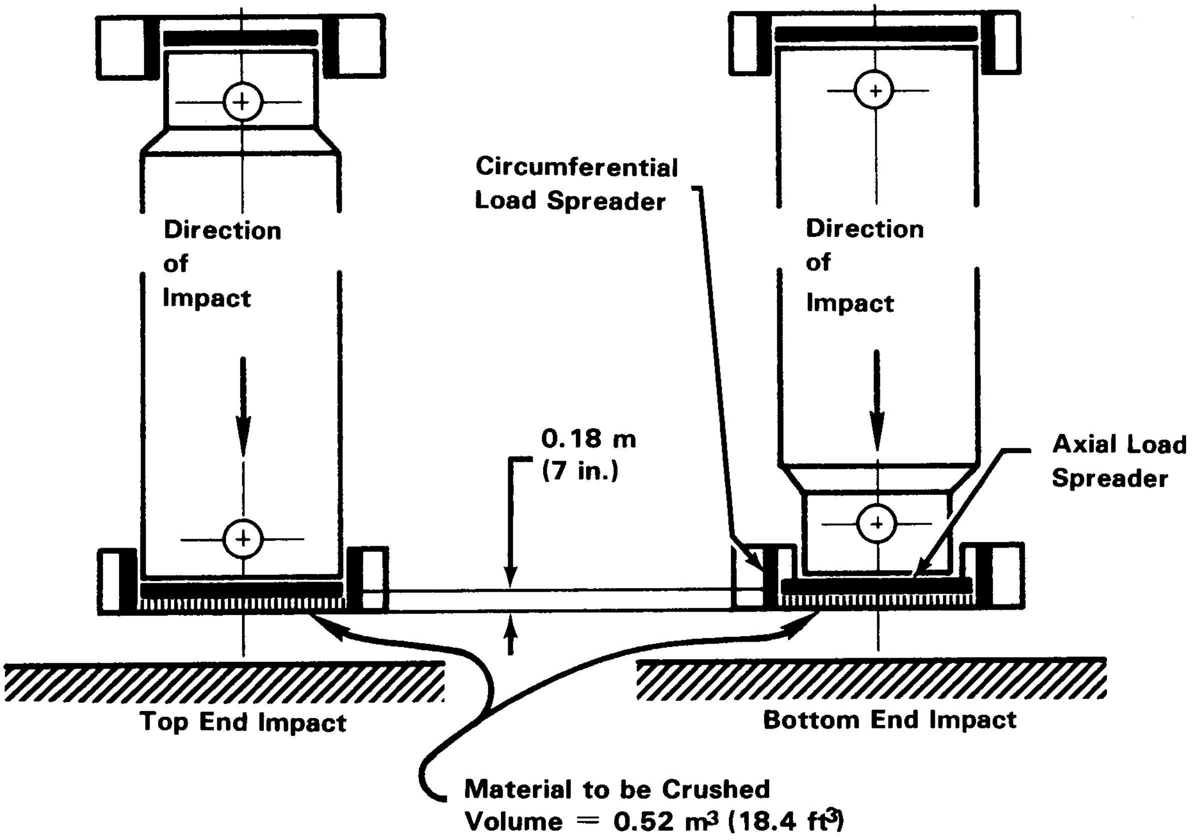

Figure 4-31 Impact Limiter Assessment Showing Bulk Material Involved in End-On Impact

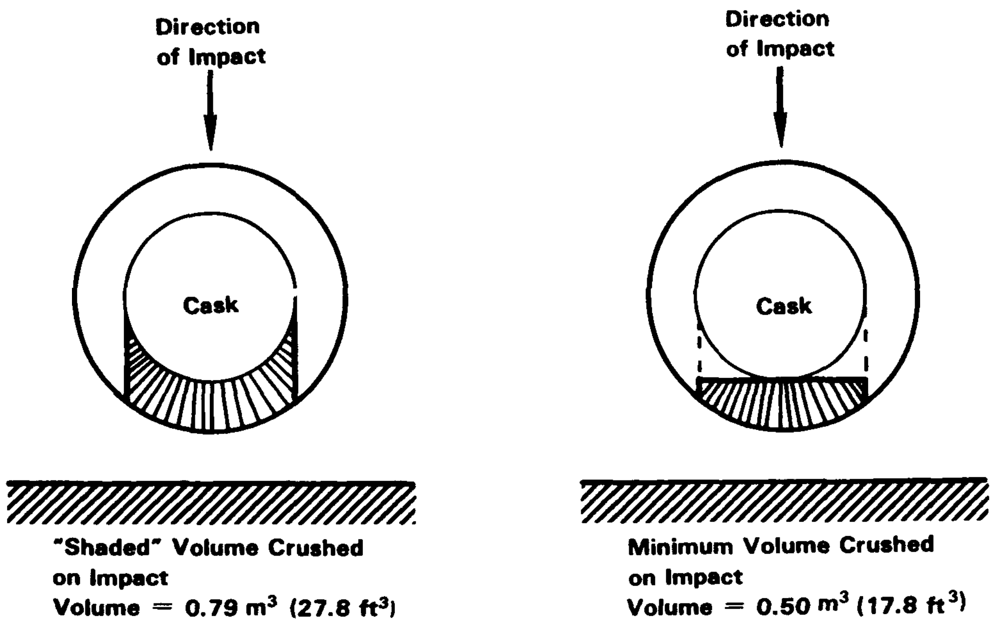

Figure 4-32 Impact Limiter Assessment Showing Bulk Material Involved in Side-On Impact, Bounding Cases

Table 4-7 Impact Limiter Assessment

	Energy [kJ (ft-lbf)]	Percent Excess Energy Absorption
Kinetic energy of cask and limiters to be absorbed in 9-m (30-ft) drop (90.8 + 5.8) tonne x (9 m) x (9.8 m/s^2)	8,649 (6.4 x 10^6)	—
Energy absorbed by redwood impact limiters during end-on impact (0.52 m^3) x (360 kg/m^3) x (66.6 kJ/kg)	12,470 (9.2 x 10^6)	44
Energy absorbed by "shaded" volume of limiter during side-on impact (cos 45 deg) x (0.79 m^3) x (360 kg/m^3) x (66.6 kJ/kg)	13,390 (9.9 x 10^6)	55
Energy absorbed by minimum volume of limiter during side-on impact (cos 45 deg) x (0.5 m^3) x (360 kg/m^3) x (66.6 kJ/kg)	8,476 (6.3 x 10^6)	0

The results of the calculations show that a set of redwood impact limiters can be designed as shown that will successfully cushion impact loads in the cask. For the design illustrated in Figures 3-21, 4-31, and 4-32,

1. The length of cask system would increase 8%, from 5.35 to 5.76 m (210.5 to 227 in.),
2. The diameter of cask system would increase 50%, from 1.93 to 2.89 m (76 to 114 in.),
3. The mass of cask system would increase 6%, from 90.8 to 96.6 tonnes (100 to 106.4 tons), compared to a system with no impact limiters.

4.4 Thermal Studies

Thermal studies included assessment of normal and off-normal conditions during transport and in-plant handling. Normal transport conditions used in the analysis conformed to environments as in regulations. In-plant conditions examined were cooling water requirements during loading, time restrictions on the purging of cell argon in the basket cavity before helium backfill for transport, and time limits on cooling water shutoff at the shaft. Off-normal environments studied were a loss of cooling during loading (before helium backfill) and the regulatory fire.

Thermal calculations showed that a number of possible configurations exist that meet regulatory interface and fabrication requirements. The analyses however, are based on certain assumptions derived from an inadequate experimental base. Specifically, the heat transfer mechanisms of the sodium (liquid and/or solid) within the canister are of primary importance, yet information on this is sketchy. Even given these limitations on the analysis, several options appear satisfactory.

4.4.1 Modeling Assumptions

The cask design presents two areas of difficulty in thermal analysis: the performance of the external finlets in the various orientations and the convection/ conduction heat transfer in the liquid sodium within the canister. Both are situations where data are insufficient to accurately define performance.

The external finlet performance was to be assessed through the Phase II neutron shield tests described in Section 4.2.3, which terminated at the end of FY81. In the interim, the external heat transfer was modeled by using film coefficients corresponding to vertical or horizontal orientations of cylinders. These, in turn, were used in computing standard fin efficiencies to obtain effective convective area. Radiation from external finned surfaces accounted for effective shading caused by fin length and spacing.

Because the heat output of the assembly is concentrated in a 0.9144 m (36 in.) length near the middle of the assembly, some method of axial thermal source-spreading is required. In this case, liquid sodium in the canisters serves this purpose. The heat transfer within the canister has not been specifically modeled. Instead, some assumptions based on limited experimental data have been made in the areas of axial source-spreading, radial temperature differences, and sodium solidification and remelt in shipping configurations. Because experimental data on the effects of ullage (void spaces) when in near horizontal orientations do not exist, no correction for this was made.

The bulk of experimental data consists of work done at Karlsruhe, Federal Republic of Germany (FRG) (Reference 43), while limited data exists from Oak Ridge National Laboratory (ORNL) (Reference 44). A summary of test facility dimensions is shown in Table 4-8. Furthermore, configurations of the tests differed from the proposed shipping configuration in that all tests have been run with the assembly and canister co-axial, with uniform boundary conditions and with canisters full of sodium. In the cask, the fuel assembly will rest on the canister bottom, with circumferentially varying boundary conditions and with ullage above the sodium.

Table 4-8 Summary of Thermal Tests in Electrically Heated Mockups and Comparison to CRBRP Geometry

	FRG Test Facility	ORNL Test Assembly	CRBRP Fuel Assembly
Number of fuel pins	169	217	217
Hex diameter	100 mm (4.3 in.)	125 mm (4.92 in.)	121mm (4.745in.)
Fuel pin diameter	6 mm (0.24 in.)	6.4 mm (0.25 in.)	5.8 mm (0.23in.)
Total assembly length	3205 mm (126 in.)	5385 mm (212 in.)	4267 mm (168 in.)
Length of zone above heated length	810 mm (31.9 in.)	1830 mm (72 in.)	1306 mm (51.4 in.)
Length of heated zone (fuel zone)	950 mm (37.4 in.)	1220 mm (48 in.)	914 mm (36 in.)
Canister inner diameter	168 mm (6.6 in.)	204 mm (10 in.)	165 mm (6.5 in.)
Number of tests in sodium	98	15	N/A

Still, some general observations of the heat transfer can be made from these data. The pin temperatures increase as the angle of orientation increases from horizontal to vertical. This is due to the decreasing convection effects (and therefore decreasing efficiency in source-spreading) in the sodium as the assembly approaches the vertical. Indeed, a bare canister in the vertical has solid sodium or at least "dense zones" in the lower portions even with power outputs of up to 12 kW (Reference 43). From the FRG data, approximate source-spreading factors have been developed. A summary of these data is seen in Table 4-9.

The cask configuration differs from the test in that the cask provides more thermal resistance than that used for the insulated tests. This results in an uncertainty of bottom end sodium solidification and therefore the validity of these spreading factors is questioned.

In the analytical model, an equal spread of one-third heat output per one-third length of assembly was assumed when in the horizontal. In the vertical position, an initial distribution of 15% in bottom, 45% in middle, and 40% through top was used. The bottom third of sodium was assumed to be solid initially (before loading) but was allowed to undergo a phase change to liquid, after being loaded, followed by a redistribution of heat equal to the horizontal configuration. In some cases, this change of phase and attendant change in source spreading was not allowed. These were considered conservative conditions.

Radial heat transfer in the canister is of primary importance in determining maximum pin temperatures. The tests in this case have not examined the effect of ullage. In the horizontal position, a film of argon gas may run the length of the canister above the assembly. While the assembly itself will not be uncovered, it will reduce the canister wall area in contact with sodium by approximately 15%. This, in turn, is likely to cause a rise in pin temperature. One possible way to avoid this situation is to ensure tilting of the canister, thus driving the ullage to the end of each canister (away from the heated zone). This may solve another yet unexamined problem. If a pin should rupture, releasing a fission gas bubble while the fuel assembly is in the horizontal, that bubble is likely to stay at that spot. Sodium is then absent from the area, which could cause overheating in adjacent pins and further ruptures. It has been suggested that this cascading failure may be avoided by tilting which would force movement of the bubble away from the fuel zone to the upper end and out of the assembly. No data exist to support or refute this idea, but tilting of 5 to 6 deg is assumed.

Although there are uncertainties due to ullage in the real case, data from tests with no ullage have been used to approximate radial heat transfer from the canister wall to the hottest pin. The FRG tests indicate a maximum radial temperature difference of 20° to 35°C for the 6 to 8 kW range. The ORNL tests did not cover this heat output range but are consistent with the FRG data in the 4 to 6 kW range. Above 8 kW, results of the two tests differ.

Table 4-9 Estimated Axial Distribution of Radial Heat Transfer From Canister in Vertical and Horizontal Orientations*
(Decay Heat Output = 6 kW; Sodium Coolant)

		Percent Heat Rejected From		
Configuration	Orientation	Above Heated Zone	Heated Zone	Below Heated Zone
Reduced sodium level, no insulation	Vertical**	26	65	9
No insulation	Vertical**	39	52	9
Insulation	Vertical	37	48	15
No insulation	Horizontal	23	29	48
	Horizontal	23	28	49

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*Based upon data from Reference 43

**Sodium solidified in base of canister

4.4.2 Thermal Model

The thermal model was a two-dimensional, 30-deg, pie-shaped wedge of total cask length. Thus, circumferential variations were neglected. The cask length was divided into six axial stations, three of which contained heat sources representing the assemblies. A composite node was created of canister, assembly, and sodium at the three middle axial stations. These nodes contained the appropriate mass and capacitance for the material as well as heat generation to model the assembly. There was no radial temperature difference from canister wall to hottest pin modeled. Rather the assumption was made that this rise would be 20° to 30°C as indicated by experimental results with this adjustment made outside the model. Any axial convection within the sodium was not explicitly modeled. These effects were taken into account by spreading the heat generation of the assembly among the three axial stations in the manner already discussed.

The modes of heat transfer primarily are conduction through metals except at the canister/basket interface, basket/cask interface, and external surfaces. The gap between canister and basket is filled with a gas (argon during loading, helium for transport). At the basket/cask gap, heat is transferred by means of conduction in helium and radiation. The external rejection of heat is radiation and convection from surfaces, some with fins, others not. Standard fin efficiencies were assumed for the finlets. In cases where impact limiters were assumed present, convection and radiation from ends was prohibited.

The code used was CINDA-3G, (Reference 45) a network analyzer code that solved both steady-state and transient problems. The model developed for this cask included a total of up to 101 nodes, some steady temperature, some with mass and capacitance, others used to determine intermediate temperature profiles. The connection between nodes included conduction heat transfer, radiation heat transfer, and convection. User-supplied data and cask specific programming completed the model.

For the normal transport analysis, a number of variables were considered. Among these were heat output per assembly (6 or 7 kW), cask and basket material, as well as the basic design either of one large monolith or separate basket and cask. For the analysis of the basket/cask concept, additional variables were the size of the gap (assumed uniform around the cask), between the structures, as well as the emissivity of those surfaces. The spacing and thickness of the interstitial fins of the neutron shield could be changed as could the spacing (and hence the number) of cooling channels. External heat rejection was affected by varying the external emissivity of the surface, the external finlet length, and the existence of a sunshield and/or impact limiters. Another parameter in the cases where the cask was vertical was the modeling of a phase change in the sodium of the bottom third of the canister. The effect of the phase change appears as a shift in source-spreading from the 15-45-40% combination to a 33-33-33% combination. These spreading factors were derived from test conducted by Prussman et al (Reference 43). Also assumed was a radial temperature rise of 20° to 30°C from canister wall to hottest pin.

4.4.3 Normal Transport Analysis

The thermal conditions during normal transport are 55°C (130°F) ambient with normal solar insolation. The maximum allowable pin temperature is 538°C (1000°F). Results of this study are shown in Tables 4-10 and 4-11. Radial profiles of selected runs showing the effects of the basket/cask gap and material selection are shown in Figures 4-33 and 4-34 respectively. Note that an increase in the number of cooling channels actually raises pin temperatures in normal transport due to the introduction of the additional air gaps. "A" refers to austenitic stainless steel, "F" to ferritic steel. The ferritic steel under consideration was HY80.

4.4.4 Normal In-Plant Analysis

One in-plant condition considered was heatup during loading. In addition to the plant imposed limit of 52°C (125°F) on cask handling surfaces, the ambient was assumed to be 27°C (80°F). The canistered assemblies containing solid sodium in the lower third of their length were assumed to be loaded at a rate of one per hour. Tables 4-12 and 4-13 show the results. The last columns of these tables show suitable water flow conditions and cask configuration combinations which satisfy temperature limits in the steady state.

After loading is completed, the argon cell gas would be replaced by helium for transport. During this purging, the heat transfer across the gap between the canister and basket wall would be primarily by radiation. This would cause rising pin temperatures. Table 4-14 shows results from an analyses of the time available before the argon must be replaced with the helium. Continuous cooling during this procedure has been assumed. A maximum time of 8 hr for the purging operation is indicated by these results.

Table 4-10 Assessment of Normal Transport Steady-State Temperature Conditions, Separate Basket and Cask Design

	Cask Concept					
Parameters	B-F2	A-A3	A-A3	A-A3	A-A3	A-A3
Heat load (kW/assembly)	7	7	7	7	6	6
Basket material*	A	A	A	A	A	A
Cask material*	F	A	A	A	A	A
Basket/cask gap (mm)	2.54	5.08	2.54	2.54	2.54	2.54
Basket/cask gap emissivity	0.8	0.2	0.8	0.8	0.8	0.8
Sunshield	Yes	No	Yes	Yes	Yes	Yes
Internal fin spacing (deg)	5	5	5	5	5	5
With or without impact limiters	Without	With	With	Without	Without	Without
External fin length (cm) (in.)	10.2 (4)	10.2 (4)	10.2 (4)	10.2 (4)	10.2 (4)	10.2 (4)
External emissivity	0.2	0.2	0.2	0.2	0.2	0.2
Cooling channel spacing (deg)	10	10	10	10	10	5
Surface temperature (°C)	140	170	150	145	135	135
Canister temperature (°C)	450	590	530	525	470	490
Pin temperature (°C)	470-480	610-620	550-560	545-555	490-500	510-520

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*A indicates austenitic stainless steel; F indicates ferritic

Table 4-11 Assessment of Normal Transport Steady-State Temperature Conditions, Monolithic Design

	Options			
Parameters	M1	M2	M3	M4
Heat load (kW/assembly)	7	7	7	7
Cask material*	F	A	A	A
Sunshield	Yes	Yes	Yes	Yes
Internal fin spacing (deg)	5	5	2-1/2	5
With or without impact limiters	Without	Without	Without	Without
External fin length (cm) (in.)	10.2 (4)	10.2 (4)	10.2 (4)	10.2 (4)
External emissivity	0.2	0.2	0.2	0.2
Cooling channel spacing (deg)	10	10	10	5
Surface temperature (°C)	135	145	145	145
Canister temperature (°C)	375	495	480	515
Pin temperature (°C)	395-405	515-525	500-510	535-545

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*A indicates austenitic stainless steel; F indicates ferritic

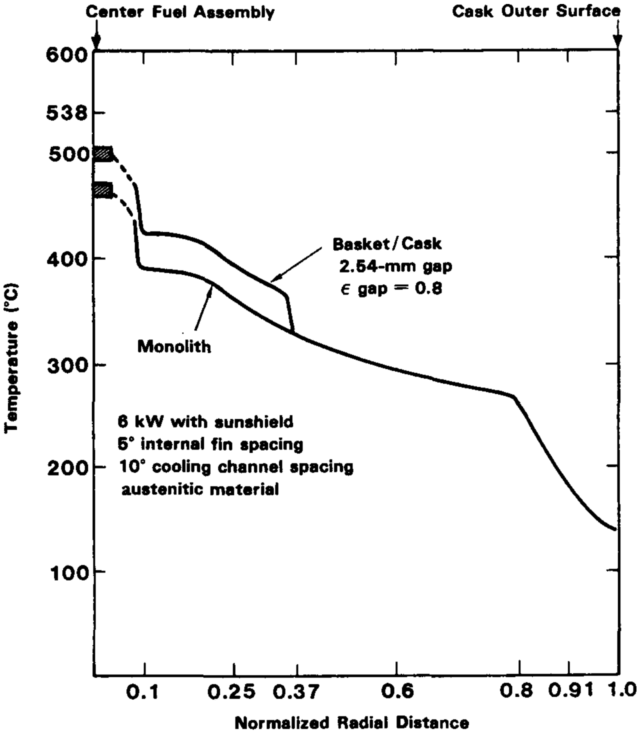

Figure 4-33 Effect of Cask/Basket Gap on Cask Radial Temperature Profile

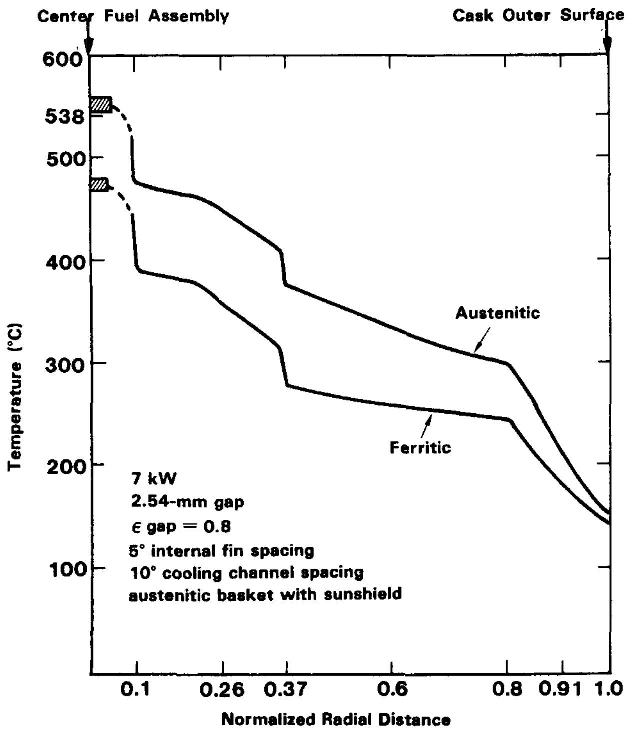

Figure 4-34 Effect of Material Choice on Cask Radial Temperature Profile

Table 4-12 Normal In-Plant Cask Handling for Basket/Cask Concept Heatup With Water Cooling for A-A3 Cask Concept

Parameters	A-A3 Cask Concept			
Heat load (kW/assembly)	7	7	6	6
Cask material	← — — — —Austenitic— — — — — →			
Basket/cask gap (mm)	2.54	2.54	2.54	2.54
Basket/cask gap emissivity	0.8	0.8	0.8	0.8
Flow rate (L/min)	48	48	48	48
Inlet temperature (°C)	32	6	6	6
Cooling channel spacing (deg)	10	10	10	5
Change of phase of sodium*	No	No	Yes	Yes
Time to reach canister limiting temperature (hr)	10	10	> 68	—
Time to reach limiting surface temperature (hr)	24	29	49	—
Steady-state surf temperature (°C)	N/A	N/A	N/A	40
Steady-state pin temperature (°C)	N/A	N/A	N/A	470-480
Comments	Was not run to steady state			Steady-state temperatures below limits

*Indicates whether source spreading factors were permitted to change during the calculation.

Table 4-13 Normal In-Plant Cask Handling for Monolithic Cask Concept Heatup With Water Cooling

Parameters	Monolithic Cask Concept						
Heat load (kW/assembly)	7	7	7	7	7	7	7
Cask material*	A	A	A	A	A	F	A
Flow rate (L/min)	48	48	48	48	480	48	48
Inlet temperature (°C)	32	6	6	6	6	6	6
Cooling channel spacing (deg)	10	10	5	10	10	10	5
Change of phase of sodium	No	No	No	Yes	Yes	Yes	Yes
Time to reach canister limiting temperature (hr)	11	11	11	> 46	> 59	—	—
Time to reach limiting surface temperature (hr)	23	29	>47	39	58	—	—
Steady-state surf temperature (°C)	N/A	N/A	N/A	N/A	N/A	45	45
Steady-state pin temperature (°C)	N/A	N/A	N/A	N/A	N/A	425-435	480-490
Comments	Was not run to steady state					Steady-state temperatures below limits	

*A indicates austenitic stainless steel; F indicates ferritic

Table 4-14 Normal In-Plant Cask Handling, Assessment of Time Limit for Evacuation of Argon Preceding Helium Backfill

	Cask Concept		
Parameters	A-A3	B-F2	A-A2
Heat load (kW/assembly)	6	7	7
Cask material*	A	F	A
Basket/cask gap (mm)	2.54	—	—
Basket/cask gap emissivity	0.8	—	—
Water flow rate (L/m)	48	48	48
Inlet Temperature (°C)	6	6	6
Time to reach pin and temperature limits for evacuated basket cavity (hr)	8	7	3

*A indicates austenitic; F indicates ferritic

After the cask is loaded, backfilled, and removed from the FHC, it is moved under the cask shaft. At this point, external cooling would be disconnected for raising the cask to the RSB. The cask body and surface immmediately begin to heat up and the times to reach temperature limits are given in Table 4-15 for the different cask configurations.

4.4.5 Off-Normal In-Plant Analysis

One possible off-normal condition would be a loss-of-cooling accident. In this case, it is assumed that the initial condition of the cask is the steady-state condition of the fully loaded cask with coolant flow and cell gas in the canister/basket gap. In this state, the water is carrying away approximately 90% of the heat generated in the fuel assemblies. At the start of this analysis the coolant is stopped, thus eliminating the primary heat removal path. The cask then slowly heats up. The temperature limitation may occur at either the pin or surface depending on the initial temperatures. The results are shown in Table 4-16. This analysis is important in determining off-normal recovery requirements. As shown in the table, a prolonged loss of coolant causes surface temperatures of the cask to exceed those normally allowed which may require different operating procedures for recovery. While these analyses were not run to steady state, it will need to be done to determine maximum pin temperatures and from that, whether backup cooling systems will be necessary to limit assembly damage.

Table 4-15 Normal In-Plant Cask Handling, Assessment of Time to Reach Temperature Limits at the Shaft After Forced Cooling Removed

Parameters	Cask Concept B-F2	 A-A3	 A-A2
Heat load (kW/assembly)	7	6	7
Cask material*	F	A	A
Basket/cask gap (mm)	2.54	2.54	—
Basket/cask gap emissivity	0.8	0.8	—
Flow rate (L/min)	48	48	48
Initial temperature (°C)	6	6	6
Cooling channel spacing (deg)	10	5	5
Tme to reach temperature limits after forced cooling terminated (hr)	3	7	5

---

*A indicates austenitic; F indicates ferritic

4.4.6 Off-Normal Transport Analysis

Regulatory thermal test conditions (Reference 10) require that a fully engulfing radiation/convection environment of emissivity 0.9 and 800°C (1475°F) for 1/2 hr be applied to the cask to obtain a thermal response. The model included a cask surface absorptivity of 0.8 and loss of the sunshield, amd impact limiters, thus permitting maximum exposure to the fire. Prefire conditions were assumed to be 38°C (100°F) ambient temperature and solar insolation, without sunshield, convection to still air and normal cask surface emissivity (0.2) in accordance with NRC Regulatory Guide 7.8. Prefire temperatures as well as maximum postfire pin temperatures are shown in Table 4-17. The regulatory fire has very little effect on the cask as a whole because its massive thermal capacitance delays and reduces the effects on cask internals. Postfire conditions were identical to prefire. No additional external cooling was applied.

Table 4-16 Off-Normal In-Plant Cask Handling Time Limits, Assessment of the Loss of Coolant With Fully Loaded Cask and Argon in Basket

Cask Concept Parameters	Cask Concept B-F2	 A-A3	 A-A2
Heat load (kW/assembly)	7	6	7
Cask material*	F	A	A
Basket/cask gap (mm)	2.54	2.54	—
Basket/cask gap emissivity	0.8	0.8	—
Flow rate (L/min)	48	48	48
Initial temperature (°C)	6	6	6
Cooling channel spacing (deg)	10	5	5
Time to reach tem perature limits following loss of coolant (hr)	2	6	4

A indicates austenitic; F indicates ferritic

Table 4-17 Pin Temperatures, Prefire and Postfire

Parameters	Cask Concept A-A2	 A-A3
Heat load (kW/assembly)	7	6
Material*	A	A
Basket/cask gap (mm)	N/A**	2.54
Basket/cask gap emissivity	N/A**	0.8
Cooling channel spacing (deg)	5	5
Prefire pin temperature (°C)	525-535	500-510
Postfire pin temperature (°C)	545-555	505-515

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*A indicates austenitic
**Monolithic structure; no gap.

4.5 Leak-Testing Assessment

It was assumed for this conceptual design that the proposed 10CFR71 (Reference 12) would have been adopted by the time licensing proceedings were begun, so sealing requirements were to be based on the proposed isotopic contents and their associated leak rates rather than on the present no release leak rate requirements.

The baseline conceptual design consists of two containment levels with independent boundaries. The innermost container is a canister that holds the spent fuel assembly and liquid sodium coolant. The canister is closed by a mechanical seal and bolted lid. The second boundary is formed by the basket that holds the canisters. The basket closure is also a mechanical seal and bolted lid. The cask closure is considered to be only a weather seal.

As part of the qualification for a containment level, a boundary must pass leak-rate tests. Boundary sections that are not disturbed during normal use are tested annually (Reference 12). Closures that are opened during loading or unloading are tested at each use. The following sections describe the closures and leak-testing more fully.

4.5.1 Canister Seal Assessment

Allowable leak rates for radioactive material shipping containers are set forth in the proposed 10CFR71 (Reference 12) as a function of the isotopes present in the contents. At this time it has not been determined what portion of the canister's isotopic contents would be in a form that could escape through a leak. Therefore, it was assumed for design purposes that 10CFR71 would require that the canister have no leaks. The NRC Regulatory Guide 7.4 (Reference 46) accepts the procedures and definitions set forth in ANSI N14.5 (Reference 47). This standard defines the practical minimum leak-test boundary as an air leak rate of 1×10^{-7} atm cm^3/s. That is, a leak rate of 1×10^{-7} atm cm^3/s or less, based on dry air at 25°C with an upstream pressure of 1 atm and a downstream pressure of 0.01 atm or lower, is accepted as being leak-tight.

Discussions were held with various seal manufacturers and users concerning possible seal types, materials, and problems for the canister lid. The consensus was that requirements for compatibility with the high operating temperature (450°C) and liquid sodium eliminated all common seal materials except fully annealed commercial pure nickel or 304 stainless steel. Several brands of metal seals were considered; among them were proprietary designs from Stanley Aviation, Gray Tool Co., Helicoflex Co., and Varian. The final selection should be based on results of evaluations being conducted by SNL under the TTC generic program.

Other comments by metal seal users (Fort St. Vrain, Argonne National Labs, Los Alamos National Lab, and Rockwell International) are that liquid sodium is quite difficult to seal, metal seal performance is dependent on sealing surface conditions and cleanness, and chances for a successful, remote makeup may only be about 50% because of the difficulty of properly cleaning and inspecting the surfaces. Generally, the manufacturers' engineering staffs do not recommend seal-reuse.

The baseline concept is that the canister seal surfaces will be inspected and refurbished as needed at or near the unloading facility (HEF). The seals, captive to the lid, will be replaced and the lids returned to CRBRP separately, outside of the cask. The canisters would be returned with cold, solidified sodium so a "return lid" with nonmetallic seals would be sufficient to meet containment requirements.

Figure 4-35 shows a cross section of the lid. Note that two seals are shown. The inner (primary) is the main seal. The outer (secondary) is not considered as a containment boundary but serves only to form a leak-test chamber around the primary seal. The leak-test procedure is discussed further in Section 4.5.4.

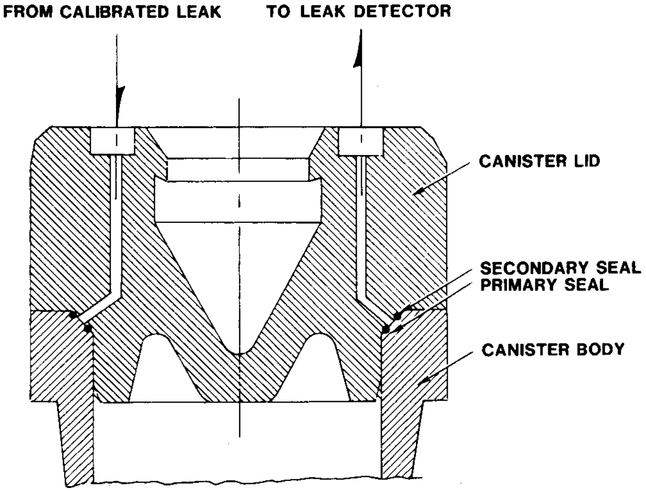

Figure 4-35 Canister Lid Seal and Leak Checking Arrangement

4.5.2 Basket Lid Seal Assessment

The BL, as the second containment boundary, was also assumed to be required to be "leak-tight" for the purpose of this study. Metal seals have been tentatively selected for the baseline concept because of estimated service temperatures (Section 4.4). It appears, however, that when more exact external film coefficient and fin efficiency data become available, thermal analyses may show peak temperatures below allowable limits for nonmetallic O-rings, which are preferable because seating surface conditions and tolerances are not as critical as for metal seals, and their cost is much lower.

As with the canisters, the concept includes captive seal replacement, inspection, and refurbishing the basket sealing surfaces at or near the unloading facility. The BL would be returned separately if metal seals are used, or, if nonmetallic seals are used, returned in the cask as the "return lid".

The primary-secondary seal configuration is again used to provide a leak-test chamber. The lid incorporates a valve used for purging and backfilling to fill the basket cavity with the desired gas, helium, or argon. This valve also has to be tested after final backfilling. The leak-test procedure is discussed further in Section 4.5.4.

4.5.3 Cask Lid Seal Assessment

Although the COL is not a containment boundary for the baseline, it is necessary to have a weather/dust seal to help keep the inside of the cask clean. This seal can be an elastomeric O-ring or flat gasket.

Inspection, service, and replacement can be done easily at CRBRP just before weather lid installation.

4.5.4 Leak Detection Methodology

Basically, a sensitive leak detector is used to compare a gas flow-rate signal caused by an unknown leak to the flow-rate signal caused by a known leak. The unknown leak rate may then be calculated since the detectors have an output that is linear with leak rate. Two detectors should be included in the system so one can serve as a backup for the other. The detectors must be capable of switchable selection between helium or argon as the test gas. It is proposed that the canister lid would be tested for argon leakage and the basket lid would be tested with helium (added to the basket to enhance heat transfer).

Because argon is the surround cell gas, leak-checking the canisters with argon may cause rejection of sealed canisters due to plumbing leaks. Maintenance procedures to check the plumbing will have to be determined and followed carefully.

Consideration was given to using helium as the canister test gas. However, it did not appear possible to add a known, verifiable quantity of helium to the canister without building a valve into the lid. This would have caused an undesirable increase in the complexity of necessary remote operations as well as providing another possible leak path.

The suggested canister and basket lid leak-test procedure is presented in detail in Appendix B.

4.6 Criticality Assessment

Criticality in the CRBRP cask was not addressed during the current study since in previous work (Reference 48) it was found that, when sodium is used as a coolant, K_{eff} is only about 0.6 for seven spent fuel assemblies in a cask. Criticality will need to be reassessed during the final design.

Chapter 5. Interfaces

During the development of the conceptual designs, a primary interface list was developed, and the expected confidence level of interface data were agreed to by both SNL/TTC and the CRBRP at the request and direction of the CRBRP. The agreed-to dates, however, could only have been attained if the cask development program continued on a properly funded basis. The primary interface list is shown in Table 5-1, which includes the plant interfacing system number, the description of the interface, the CRBRP document number, the number of the system that would maintain the document, and the dates on which various confidence or phase levels were expected to be reached. A list of all drawings developed is included as Appendix C.

Critical interface dimensions for the concepts developed in this report are shown schematically in Figures 5-1 and 5-2. It is expected that these dimensions will remain relatively unchanged as the design proceeds, except

1. Four trunnions will be located at the top end of the cask as shown in Figure 3-14
2. The lower trunnions, which serve as those support points about which the cask rotates on the rail cask, will be offset from the cask axis 50 to 75 mm (2 to 3 in.) to assist initial rotation of the cask toward the nearly horizontal shipping position during placement of the cask onto the railcar.

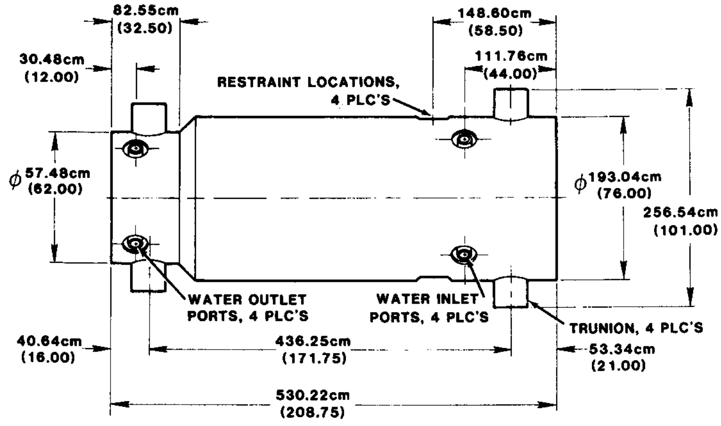

Figure 5-1 Critical Interface Dimensions for the B-F2 and A-A2 Concepts

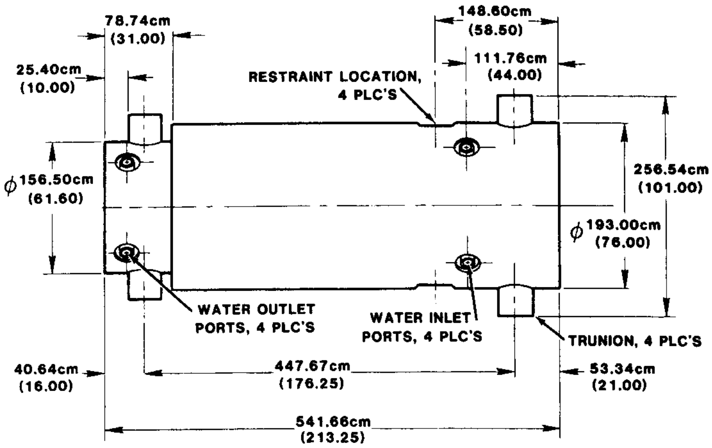

Figure 5-2 Critical Interface Dimensions for the A-A3 and A-F3 Concepts

Table 5-1 Primary Interface List

Interfacing System	Description and Top-Level Requirements of Interface	Document No. Controlling the Detailed Interface	System Maintaining Document	Expected Phase* Level of Interface Data			
				A	B	C	D
41	Canister geometric features	CL54030	41-8	9/81	9/82	9/83	TBD**
	Canister weight – loaded/unloaded	SAND81-2055		—	9/81	9/82	TBD
	Canister center of gravity			—	—	9/81	TBD
	Canister lid design	CL54032		9/81	9/82	9/83	TBD
	Canister identification			—	—	9/81	TBD
	Canister loading						
	• Heating requirement in cell			—	9/81	9/82	TBD
	• Sodium filling/draining requirements			—	9/81	9/82	TBD
	Canister decontamination & cleaning requirements			9/81	9/82	9/83	TBD
	Canister handling	CL54032					
	• Lifting points – sealed/unsealed			—	9/81	9/82	TBD
	Canister seal requirements			9/81	9/82	9/83	TBD
	Canister lifting & setdown points & loads						
	• Normal conditions			—	9/81	9/82	TBD
	• Accident conditions			9/81	9/82	9/83	TBD
	Cask/cell geometric features			9/81	9/82	9/83	TBD
	Cask/FHC seal makeup			9/81	9/82	9/83	TBD
	Temporary FHC storage requirements (lids, seals, etc)			—	9/81	9/82	TBD
	Basket seal requirements	CL54024		9/81	9/82	9/83	TBD
	Cask decontamination requirements			—	9/81	9/82	TBD
	Cask thermal (cooling) requirements						
	• Water						
	★Normal	SAND81-2055		—	9/81	9/82	TBD
	★Off-normal	SAND81-2055					
	– Service			—	9/81	9/82	TBD
	– Fixtures			9/81	9/82	9/83	TBD
	Cask accessible surface temperatures	SAND81-2055		—	—	9/81	TBD
	Cask sealing surface temperatures	SAND81-2055		—	9/81	9/82	TBD
	Sensor requirements						
	• Type			9/81	9/82	9/83	TBD
	• Location			9/81	9/82	9/83	TBD
	• Readout			—	9/81	9/82	TBD

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*

Phase	Confidence Level (%)	Description
A	40	Data generated in the conceptual design stage
B	70	Data generated in the preliminary and final design stages
C	90	Baselined data
D	99	Final design reviewed and released for fabrication

**To be decided

Table 5-1 (cont)

Interfacing System	Description and Top-Level Requirements of Interface	Document No. Controlling the Detailed Interface	System Maintaining Document	Expected Phase* Level of Interface Data			
				A	B	C	D
41 (cont)	Cask weight						
	• Loaded	SAND81-2055		—	9/81	9/82	TBD**
	• Unloaded	SAND81-2055		—	9/81	9/82	TBD
	Cask geometric features	CL54020					
	• Maximum envelope			—	9/81	9/82	TBD
	• Details			9/81	9/82	9/83	TBD
	Cask trunnions						
	• Number			12/81	9/82	9/83	TBD
	• Size			3/82	9/82	9/83	TBD
	• Location			3/82	9/82	9/83	TBD
	Cask center of gravity		41-8				
	• Loaded			—	9/81	9/82	TBD
	• Unloaded			—	9/81	9/82	TBD
	Corridor laydown area required for cask lids			—	—	9/81	TBD
	Dose rate measurement requirements			—	—	9/81	TBD
	Cask seal makeup requirements			9/81	9/82	9/83	TBD
	Cask/glove box seal interface			9/81	9/82	9/83	TBD
	Cask/purge/fill requirements			—	—	9/81	TBD
21A	Railcar	CL54035	41-8				
	• Enveloping load			—	9/81	9/82	TBD
	• Details			9/81	9/82	9/83	TBD
	Cask/railcar washdown requirements			—	—	9/81	TBD
	Crane/cask interface requirements						
	• Seismic			—	9/81	9/82	TBD
	• Rigging			—	9/81	9/82	TBD
	Cask weight — loaded/unloaded	SAND81-2055		—	9/81	9/82	TBD
	Cask geometric features	SAND81-2055		9/81	9/82	9/83	TBD
	Cask center of gravity			—	9/81	9/82	TBD
45	Power to move railcar/cask system		41-8	—	9/81	9/82	TBD
44	Laydown area for accessories		41-8	—	9/81	9/82	TBD
25	HVAC requirements		41-8				
	• Normal			—	—	9/81	TBD
	• Off-normal (thermal load, locally)			—	—	9/81	TBD

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*

Phase	Confidence Level (%)	Description
A	40	Data generated in the conceptual design stage
B	70	Data generated in the preliminary and final design stages
C	90	Baselined data
D	99	Final design reviewed and released for fabrication

**To be decided

Chapter 6. In-Plant Time and Motion Assessment

A detailed assessment was performed of the activities in the CRBRP involved with the handling and loading of the spent fuel shipping cask. The purpose of the assessment was to

1. Define the step-by-step procedure involved in loading the cask
2. Determine the average time required to load the cask
3. Assess the personnel exposure that will result from the loading operation
4. Identify any problem associated with cask handling.

6.1 Basic Conceptual Assumptions

Of the conceptual designs discussed in this report, the casks with three levels of containment—the A-A3/A-F3 concepts—would result in the greatest number of operations in-plant during loading and unloading. For this reason, the three-level containment concept was selected as the basis for the time and motion study to provide a definition of the greatest number of steps required, the most hardware, the longest cask turnaround time, and the greatest personnel exposure. With the A-A3/A-F3 cask, the canister, the basket and the cask all have lids with seals, each of which must be leak-tested and verified before shipment. This is the first time that the interface between the shipping cask and the CRBR facility has been evaluated, and only a superficial framework upon which to base detailed procedures is provided. As a result, all of the assumptions that were made dealing with the various operating steps, working times, and exposures tend to be conservative.

For this system, 127 steps were identified that must be accomplished in order to turn the cask around within the CRBRP. That is, individual operations were defined that would permit an empty cask received from the railroad at the CRBRP site to be loaded with spent fuel and released to the railroad for shipment. Each of the 127 steps were broken down into specific operations required, the operating staff considered necessary to accomplish the operations, the time required to complete each operation, and the exposure each staff member would receive from completing his operation. These results are summarized in Sections 6.5, 6.6, and 6.7. The most significant assumptions made in this study are

1. A cask system requiring three levels of containment formed the basis of this evaluation.
2. One hundred twenty-seven steps were defined as being required to prepare a cask to ship a full load of spent fuel after having received it empty of spent fuel.
3. The defined steps were assumed to be sequential, with no overlap of operations or staff workers.
4. The empty cask, when it is received at the CRBRP, will contain sealed canisters with contaminated sodium. These canisters will be removed before the canisters containing the spent fuel can be placed into the cask.
5. All spent fuel will be carried in sealed cans containing sufficient sodium to transfer heat from the fuel assemblies to the canister wall.
6. The cask is transported by a dedicated railcar.
7. A background radiation level of 0.2 mrem/hr was assumed throughout all facilities.*
8. Two 8-hr working shifts per day were assumed.
9. The maximum dose rate at the cask surface is 10 mrem/hr. Dose rates at the various locations around the cask are

a. Top and bottom surface	.....	1 mrem/hr
b. Side surface, cask middle	.....	10 mrem/hr
c. Side, 2 m from surface	.....	3 mrem/hr
d. Side, 4 m from surface	.....	2 mrem/hr

10. Staff operators/workers receive the greatest radiation exposures to their extremities. However, for this study, they will be considered the same as whole-body exposures.
11. Staff members will be limited to 125 mrem/quarter. Since there are 13 weeks in each quarter, any staff member's dose commitment should not exceed 10 mrem/week.

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*Personal communication with J. E. Rutenber, CRBRP Projects Office, Oak Ridge, Tennessee

12. The maximum number of shipments made in any year is assumed to be 29. Twenty-three of these will be fuel assemblies, while the balance will contain mostly blanket assemblies.

6.2 The CRBRP Facilities

The receiving, unloading, loading, and shipping of the CRBRP cask is accomplished adjacent to, and inside the RSB. The layout of the facility is shown in Figure 6-1. The RSB bridge crane is to be used for lifting all equipment from the railcar. Thus, tracks pass into the RSB to permit the interface between the railcar and the crane. The operating floor of the RSB is above the top of the hot cell used to store the spent fuel awaiting shipment. Since the spent fuel is to be lowered from the hot cell into the cask, a shaft has been designed from the operating floor to a tunnel, or corridor, that passes underneath the hot cell. This shaft and corridor provide the access required to the underside of the hot cell. The building design is such that the cask, once it is lifted from the railcar inside the RSB, cannot be set down on the floor because it exceeds floor loading limitations. It must be transported to the cask shaft and lowered down below the operating floor to be mated up with the cask transporter located in the cask corrider. The crane can then be removed and the cask is then free to move under the FHC. Once loading is accomplished, procedures are reversed to place the loaded cask onto the railcar and ship it off-site.

6.3 Cask Description for Time and Motion Study

A schematic drawing of the cask, including some of its main features, is shown in Figure 3-12. The cask was designed to carry seven spent fuel assemblies canistered in sodium. These assemblies were assumed to be fabricated from recycled plutonium, stored for 5 years, and irradiated to the maximum extent possible; they consequently have high radiation levels associated with them. The cask was designed to reduce the surface dose rate to a maximum of 10 mrem/hr. This was done and a description of that analysis is in Section 4.1.

Because the cask was assumed to be a basically right circular cylinder and the most radioactive section of the fuel is in the rather short 0.91-m (3-ft) core zone located about in the center of the fuel assembly, the dose rate falls off rapidly toward the ends of the cask. The isodose lines for total dose are shown schematically in Figure 6-2. The fully loaded cask configuration included depleted uranium shields in both top and bottom.

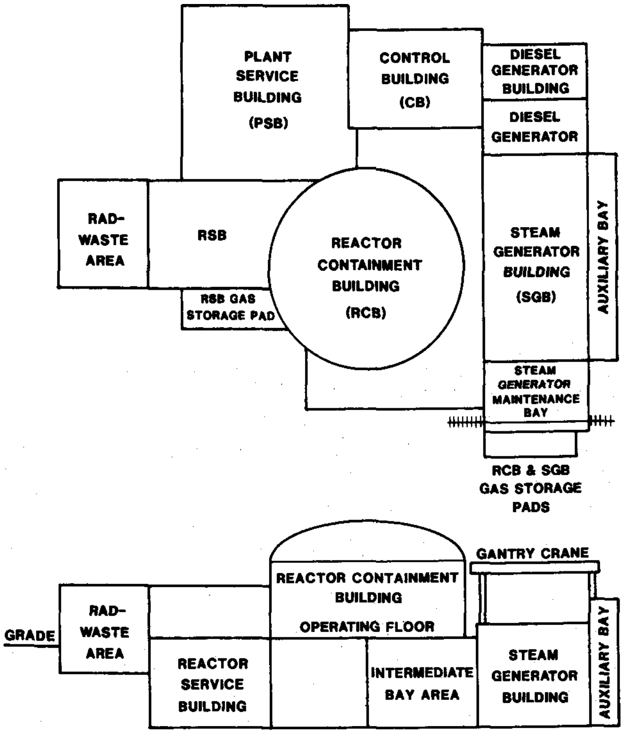

Figure 6-1 Layout of CRBRP Facility

The cask is assumed to have three levels of containment for the fuel provided by the canister, the basket and BL, and the cask and CIL. A COL has also been included in the design of the cask but it is intended to provide impact and weather protection to the BL and CIL and is not counted on for containment. Procedures call for the cask lids, but not the BL, to be removed before the cask is mated to the bottom of the FHC. The BL is to remain in place to provide shielding and a seal until the mating is accomplished.

The weight of the A-A3 cask is 95 tonnes loaded, and the B-F2 cask weighs approximately 92 tonnes loaded. Because this part of the study assumed the need for three levels of containment, the cask would be the heaviest, although such a weight variation would have a negligible effect on the 127 operating steps that were identified. However, the B-F2 concept would result in fewer operating steps since the CIL is not present. Furthermore, the A-A2 concept would result in the least number of operating steps since, not only is the CIL not present, but the cask/basket cavity does not exist and the cavity gas does not require verification before loading and shipping.

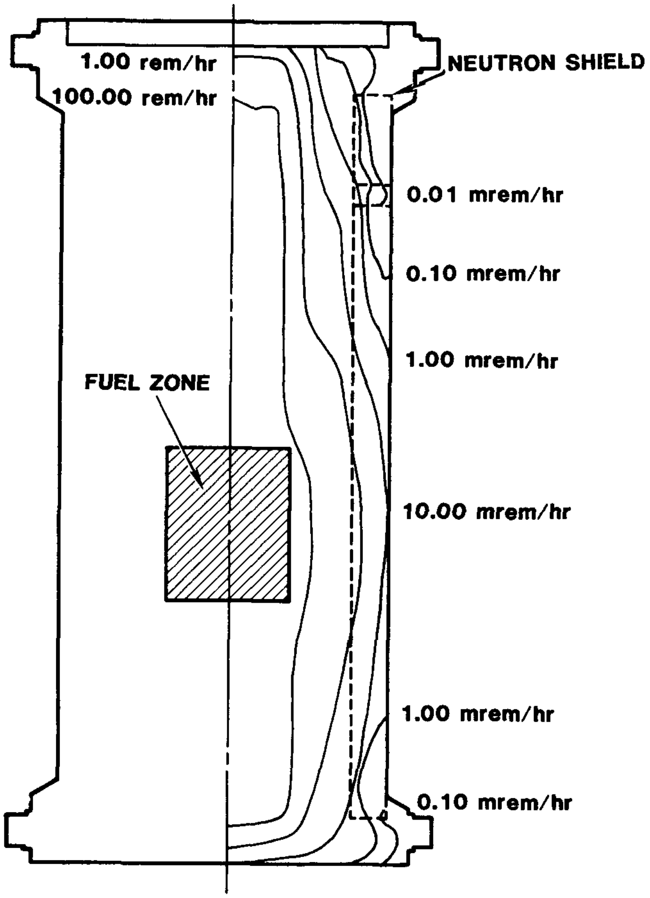

Figure 6-2 Isodose Lines of Cask

6.4 Normal Operational Procedures for Receiving and Shipping CRBRP Casks

The normal procedures for receiving, loading, and shipping spent fuel casks at the CRBRP were developed and studied. One hundred twenty-seven steps were identified; the details of each step were established, along with the type of person(s) that would be required to perform each operation within the step. No account was taken of proposed operating staff levels established by CRBRP personnel to accomplish other functions; once an operation was identified, the person required to accomplish it was assumed to be available. All operational steps are shown, along with a brief description (Figures 6-3).

It is important to note that all possible operating steps considered necessary to turn the cask around under the worst-case situation were identified. Should changes in the cask system occur, the dose to the operating personnel will be lessened. For example, should only two levels of containment be required for the cask, the CIL would disappear and with it, steps 35 through 42 and 95 through 102. Should the personnel barrier be designed to open like a clamshell on the railcar and without the aid of the RSB bridge crane, steps 6 through 8 could be eliminated.

Fuel loading is accomplished by moving the cask under the FHC and elevating it so that it can be sealed to the underside of the FHC (step 51). All cask lids except the BL containing the bulk of the shielding, will have been removed before the cask is elevated. Once the cask is sealed to the underside of the cell, both the cell floor plug and the BL are pulled up into the cell, exposing the cask internals to the cell atmosphere. The removal of the empty canisters and their replacement with loaded ones can then be carried out.

Details of the operations associated with elevating the cask and sealing it to the underside of the FHC are probably the most uncertain of all the operations that have been defined. Presently, there is very little space in which to work once the cask is in the position under the cell, but some hands-on operations will be required; seals must be verified, bolts must be removed, and a shroud to protect the seals must be installed. The time associated with these operations is the most uncertain and results in uncertainties in the associated doses.

These procedures need to be carefully examined and evaluated by facility designers and operators. Once they are well-defined and understood, greater confidence can be placed in the projected exposures resulting from them.

6.5 Operating Staff Radiation Exposure History

The operating staff required to do each job and the dose each staff member received was evaluated. The exposures are based on handling the hottest fuel assemblies as defined in Section 4.1. Based on the dose rates estimated from the shielding calculations, doses are summarized by step and by cumulative total in Figure 6-4. Note the higher exposures of steps 80, 90, 93, 103, 117, and 118 which are performed when the cask is filled with spent fuel.

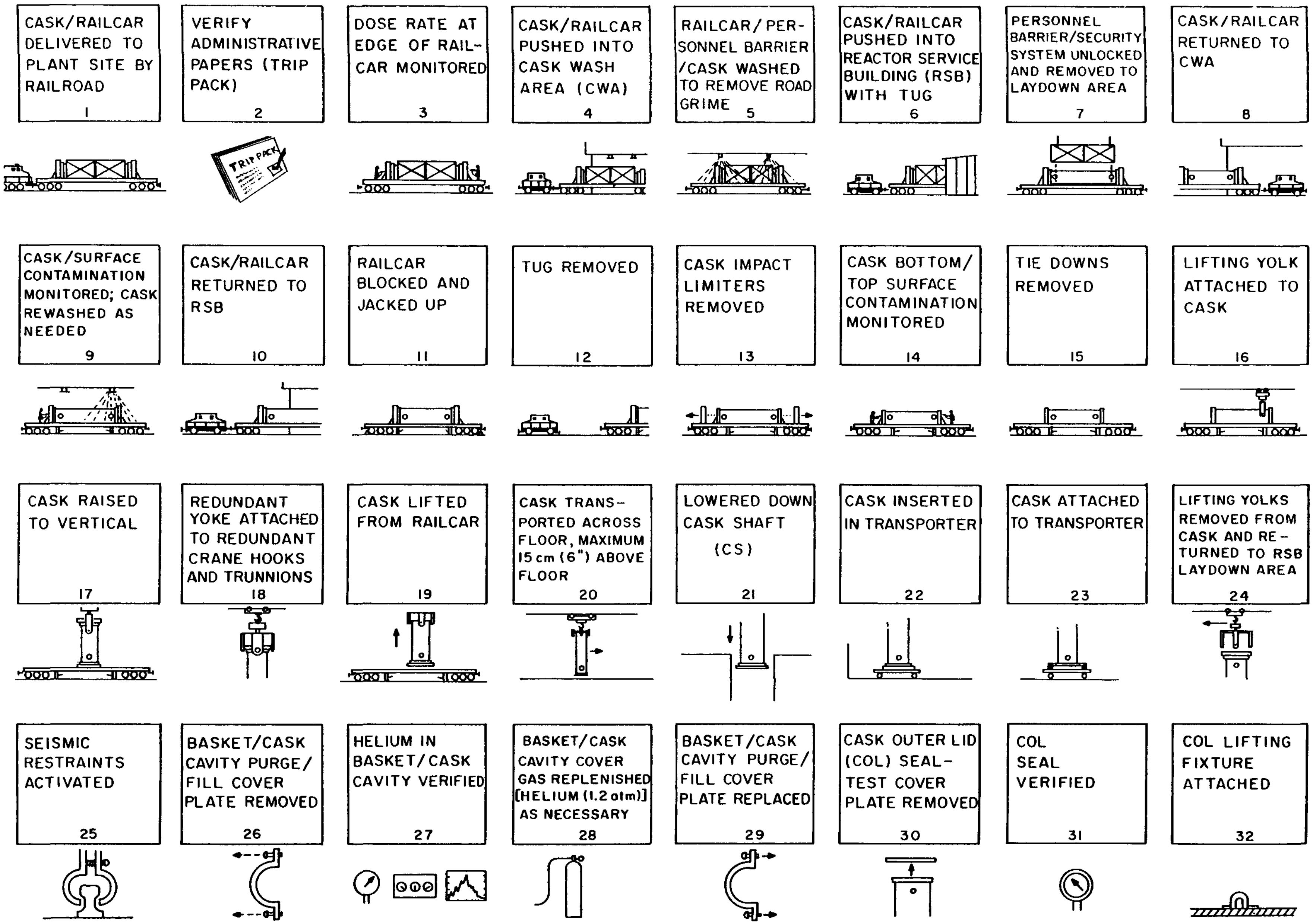

Figure 6-3 Normal Procedure for Receiving and Shipping Casks at the CRBRP

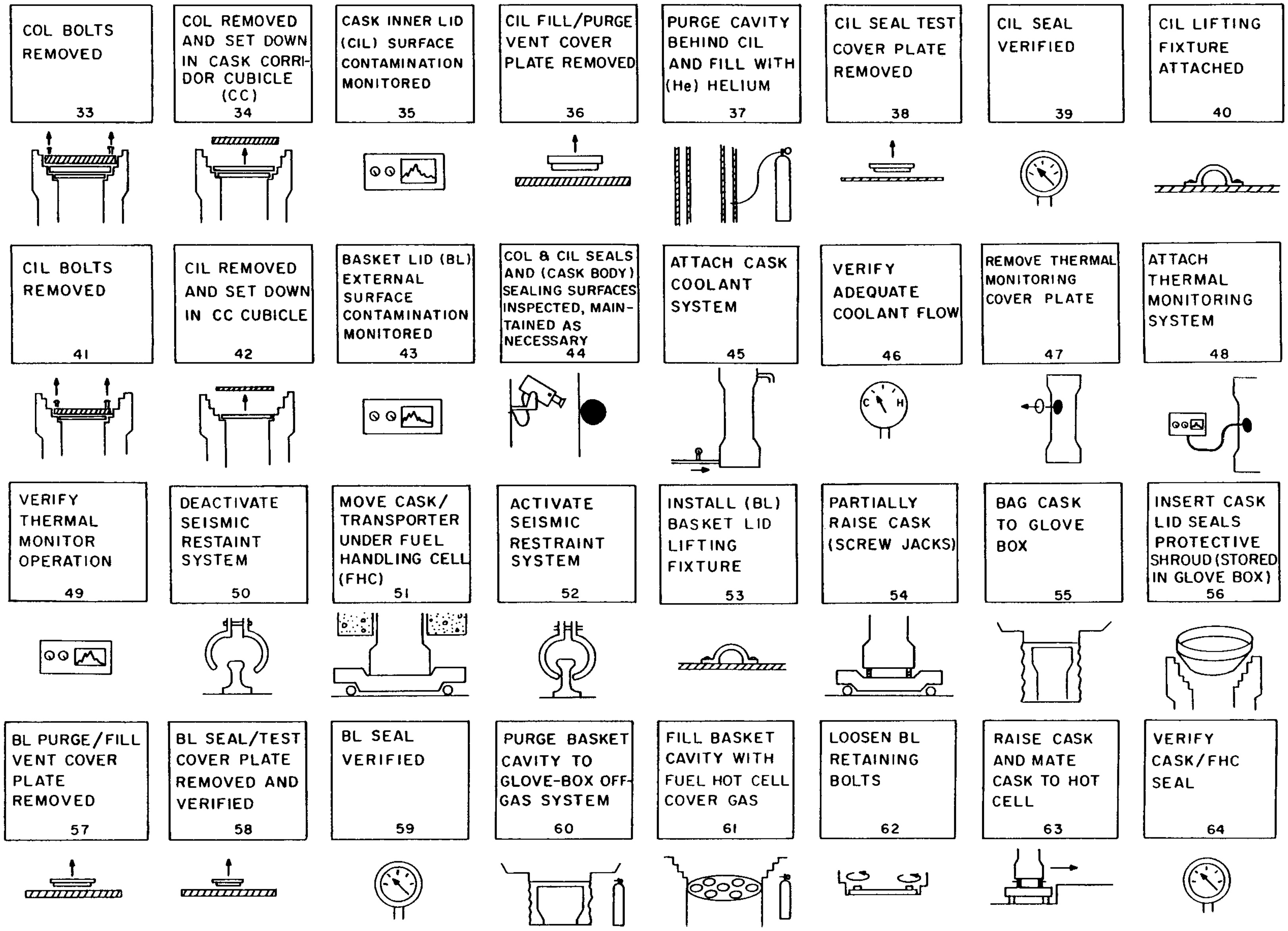

Figure 6-3 (cont)

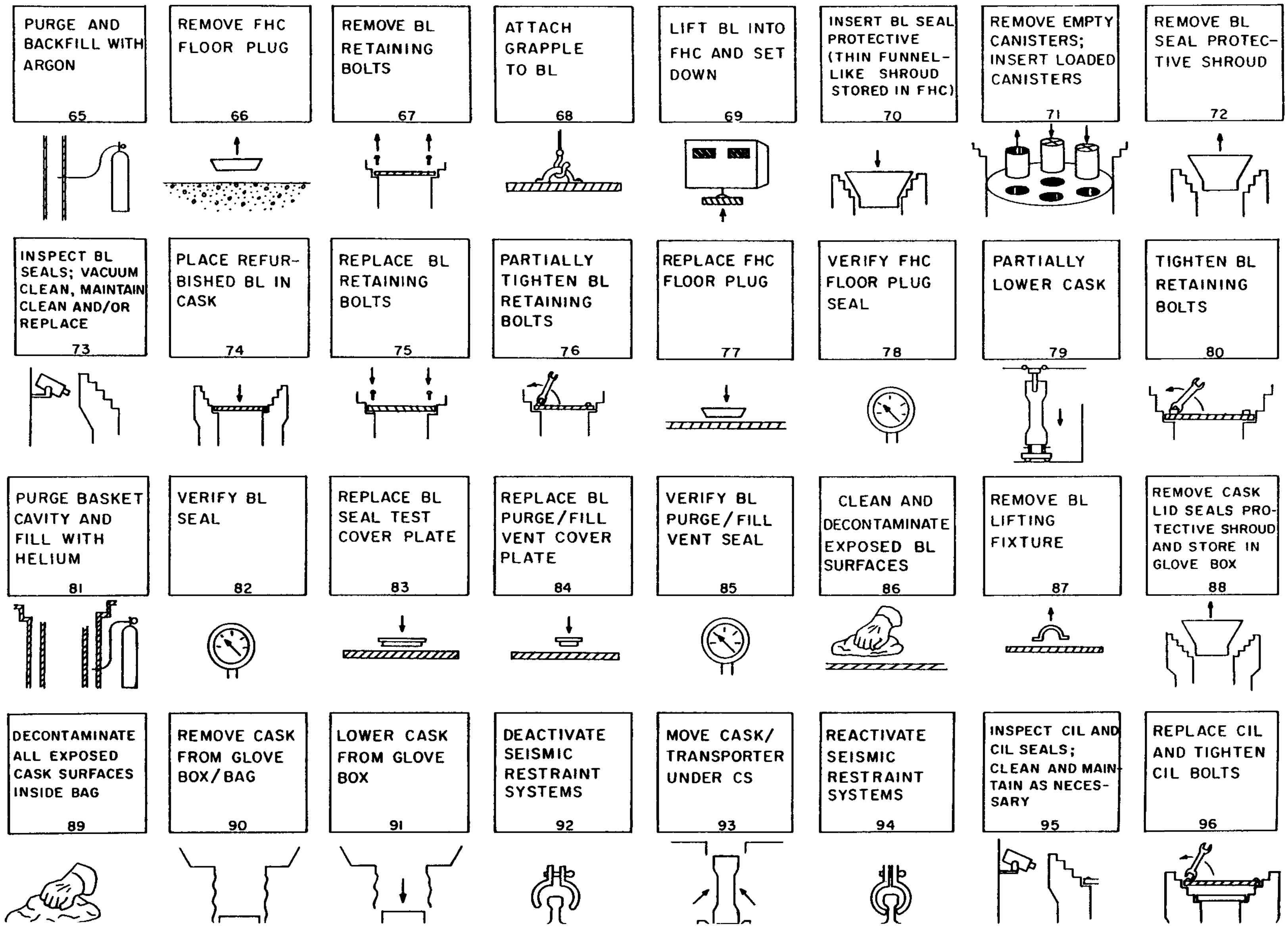

Figure 6-3 (cont)

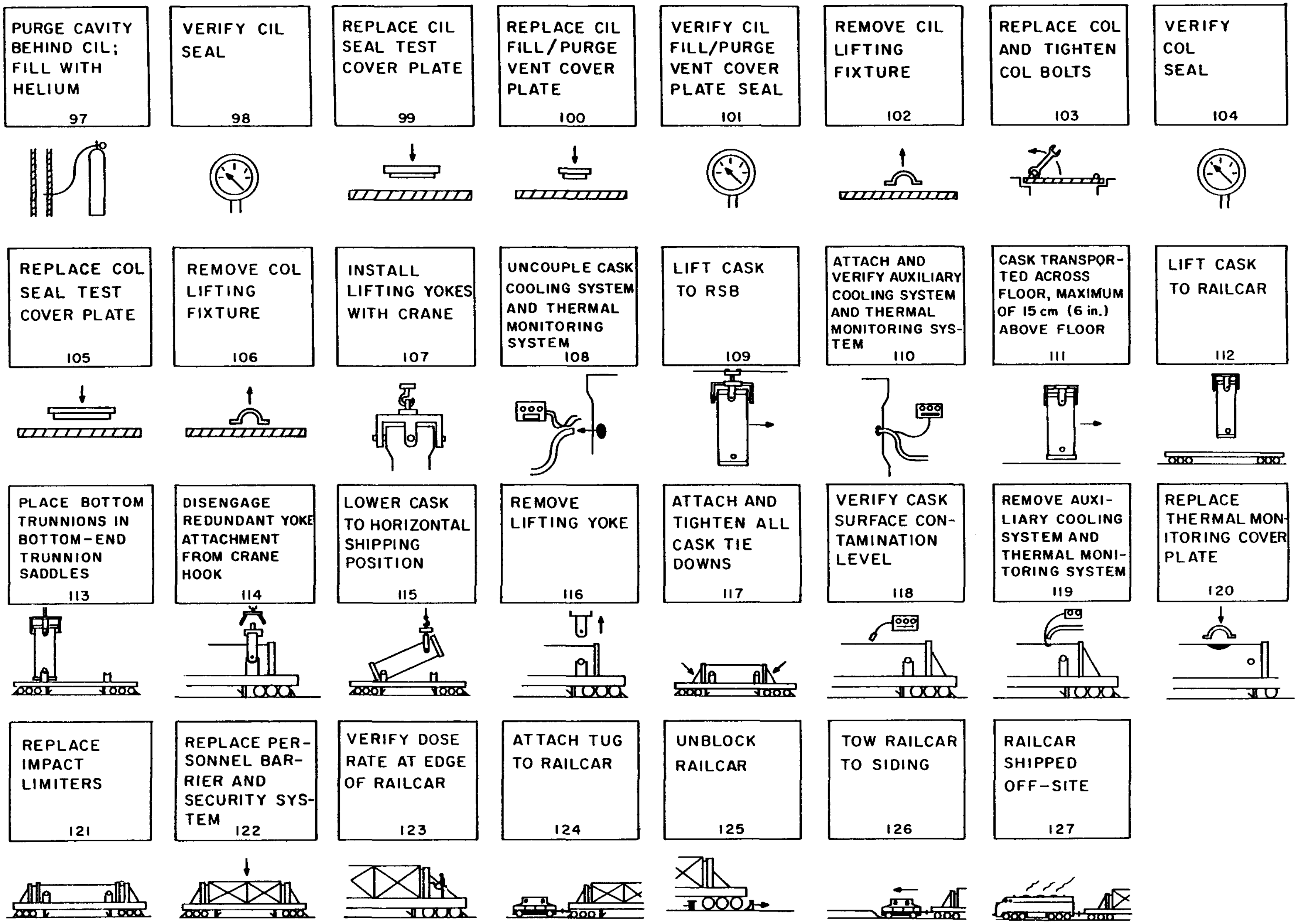

Figure 6-3 (concluded)

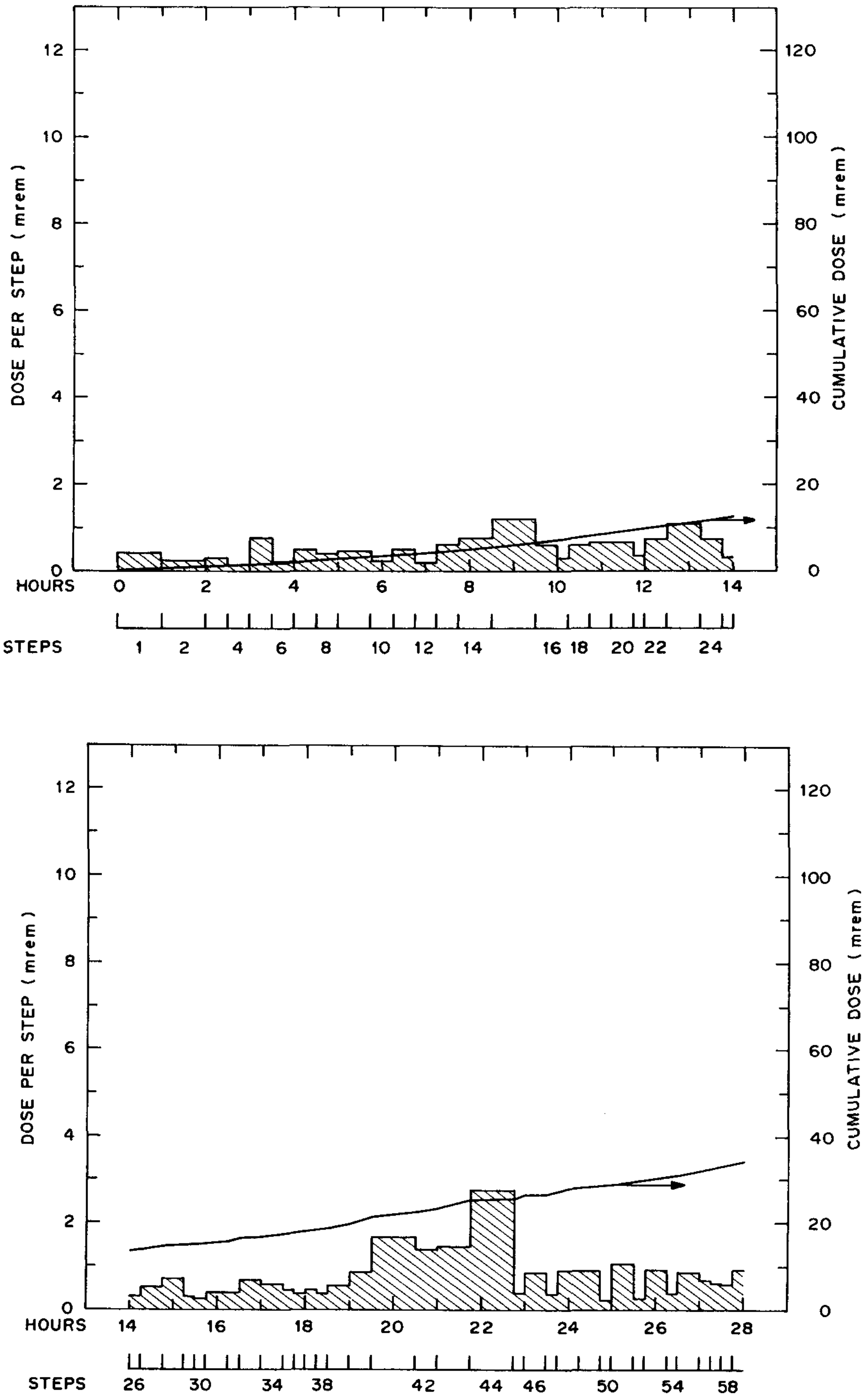

Figure 6-4 Calculated Dosage for Cask Turnaround

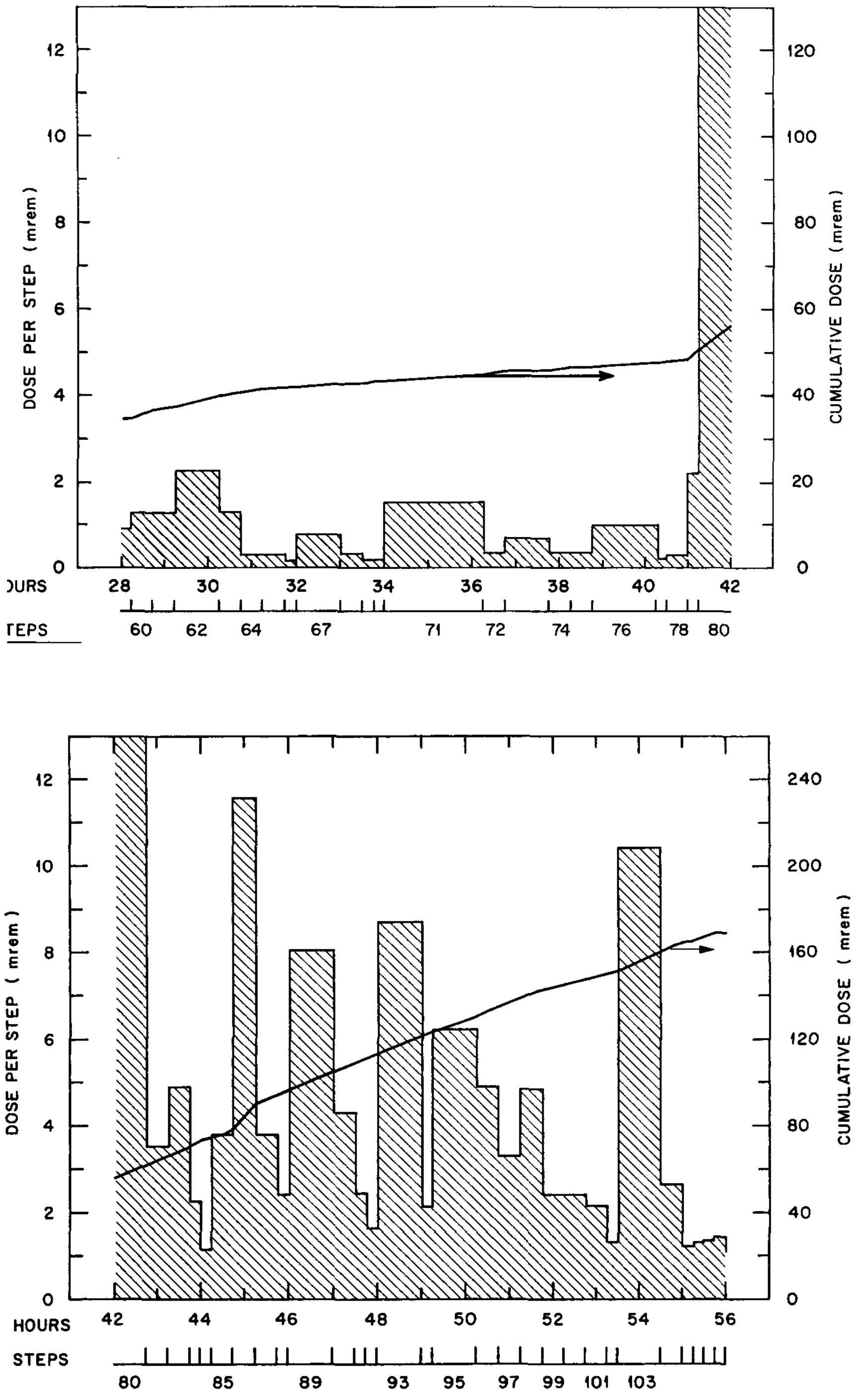

Figure 6-4 (cont)

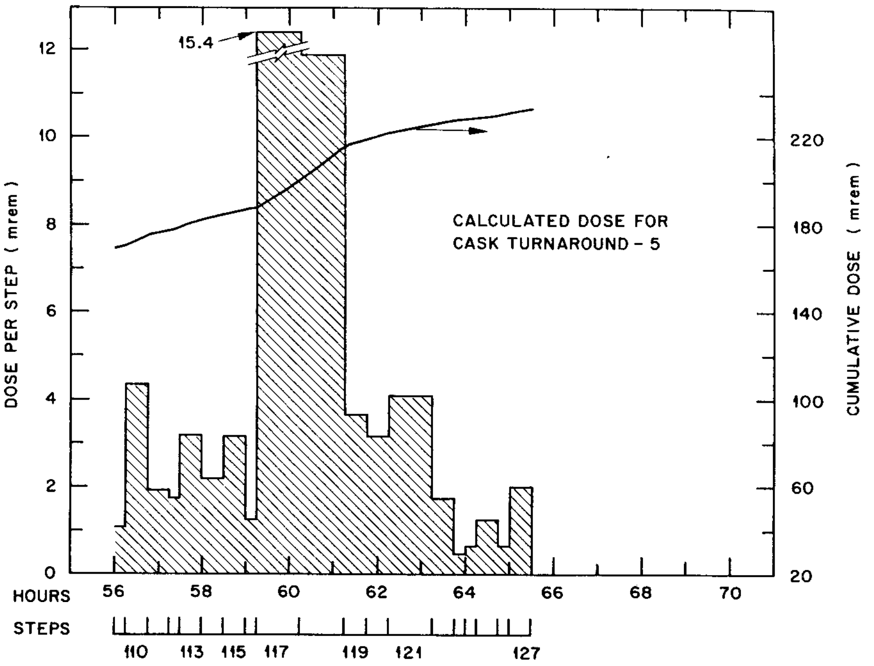

Figure 6-4 (concluded)

6.6 Summary of the Operating Radiation Exposure From a Cask Turnaround Cycle

The identification of CRBRP operating staff members receiving radiation exposures during one cask turnaround cycle is described in Table 6-1. Their exposures are summarized by shift, assuming two 8-hr working shifts per day.

The cumulative dose for any individual during a single cask turnaround is given in the two right-hand columns of Table 6-1. The numbers in these columns can be evaluated by noting that each individual should not exceed 10 mrem per week to remain under the quarterly limit of 125 mrem established by the program office.

In some instances, more than one type of craftsman was required to accomplish a particular job in a given step. There were cases in which three health physicists (HPs) were required simultaneously, and in which four mechanical operators were required at the same time. All are, therefore, identified in Table 6-1. However, if only one person for a given craft was required in a given step, that dose was always given to the first one identified in the list. This maximized that individual's dose and would reveal if there might be a problem for a given craft.

For example, in the case of HPs, the maximum dose anyone could receive was 13.4 mrem for a single cask turnaround. Since it requires essentially the entire week to turn one cask around, that would be his weekly dose. While this exceeds the limit of 10 mrem noted previously, it is apparent that a total of 20.17 mrem must be shared between three HPs on the night shift (13.4 + 3.57 + 3.2 mrem). Thus, no single HP is likely to exceed his limit.

The dose to mechanical operators is different. The maximum dose commitment to any one individual is 47.75 mrem which is exceptionally high and cannot be easily shared with others of the same craft. In this case, four individuals have been identified but all would receive a total dosage of 96.47 mrem (47.75 + 42.32 + 3.2 + 3.2 mrem). This is still too large to spread over four individuals and, therefore, the operating procedures must be re-examined to determine if more mechanical operators are needed, if others can substitute for mechanical operators, if additional shielding could be used to further protect the operators, or if the procedures could be modified to the extent that a lower dose could be achieved. Such an analysis was beyond the scope of this study and, therefore, Table 6-1 serves as a guidepost to identify where such problems might occur.

6.7 Annual Doses

The cask interface analysis indicates that it is possible to turn a cask around in about 65.5 working hours, or a little over four days if two 8-hr shifts per day are used. Reference 49 indicates that there would be an average of 29 shipments per year of which 23 would carry spent fuel and the balance would carry blanket assemblies in one year, and all 29 shipments would involve nonfuel assemblies in the next year. Shipments of the blanket assemblies would not produce the dose that shipments of the fuel assemblies would, but the total reduction has not been evaluated in this study.

The annual dose can be estimated by multiplying a total of 234 mrem/cask turnaround by the number of casks with full assemblies shipped per year; the results, while conservative because radioactive decay following the minimum cooling time was not taken into account, indicate an annual commitment of 5.38 man-rem per year associated with cask operations.

Table 6-1 Summary of Radiation Exposure

Personnel	Day 1	Night 1	Day 2	Night 2	Day 3	Night 3	Day 4	Night 4	Day 5	Day Shift Total Dose (mrem)	Night Shift Total Dose (mrem)
Staff supervisor	-	-	0.200	0.950	-	1.100	2.200	6.300	0.500	2.900	8.350
Security guard	0.400	-	-	-	-	-	-	-	0.500	0.900	-
Schedule supervisor	-	-	-	-	-	-	-	-	0.500	0.500	-
Receiving agent	0.050	-	-	-	-	-	-	-	-	0.050	-
Vehicle operator	0.500	-	-	-	-	-	-	-	0.500	1.000	-
Flagman	0.450	-	-	-	-	-	-	-	1.000	1.450	-
Cleaner operator	0.250	-	-	-	-	-	-	-	-	0.250	-
Helper 1	0.250	-	-	-	-	-	-	-	-	0.250	-
Helper 2	0.250	-	-	-	-	-	-	-	-	0.250	-
Health physics 1	0.525	0.853	1.275	1.114	-	5.192	5.200	6.234	0.300	7.300	13.393
Health physics 2	0.375	0.375	0.375	-	-	-	-	3.200	-	0.750	3.575
Health physics 3	-	-	-	-	-	-	-	3.200	-	-	3.200
Crane operator	0.200	1.000	-	-	-	-	0.100	1.100	-	0.300	2.100
Mechanical operator 1	0.850	3.500	3.750	4.900	-	25.100	21.600	14.250	0.500	26.700	47.750
Mechanical operator 2	0.650	3.125	2.375	4.900	-	21.500	10.250	12.794	0.500	13.775	42.319
Mechanical operator 3	-	-	-	-	-	-	3.200	3.200	-	3.200	3.200
Mechanical operator 4	-	-	-	-	-	-	-	3.200	-	-	3.200
Inspector	0.075	1.053	1.481	1.265	0.848	6.846	6.478	4.758	0.634	9.516	13.922
Instrument technician 1	-	0.400	0.400	0.975	-	1.200	2.200	2.000		2.600	4.575
Instrument technician 2	-	-	-	0.250	-	-	-	-	-	-	0.250
TV operator viewer	-	-	1.300	0.450	1.650	2.150	1.200	-	-	4.150	2.600
Seal specialist	-	-	0.500	-	-	-	-	-	-	0.500	-
Transporter operator	-	-	-	0.250	-	0.550	4.550	-	-	4.550	0.800
FHC operator 1	-	-	-	0.300	1.650	0.150	-	-	-	1.650	0.450
FHC operator 2	-	-	-	0.150	1.650	0.050	-	-	-	1.650	0.200

Chapter 7. Estimated Transportation Costs

The lifetime spent fuel transportation costs were estimated for the CRBRP. The estimates were made assuming 4832 assemblies (including fuel, blanket, control, and shield) are shipped with seven assemblies per shipment, for a total of 691 trips (see Reference 49 for details of shipment schedule). The estimates were made for a lightweight cask designed for a maximum dose rate of 10 mrem/hr at 2 m from its surface, and for the A-A3 cask designed for a maximum dose rate of 10 mrem/hr at its surface. The estimates provide data for determining the cost impact of introducing the lower dose rate requirement in the cask design requirement.

The concepts developed in this study were constrained to have surface dose rates that did not exceed 10 mrem/hr, which is more restrictive than the 10 mrem/hr at 2 m from the surface requirement of the transportation regulations. This extra dose requirement results in

1. A cask that weighs 26 tonnes more than a cask designed to transportation regulation
2. A cask that must be transported by a railcar with more than four axles (a lightweight cask with a dose rate of 10 mrem/hr at 2 m could be transported on a four-axle railcar)
3. A cask system that would have lifetime cost of \$6 million to \$14 millon greater than the lightweight cask, depending upon the shipping distances.

The results of the cost estimate and the basis for the estimate are shown in Table 7-1, for a 805 km (500 mi) roundtrip distance. The effect of different roundtrip distances on costs are summarized in Table 7-2. Reducing dose rate from the cask increases lifetime transportation costs. These cost estimates do not include cask development costs.

Table 7-1 Estimate of Cost Impact of Reducing External Dose Rate for the Austenitic CRBRP Spent Fuel Shipping Cask

Cask	Lightweight Cask With Dose Rate of 10 mrem/hr 2 m From Surface	A-A3 Cask With Dose Rate of 10 mrem/hr at Surface
Steel wall thickness	30.5 cm (12 in.)	41.9 cm (16.5 in.)
Neutron shield thickness	20.3 cm (8.in)	18.0 cm (7.1 in.)
Empty cask weight	65.4 tonnes (72 tons)	91.7 tonnes (101 tons)
Shipping weight	92.6 tonnes (102 tons)	149.8 tonnes (165 tons)
Transportation cost per mile[a]	\$19.20/mi	\$31.00/mi
Fabrication cost[b]	\$6.5 x 10^6	\$12.1 x 10^6
Total transportation cost for 29-yr period[c]	\$6.6 x10^6	\$10.7 x 10^6
Operational & maintenance cost[d]	\$3.5 x 10^6	\$3.5 x 10^6
	\$16.6 x 10^6	\$26.3 x 10^6

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[a] Estimated using \$9.4/cwt tariff for 1000-mi roundtrip (1981 dollars)

[b] Based upon estimated cost of \$33/kg for the lightweight cask and \$44/kg for the A-A3 cask, 1981 dollars, three casks

[c] Based upon 691 trips, 805-km (500-mi) roundtrip distance

[d] Based upon \$2500 per trip for seal replacement and \$2500 per trip average maintenance cost

Table 7-2 Effect of Shipment Distance on CRBRP Lifetime Costs for Transportation

Roundtrip Distance (km)	Roundtrip Distance (mi)	29-Yr Cost for 65.4-Tonne* Cask ($M)	29-Yr Cost for 91.7-Tonne** Cask ($M)	Cost Difference
32	20	10.3	16.0	5.7
161	100	11.3	17.7	6.4
805	500	16.6	26.3	9.7
1609	1000	23.2	37.0	13.8

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*Lightweight cask with dose rate of 20 mrem/hr at 2 m, 4 axle railcar

**A-A3 cask with dose rate of 10 mrem/hr at surface, 8 axle railcar

Chapter 8. Applicability of Cask and Cask Design Effort to Other LMFBRs

In this chapter, the applicability of the cask designs to two other United States LMFBR facilities will be addressed. The reactors of concern are the Fast Flux Test Facility (FFTF) and any plant resulting from the DOE's Conceptual Design Study, which will be denoted as the Large Development Plant (LDP).

8.1 Fast Flux Test Facility

The FFTF is currently operational, and has the capability of storing spent fuel until approximately 1986. The spent fuel which eventually may be shipped from FFTF (1) has a cross section identical to CRBRP spent fuel, (2) is 0.6 m (2 ft) shorter than CRBRP spent fuel, and (3) will produce low levels of decay heat—less than 1.4 kW.

The cask concepts being developed for CRBRP should certainly be able to accommodate FFTF spent fuel. For FFTF spent fuel producing less than 0.8 kW, the assemblies could either be shipped in argon-filled canisters or even placed directly in the basket without canisters and shipped with an argon cover gas (Reference 50). For FFTF fuel assemblies producing more than 0.8 kW, the assemblies could be shipped in canisters using pressurized helium as a coolant (Reference 50). However, the FFTF plant must be modified to allow the CRBRP cask to be loaded.

8.2 Large Development Plant

It is assumed that the LDP will follow in time, the CRBRP. The following LDP-related data were obtained from Reference 51.

A fuel assembly for the LDP will be larger in cross section—152.4 mm (6 in.) across the hexagonal flats for LDP as compared with 120.5 mm (4.745 in.) for CRBRP—and will be longer—4572 mm (180 in.) for LDP as compared with 4267 mm (168 in.) for CRBRP. In addition, the LDP guidelines are that (1) the fuel assembly will produce no more than 7 kW decay heat; (2) a fuel assembly must be shipped in a core-component pot (CCP), which is a vessel to be used within the plant for moving assemblies; (3) 278 spent assemblies must be shipped between yearly refueling (40-week period allowed); (4) an average of seven assemblies per week must be shipped; (5) a total of 263 fuel and blanket assemblies will be shipped; (6) fuel will be inspected selectively; and (7) 278 new core assemblies must be received during same period (7 per week average).

The cask loading scheme would be similar to that for CRBRP, except railcar access is provided directly under the Fuel Handling Cell. Other than the larger size of the spent fuel assembly, and the requirement to also ship the CCP, the cask being designed for CRBRP would service the LDP. In addition, the technology and experience which will be developed as the CRBRP cask design evolves, and its licensing history, will all apply to the LDP. Basic modifications to the CRBRP design to allow canistered CCP's, would probably result in a 95 to 105 tonne cask which could carry 3 or 4 spent LDP fuel assemblies.

Chapter 9. Packaging Design Philosophy and Cask Development Schedule

This section describes the process involved to complete conceptual, preliminary, and final phases of design, construction, fleet development, and operation of new cask systems in instances where licensed systems are not available.

Cask systems have been designed for light water reactor (LWR) spent fuel assemblies and for FFTF fuel pins, and there are contractors available who are qualified to pursue the development of certificated transportation systems. Problems have arisen recently concerning brittle fracture, joining methods for dissimilar metals, welding of thick metal sections, safeguard requirements, analytical methods, facility interfaces, radiation exposure limits, carrier acceptance, quality control, and overall acceptance by the public. Efforts should be made early in the system development program to minimize the effects of these potential problems, and any others that may be defined.

The period of time required to have the first production unit available is estimated to be 6 to 8 years from the time specific preliminary design is initiated. A schedule for the CRBRP cask development is shown in Table 9-1.

The program schedule for the development of a new transportation system involves the following major phases:

I. Conceptual Design
II. Preliminary Design
III. Model and Subsystem Testing
IV. Final Design and Licensing Activities
V. Fabrication of Prototype
VI. Prototype Testing and Certification and Delivery of First Production Unit

A more optimistic time schedule than shown in Table 9-1 is indicated in Reference 52 for an LWR cask. Reference 52, suggests that a cask design can be developed and licensed to ship radioactive materials in 22 to 49 months. To complete the job in 22 or even 49 months, the design requirements and technology would have to be very well defined when the program is begun. If a number of system parameters are undefined in the early stages of the program, technology is not available, and/or there are a number of institutional issues and facility interfaces that must be worked into the program, the schedule shown in Table 9-1 indicating 6 years from program initiation to completion of licensing, is much more realistic.

To complete the design and obtain a license requires that many activities be completed. A partial listing of these activities is as follows:

- Shielding Analysis
- Thermal Analysis
- Structural Analysis
- Concept Development
- Data Acquisition (spent fuel characterization, material properties)
- Interface Definition
- System Studies (logistics, risk assessment, cost)
- Reference Design Selection
- Quality Assurance Program Development
- Design Criteria Definition
- Advanced Concept Development
- Safety Analysis Report Preparation
- Testing (develop plan, design models, fabricate, reduce data)
- Design Definition

The time schedule can often be compressed by initiating program activities before all information for that activity is available. There is a certain amount of financial risk involved in pursuing this approach, but the potential saving of time can possibly be measured in years for very involved programs.

Model testing of system components is very much a part of the cask development process. The capability for predicting system response on a gross scale using scale models has been demonstrated repeatedly and is now a very acceptable method of design. Scale models are not generally adequate for predicting response of smaller components of the system that are often of much interest (e.g., nuts, bolts, connections, valves, seals, welds, etc). The tests must be conducted in the temperature ranges specified in the governing regulations to support the analysis and assumptions used in generating the SARP. If materials are used where little is known about their performance in the temperature regime to which they will be exposed, different (and possibly novel) welding and joining techniques are required or new physical phenomena are

Table 9-1 Planned Development Schedule (Based on July 1, 1981 Funding Guidance)

Phase	Fiscal Year
I. Cask Conceptual Design Release	81
II. Cask Preliminary Design Release	82
III. Model and Subsystem Testing	
Canister Testing Complete	83
First Phase Thermal Testing Complete	83
First Phase Leak Testing Complete	83
Thermal Testing Complete	85
Leak Testing Complete	85
IV. Final Design and Licensing Activities	
Cask Final Design Release	83
Safety Analysis Report for Packaging Complete	85
V. Fabrication of Prototype Complete	85
VI. Prototype Testing, Certification and Delivery of FPU	
Cask Prototype Testing Complete, SARP Updated	87
Cask Certified, Production Drawings Completed	88
First Production Unit (FPU) Available	90

involved, then an extension of the state-of-the-art in one or more basic technology areas may be required.

A problem that frequently occurs in the development of cask transportation systems involves neglecting details that affect fabrication ease. On occasions the effects of fabrication practices and material limits are considered too late in the design sequence or not at all. The best overall approach is to use design personnel who are totally familiar with the in-plant manufacturing capabilities or invite, or contract with, a fabricator to participate in the design phase to offer advice to improve fabrication ease. If the fabrication methods are examined in a structured manner during the early phase of a program, the cost effects of the alternatives available can be analyzed and included in economic studies that guide the selection of design methods.

The following specific areas are of major importance in a cost analysis that considers fabrication alternatives:

1. Material selection as it affects fabricability and cost
2. Material form such as plate, casting, or forging
3. Welding design and its effect upon cost and other welding problems
4. The effect of tolerance requirements
5. The tradeoff in acceptance criteria for various production procedures
6. Assembly techniques
7. Nondestructive testing requirements
8. Production and license compliance testing
9. The effect of all these items upon delivery cycles and thus upon cost.

Prototype testing and personnel training should also include the verification that quality control programs developed earlier in the program have been effectively employed. The requirements for the QA programs are spelled out in the regulations and can be significantly more stringent than might be applied to a normal manufacturing process. There will be additional costs incurred in the fabrication process to accommodate the additional QA requirements. A time penalty results when working with nuclear grade components in the neighborhood of 15% to 80% when compared with the time required to work with standard commercial grade components (Reference 52).

Prototype testing and personnel training can be at least partially combined. Prototype testing may include any or all of the following types of tests:

1. *Functional Tests*—Checking for fit and dimension tolerances. Assessing ability to place and remove baskets, canisters, and lids
2. *Load Tests*—Evaluating load capabilities of yokes, trunnions, etc
3. *Shielding Tests*—Examining for bond of shielding materials, voids, proper material thicknesses, etc
4. *Leak Tests*—Testing to assure the integrity and leak tightness of closure seals. This may also include tests of gaskets, bolting preload effects, etc.

5. *Containment Test*—Typically, hydrostatic pressure testing of the containment to assure structural adequacy
6. *Thermal Test*—Comparing analysis with actual operating temperatures experienced with "as-built" systems
7. *Vehicle Tests*—Ascertaining that the vehicle (rail flat car) meets industry standards. The AAR specifies that both dimensional and structural (static and impact) tests be performed.
8. *Weight Tests*—Weighing the assembled components to assure that transport restrictions can be met
9. *Nondestructive Examination*—Various in-process examinations of the cask structure, auxiliary equipment, and raw material supplied for fabrication. Typically, this would include radiography and/or dye-penetrant inspection of selected weld joints and machined surfaces, ultrasonic tests of clad surface, shield bonding areas, etc. Also, visual inspection for surface finish and in-process dimensional checks, are included.
10. *Destructive Testing*—Impact, puncture, and thermal testing to demonstrate compliance with regulations.

A series of functional and compliance checks after fabrication may add 2 to 4 months to the delivery cycle of a complicated rail system.

Training of personnel could also include additional checkout of the transportation system hardware under actual operating conditions. Valuable information can be obtained during this period since there are probably a number of system features which will not perform exactly as planned and the areas where human errors occur will begin to be noted. The complexity of most systems and the massiveness of the hardware components make it nearly impossible to foresee all problem areas that will be encountered. The packaging used to contain the radioactive material must also be handled by following a very detailed procedure that allows little or no variation; this increases the training time. It is not essential that training include actual radioactive material in the packagings, and in fact, surrogate material should be used when the training is carried out under simulated conditons.

The checkout procedure should investigate the operations involving all of the package-handling hardware, the performance of spacers, liners, and other miscellaneous hardware within the package, the operation of any auxiliary systems, the techniques for decontamination of internal and external surfaces, and the methods to verify leak tightness of seals.

Reference 52 is again cited as a source for reasonable time estimates for activities associated with the operational checkout of a transportation cask. A typical cycle for operational checkout of a cask system would include the following:

1. *Procedure Preparation*—(1 to 2 months) Development of special procedures for testing and expected normal handling procedures. These procedures must be coordinated and generally developed in conjunction with the facility operators where checkout is to occur.
2. *Test Equipment Procurement*—(1 to 3 months) Design and procurement of special equipment is needed to ensure that the packaging can be operated at the facility where the test is being performed. It may be necessary to design and procure test items, not normally part of auxiliary equipment supply.
3. *Test Cycle*—(2 to 6 months) The following tests are normally included:
    a. Package vehicle movement/spotting at proper position
    b. Disengagement of tiedowns
    c. Removal from the vehicle
    d. Compatibility checks with lifting hardware
    e. Loading/unloading simulation
    f. "Changeout" of internals
    g. Checkout of instrumentation (thermocouples, load cells, etc)
    h. Fastener torquing/untorquing
    i. Closure seal and leak tests
    j. Checkout of auxiliary tools
    k. Full-scale evaluation of decontamination tests
    l. Interior cavity sampling techniques (if necessary)
    m. Simulated maintenance operations and periodic compliance tests
    n. Miscellaneous (possibly license compliance and thermal tests not performed at manufacturer's plant).
4. *Test Review*—(1 to 2 months) Review of test results, development of final operational procedures, and engineering of design modifications to the production model.
5. *Preparation of Operations Manual*—(2 to 6 months) Development of general operational procedures for equipment.

An additional period for training of personnel at the shipping and receiving ends of the transportation cycle can easily add another 2 or 3 months to the time period required to deliver the first production unit. Reference 52 indicates that ideally this period should be as much as 6 months to allow for debugging.

In summary, it appears that it will take from about 8 to 10 years to develop a new cask system for CRBRP from the time the preliminary design is initiated until the first production unit is available and this development program will cost several million dollars. Restrictions imposed by regulations or other conditions requiring technology development to extend the state-of-the-art can also impede progress. The time required to develop a transportation fleet will depend on the number of units needed, and the rate at which units can be fabricated.

The cost for purchasing hardware for the operational fleet will depend entirely on the fabrication techniques, the materials required for construction, and the amount of inspection and quality control that will be necessary to fulfill the requirements of the regulatory agencies certificate of compliance. Operating costs can be estimated early in the program development.

Chapter 10. Conclusions and Recommendations

The conceptual design study of the CRBRP spent fuel shipping cask reported herein has resulted in a baseline and three alternate design concepts.

The primary features of the baseline concept design are

1. The cask carries seven assemblies per shipment
2. The cask provides a minimum of two containment levels
3. The cask weighs 93 tonnes
4. The cask can be transported by either a six- or eight-axle car.

Conclusions reached during this study are that

1. The cask will be expensive
2. The plant proposed exposure limits are costly
3. The lead time for fabrication of a production unit is 10 yr from completion of such conceptual design work.

These concepts were developed despite uncertainties in existing design technology, ability to fabricate, and interpretation of regulatory requirements. Uncertainties in the design include

1. Whether more than 50 g of sodium can be shipped in conjunction with fissile material with exemption from DOT regulations
2. Whether the canister should be mechanically sealed or seal-welded
3. Whether the canister should be qualified for normal form or special form
4. How to qualify the canister (and basket) seals to newly proposed isotopic leak-rates
5. Which mechanical seal would be best for the canister (and basket)
6. Whether "return lids" on the canister and basket can be used for empty shipments from the reprocessing facility to CRBRP
7. How to handle and seal canister and basket lids remotely when testing for proper leak rates
8. Whether the mechanical seals are reusable
9. Whether and to what extent the basket-lid seal will lose its integrity in a dynamic drop-test environment
10. Whether the effects of (a) sodium solidification and remelt, (b) ullage, (c) "nonnatural" thermal boundary conditions on the canister (i.e., boundary conditions different than those already evaluated in the laboratory), (d) the assembly orientation in the canister, and (e) fission gas bubble leakage on heat transfer will significantly alter thermal performance
11. Whether the neutron shield performance is satisfactory
12. Whether finlet heat-rejection performance data are adequate
13. Whether ferritics can be certified for use as the cask body when brittle fracture is considered
14. Whether large monolithic structures of either austenitic or ferritic steels can be fabricated in the United States.

Clearly the uncertainties need to be addressed to allow progress in the cask design toward higher confidence levels. Many need to be addressed in the preliminary design phase in order to minimize their impact.

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APPENDIX A

Interface Control Document CL54003 (Revision 3)

ENGINEERING RELEASE ORDER

ERO NO. L-00106

ERO DATE 3/2/81

THE FOLLOWING ARE APPROVED FOR ENGINEERING RELEASE BY ARD

DOCUMENT NUMBER	REV. NO.	TITLE	DATA TYPE
ICD CL54003	3	Spent Fuel Shipping Cask (SFSC) Interface Requirements	2

SPECIAL RELEASE INSTRUCTIONS

DISTRIBUTE TO: Standard Distribution

PROJECT DISTRIBUTION

APPROVALS

REFERENCE DOCUMENT:

ICD CL54003, Rev. 2, forwarded by
LA810026, 1/23/81

COGNIZANT ENGINEER James E Dutcher

COGNIZANT MANAGER

S13:1

WESTINGHOUSE ELECTRIC CORPORATION
ADVANCED REACTORS DIVISION
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I.C. DOCUMENT NO. CL54003
REVISION NO. 3 | Rev. 3
REVISION DATE 01/08/81
DATA TYPE 2
PAGE 1 OF 8 PAGES
ERO L-00106 DATE 03/02/81 | Rev. 3

INTERFACE CONTROL DOCUMENT

DOCUMENT TITLE

Spent Fuel Shipping Cask (SFSC)
Interface Requirements

ABSTRACT

This document identifies the interfaces between the Spent Fuel Shipping Cask (SFSC) and the CRBRP facilities. The defined interfaces include weight, length, diameter, handling bail, seating surfaces, sealing surfaces, heat dissipation, cask cooling, and cask coolant. The building interfaces affected the RSB crane, laydown area, cask shaft and corridor, fuel handling cell, cask transporter, HVAC System, and the liquid and gas coolant systems.

APPROVAL/DATE

W-RM	AI	GE	LRM	B&R
			J E Rutenber 3/9/81	

LMFBR CHANGE CONTROL RECORD	TITLE Spent Fuel Shipping Cask (SFSC) Interface Requirements	DOCUMENT NO. CL54003

REV. NO./ DATE	CHANGE RELEASE/ SIGNATURE	PAGES AFFECTED	REMARKS
Rev. 1	9/24/80	Pg. 1, Pg. 2, Pg. 3, Pg. 4	ECP L41-001 incorporated change page added
Rev. 2	1/21/81	Pg. 4, Pg. 7	ECP L41-002 incorporated
Rev. 3	3/9/81	Pg. 3, Pg. 7	ECP L41-003 incorporated

10-79-WL:887-1

SPENT FUEL SHIPPING CASK (SFSC)
INTERFACE REQUIREMENTS

1.0 CRBRP Interfaces The SFSC and transport vehicle interfaces within the Reactor Service Building (RSB) will be as follows:

(a) Railroad track and car door

(b) Crane, Hydraset lifting, rigging, and positioning equipment

(c) Preparation and closeout facilities, including coolant and gas filled drain system

(d) Cask corridor transporter - CA53126

(e) Fuel Handling Cell (FHC)/SFSC interface seal - The adapter between the SFSC and the seal in the FHC will be provided by CRBRP System 41.

(f) FHC Operating Gallery

(g) Records kept to ANSI N45.2.9

(h) The cask hatch, lid, and other cask components to be lifted into the FHC cannot exceed 4.5 tons or 63 inches in any dimension.

Each component must be compatible with FHC handling equipment and with operating gallery.

Laydown space will be provided in the Fuel Handling Cell for a cask cover that weighs no more than 4.5 tons and does not exceed 63 inches in diameter.

(i) The SFSC must be compatible with the argon atmosphere in the FHC.

2.0 Assemblies to be Shipped - The SFSC shall accommodate sodium wetted core assemblies as defined in Table I. Assemblies which are suspected of leaking may be canistered. [Fuel assemblies may be canistered.] HOLD L41600390

3.0 Assembly Temperatures

3.1 Maximum Temperatures for Normal Conditions The following temperatures shall not be exceeded for normal conditions:

(a) Fuel cladding surface average -1000 degrees F

(b) Working or maintenance surfaces where practical -Below 125 degrees F, | Rev. 3

(c) Coolant -Temperature at which severe degradation of coolant heat removal properties occur, resulting in cascading degradation of coolant and rising cladding temperatures

3.2 Maximum Temperatures for Emergency and Faulted Conditions For emergency and faulted conditions the fuel cladding temperature shall not exceed the lesser of:

(a) 1500 degrees F; or

(b) Temperature at which severe degradation of coolant heat removal properties occur, resulting in cascading degradation of coolant and rising cladding temperatures.

3.3 Cooling Cooling means shall be provided and shall maintain SFSC temperatures within the limits specified in 3.1. Cooling will not be provided by the CRBRP. Auxiliary cooling requirements while loading the SFSC are to be determined.

HOLD 41600391

3.4 Accident Condition Cooling In the event of failure of forced convection cooling (if employed), fuel cladding temperatures shall not exceed the temperatures specified in 3.2(a).

3.5 Cask Surface Temperature The cask support surfaces, when the cask is set down in the vertical position, shall not exceed 400 degrees F, in an ambient temperature of 125 degrees F.

The contact area shall be less than 50 square feet.

3.6 The cask shall be designed to carry no more than 12 fuel assemblies and, when loaded, shall dissipate no more than 84 kilowatts.

4.0 Radiation Criteria The design of the SFSC shall be based on the following criteria:

(a) Source strength - See 11.0 Reference (b)

(b) Gamma Energy Release - See 11.0 Reference (b)

(c) Fuel Assembly Decay Power - See 11.0 Reference (b)

(d) Fission gas inventory - See 11.0 Reference (b)

(e) Cladding failures - The cask shall be capable of handling fuel assemblies that have experienced cladding failures in the reactor.

(f) Decay power - The highest powered assemblies transported in the SFSC shall be 7 KW. This is based upon shipping spent fuel 100 days after refueloing.

(g) Activation of sodium wetting the core assemblies - See 11.0 Reference (b).

(h) The shielding shall limit the quarterly radiation exposure of operating personnel to 125 mrem. The surface dose rate on the cask as it is set up for loading should be less than 10 mrem/hr. - See 11.0 Reference (c) Sections 1.6.4.2 and 1.6.4.3.

5.0 Residual Sodium The SFSC and coolant shall be capable of accommodating 2.2 pounds of residual sodium per assembly.

6.0 Loading Characteristics The SFSC shall be loaded vertically from the top while mated with the floor of the fuel handling cell.

7.0 Assemblies to be Shipped

7.1 Dimensions The dimensions of the fuel assembles to be shipped in the SFSC will be as shown in Reference (d) - See 11.;0. The following is for information only:

(a) Minimum dimensions with no twist, free bow, or growth: 168" long X 4.745" across hex flats;

(b) Range of dimensions:

Minimum plus	
Free bow	1.0 inch
Twist (over entire length)	30 degrees
Dilation	
Radial	0.085 inch
Axial	2.0 inch

7.2 Weights, Volumes and Surface Areas Weights, volumes, and surface areas of assemblies to be shipped will be as shown on Table 1.

8.0 Receiving, Handling and Shipping

8.1 Receiving The SFSC shall be brought into the Reactor Service Building (RSB) by rail or truck. The rail area in the RSB will be capable of supporting a 210-ton load. If a truck is employed as the transport vehicle, the truck wil travel over the rail area. The RSB crane will provide coverage over the last 50 feet of the rail area.

8.2 Tilting Fixture Means shall be provided to lift the SFSC from the horizontal shipping position to a vertical position. The RSB crane will be used for this operations.

8.3 Washing The SFSC shall be capable of being washed with hot water or steam to remove dust, dirt, mud, or snow, or any other foreign matter without the SFSC being lifted from the Transport Vehicle.

8.4 Hook to Rail Dimension The hook to rail dimension will be 42 feet.

8.5 Preheat Means shall be provided to melt frozen coolant in the SFSC without opening the cask.

8.6 Coolant and Cover Gas Sampling Means shall be provided to sample the coolant and cover gas before loading and after unloading, without over-exposure of personnel to radiation.

8.7 Coolant and Gas Quantities Means shall be provided to monitor and control coolant and gas quantities during loading and unloading.

8.8 Core Assembly Loading Means shall be provided to prevent the fuel assembly grapple from being immersed in the coolant, except for sodium or gas.

8.9 Cask Handling Criteria Cask handling criteria shall be in accordance with RDT F8-6T.

8.10 Leak Checking Means shall be provided to leak test the pressure boundary or boundaries before and after loading, for conformance to the cask test specifications (to be furnished by the supplier).

8.11 Handling and Shipping The SFSC shall be designed such that receipt, loading, and preparation for shipment will take no longer than 5 days. The cask(s) must support shipment on an average of 6 assemblies per week (9/1.5 weeks or 18/3 weeks).

8.12 Heat Dissipation The SFSC shall be able to dissipate the heat generated by fuel assemblies which have deayed for 100 days.

8.13 Operating Basis Earthquake (OBE) The SFSC shall remain operational during the following exposure to the seismic loads of an OBE .125 G. The seismic response spectra for an OBE is in Reference (a) - See 11.0.

8.14 Safe Shutdown Earthquake (SSE) The SFSC shall suffer no loss of safety functions during and after exposure to the seismic loads of an SSE .250 G. The seismic response spectra for an SSE is in Reference (a) - See 11.0.

9.0 Licensing The SFSC shall be a licensed cask and shall meet all applicable federal, state, and local regulations, including 10 CFR 71, 10 CFR 73, 49 CFR 173, USAEC Regulatory Guide 7.1.

10.0 Physical Characteristics

10.1 Lifting Weight The lifting weight of the SFSC shall not exceed 115 tons. This weight shall include the cask, core assemblies, coolant, and handling fixtures.

10.2 Dimensions The overall dimensions of the SFSC (including all appurtenances, i.e., cooling fans, handling trunnion, etc.) shall not exceed 96" o.d. by 22' long. The cask on the transport vehicle, with the sunshade attached for shipping, shall be able to pass through the RSB doors. The door opening is 17 feet wide by 22 feet high.

10.3 Useful Life and Availability The design life for SFSC components shall be as follows:

(1) Structures and static componenets shall be designed for a 30-year life.

(2) Dynamic (i.e., moving) components shall be designed for a 10-year life.

(3) Instrumentation shall be designed for a 10-year life.

(4) Elastomer seals shall be designed for a 5-year life (goal).

Those structures and components for which the preceding life expectancies cannot be assured or are not economically justified shall have a shorter design life compatible with operation and maintenance schedules. The number of shipping cycles in the 30-year design life shall be 300 per cask.

10.4 Maintenance Design The SFSC shall be drainable and fillable. The cask design shall facilitate decontamination and cleaning.

11.0 References - References will be provided upon request.

(a) WARD-D-0037 Seismic Design Criteria for the CRBRP, Rev. 1 Rev. 3

(b) "WARD D-0193, Radioactive Source Terms."

(c) SDD-41 "Clinch River Breeder Reactor Project System Design Description for the Reactor Refueling System"

(d) ICD CA53299, "Reactor Refueling System to Reactor System (General) Interfaces"

12.0 Quality Assurance

RDT Standard F2-2 Amendments 1, 2 & 3, Sections 1, 2, 3, 4 & 8.

TABLE I

Component	Drawing No.	Design Values			
		Maximum # Weight in Air (lb)	Maximum # Envelope (in.)	Maximum # Surface Area (ft^2)	Actual Displacement Volume (ft^3)
Fuel Assembly	766J697	500	6.5D x 170	220	1.0
Blanket Assembly	766J689	600	6.5D x 170	130	1.1
Primary Control Assembly	766J688	400	6.5D x 170		
Secondary Control Assembly	273R225	320	6.5D x 170	94	0.75
Removable Radial Shield	766J723	400	6.5D x 170		0.78

This table is provided for general sizing and weight.

ENGINEERING CHANGE PROPOSAL

ROUTINE ☒ URGENT ☐ EMERGENCY ☐

1. RESP. CCB: CRBRP PO ☐ LRM ☒ AE ☐ AI ☐ GE ☐ W-RM ☐

2. APPROVAL CLASS: ☐ 1 ☐ 2 ☒ 3

3. CHANGES SPECS no PSAR no ER no
AFFECTED DOC. CL54003, Rev. 2

4. ECP TYPE: ☐ ADVANCE ☒ FOR CHANGE ACTION

5. ECP No. L41-003 REV. 0

6. RESP. ORG. LRM

7. COG. ENGR. Rutenber

8. DATE OF PREP. Dec. 15, 1980

9. REQUIRED APPROVAL DATE Feb. 10, 1981

10.

	YES	NO
ALARA IMPACT	☐	☒
OPERATION, MAINTENANCE, & TEST (OMT) IMPACT	☐	☒
CABLE IMPACT Key System Review	☐	☒

11. TOTAL COST IMPACT $ none
SITE RELATED COST $ none

12. SCHEDULE IMPACT

13. WBS ELEMENT IMPACTED none

14. TITLE AND DESCRIPTION OF CHANGE:

Editorial corrections to Spent Fuel Shipping Cask (SFSC) interface requirements

See attachment for specific changes.

15. JUSTIFICATION OF CHANGE:

To provide current title and number of a reference document

16. REASON FOR CHANGE: FUNCTIONALLY NECESSARY ☒ SAFETY ☐
SIGNIFICANT IMPROVEMENT ☐ REDUCE COST ☐

17. ECP IMPACTS:

	COST IMPACT YES	COST IMPACT NO	STD. COST IMPACT / SITE RELATED COST	SCHEDULE IMPACT YES	SCHEDULE IMPACT NO	RESP REP SIGNATURE/DATE
CRBRP PO	☐	☒	0 / 0	☐	☒	
AE	☐	☒	0 / 0	☐	☒	
LRM	☐	☒	0 / 0	☐	☒	
AI	☐	☒	0 / 0	☐	☒	
GE	☐	☒	0 / 0	☐	☒	
WARD	☐	☒	0 / 0	☐	☒	
S & W	☐	☒	0 / 0	☐	☒	

18. AUTHORIZED: COG. MGR. E H Peter

19. CCB ACTION: ☐ APPROVED ☐ DISAPPROVED ☐ APPROVED AS MODIFIED

CCB CHAIRMAN'S SIGNATURE AND DATE

EXECUTIVE SUMMARY

ECP L41-003
SFSC Interface Requirements

PURPOSE

To revise the surface temperature requirement for the Spent Fuel Shipping Cask to be consistent with plant requirements for uninsulated metal surfaces. Also, to correct a reference title.

DESCRIPTION OF CHANGE

(1) Revise the temperature of the working or maintenance surfaces

(2) Correct the title of a reference document (see attachment for specific changes)

JUSTIFICATION

To meet plant requirements and to provide current title and number of a reference document

IMPACTS

Cost - None
Schedule - None
ALARA - None
PSAR - None
Key Systems Review - None
OMT - None

RECOMMENDATION

Approve the ECP as presented

JER/jka

1/26/81

APPENDIX B

Proposed Detailed Leak Test Procedure

Nomenclature (refer to Figure B-1)

AVP1,AVP2	Mechanical vacuum pumps, Varian 11 cfm or equal
BLF	Basket lid fixture
CF	Canister fixture
CGS	Contaminated gas system
CLF	Cask lid fixture
CL1-CL4	Calibrated helium/argon leaks, 1 x 10^{-7} to 1 x 10^{-8} atm cm^3/s range, for determining sensitivity and demonstrating proper leak detector operation
FH	Flexible vacuum quality hose, all metal
FHC	Fuel handling cell
FMA	Flowmeter for cask argon backfill
FMH	Flowmeter for helium
ALD1, ALD2	Helium/argon leak detectors with vent modifications and 11 cfm mechanical vacuum pumps
P1, P2	Thermocouple vacuum gases, 2 to 1 x 10^{-3} Torr
PA	Argon pressure, 0 to 5 psig
PAS	Plant argon supply
PH	Helium pressure, 0 to 100 psia
PHS	Plant helium supply
PV	Vacuum pressure, range TBD
PVS	Plant vacuum system (1 to 2 Torr)
SVT1,SVT2	Sodium vapor traps, vacuum quality construction
SP	Sniffer point, used for verifying helium or argon
TBD	To be determined
V1-V21	Shutoff valves, helium tight, bellows sealed, metal tip, NUPRO series, "BG" or "BW" or equal; powered operators optional

All lines to be 0.75-in. OD x 0.03-in. wall stainless steel.

Canister Leak Test Procedure in Fuel Handling Cell

1.0 Initial Valve Setting and Powerup

1.1 Close all valves, V1 through V21. Open V9 and V19.

1.2 Powerup ALD1 and ALD2 per manufacturer's instructions.

1.3 Powerup heat-traced lines and allow to reach operating temperature.

2.0 Preliminary ALD1 and AVP1 Checkout
The FHC gallery system is the primary and the cask corridor system is the backup.

2.1 Open V5 and start AVP1. P1 should drop to TBD in TBD minutes. Close V5. P1 should not rise more than TBD in TBD minutes.

2.2 When ALD1 is ready to go on line, switch ALD1 to VENT. Open V6 and V8 to refill SVT1 with argon.

2.3 Switch ALD1 to START. P1 should drop to TBD in TBD minutes.

2.4 Open V5. Proceed with calibration and tuning of ALD1 per manufacturer's instructions. Use V7 and CL2.

2.5 Close V7 and V5. Switch ALD1 to VENT. Open V4 and close V8.

3.0 Preliminary ALD2 and AVP2 Checkout
The procedure given below is for setting ALD2 as the backup system during canister testing.

3.1 Open V13 and start AVP2. P2 (and P1) should drop to TBD in TBD minutes. Close V13. P2 (and P1) should not rise more than TBD in TBD minutes.

3.2 When ALD2 is ready to go on line, switch ALD2 to VENT. Open V14 and V16 to refill SVT1 and SVT2 with argon.

3.3 Switch ALD2 to START. P2 (and P1) should drop to TBD in TBD minutes. Open V13. Proceed with calibration and tuning of ALD2 per manufacturer's instructions. Use V7 and CL2.

3.4 Close V7 and V13. Switch ALD2 to VENT. Close V4.

4.0 Canister Test Using Primary System
It is assumed that the canister is loaded, the head has been torqued, and the seal area is free

of sodium or its temperature is less than 350°C. The canister has argon cover gas.

4.1 Attach the CF to canister with manipulators.

4.2 Open V5, V6, and V8. Switch ALD1 to START.

4.3 When ALD1 pressure indicates in the proper range, switch to TEST. Record reading when ALD1 readout stabilizes. This is the "Zero" reading, R0.

4.4 Close V6, open V3. P1 should drop to TBD in TBD minutes. When P1 is stable and below TBD Torr, open V6.

4.5 When P1 again stabilizes and ALD1 pressure indicates in the proper range, record ALD1 reading, R1.

4.6 Open V1. When P1 has stabilized and ALD1 pressure indicates in the proper range, record ALD1 reading, R2.

4.7 Observed leak, QO, for normal case, both readings on scale and R2 larger than R1,
QO=CL1*(R1-R0)/(R2-R1).
Correct QO to air equivalent by use of procedures in ANS1 N14.5-1977.

4.8 Close V1 and V5. Switch ALD1 to VENT, close V3 and V6. Disconnect CF from canister.

4.9 If R2 and R1 were approximately the same value, or QO is higher than allowed, remove and replace canister lid. Repeat procedure starting at 4.0.

4.10 If resealed and retested canister still exceeds allowable leakages and no problems can be found in the leak detection system, remove fuel assembly and return empty canister with solidified sodium to HEF.

5.0 Canister Test Using Backup System
It is assumed that the canister is loaded, the head has been torqued, and the seal area is free of sodium or its temperature is less than 350°C. The canister has argon cover gas.

5.1 Attach the CF to canister with manipulators.

5.2 Open V4, V13, V14, and V16. Switch ALD2 to START.

5.3 When ALD2 pressure indicates in the proper range, switch to TEST. Record reading when ALD2 readout stabilizes. This is the "Zero" reading, R0.

5.4 Close V14, open V3. P2 (and P1) should return to TBD in TBD minutes. When P2 is stable and below TBD Torr, open V14.

5.5 When P2 again stabilizes and ALD2 pressure indicates in the proper range, record ALD2 reading, R1.

5.6 Open V1. When P2 has stabilized and ALD2 pressure indicates in the proper range, record ALD2 reading, R2.

5.7 Observed leak, QO, for normal case, both readings on scale and R2 larger than R1,
QO=CL1*(R1-R0)/(R2-R1).
Correct QO to air equivalent by use of procedures in ANSI N14.5-1977.

5.8 Close V1 and V13. Switch ALD2 to VENT, close V3 and V14. Disconnect CF from canister.

5.9 If R2 and R1 were approximately the same value, or QO is higher than allowed, remove and replace canister lid. Repeat procedure starting at 5.0.

5.10 If resealed and retested canister still exceeds allowable leakage and no problems can be found in the leak detection system, remove fuel assembly and return empty canister with solidified sodium to HEF.

Basket Lid Leak Test Procedure in Glove Box

6.0 Initial Valve Setting and Powerup

6.1 Close all valves, V1 through V21. Open V9 and V19.

6.2 Powerup ALD1 and ALD2 per manufacturer's instructions.

6.3 Powerup heat-traced lines and allow to reach operating temperature.

7.0 Preliminary ALD2 and AVP2 Checkout
The procedure given below is for setting ALD2 as the primary system during basket lid testing.

7.1 Open V13 and start AVP2. P2 should drop to TBD in TBD minutes. Close V13. P2 should not rise more than TBD in TBD minutes.

7.2 When ALD2 is ready to go on line, switch ALD2 to VENT. Open V14 and V16 to refill SVT2 with argon.

7.3 Switch ALD2 to START. P2 should drop to TBD in TBD minutes.

7.4 Open V13. Proceed with calibration and tuning of ALD2 per manufacturer's instructions. Use V15 and CL4.

7.5 Close V15 and V13. Switch ALD2 to VENT. Close V16.

8.0 Preliminary ALD1 and AVP1 Checkout
The procedure given below is for setting ALD1 as the backup system during basket lid testing.

8.1 Open V5 and V4, start AVP1. P1 (and P2) should drop to TBD in TBD minutes. Close V5. P1 (and P2) should not rise more than TBD in TBD minutes.

8.2 When ALD1 is ready to go on line, switch ALD1 to VENT. Open V6 and V8 to refill SVT1 and SVT2 with argon.

8.3 Switch ALD1 to START. P1 (and P2) should drop to TBD in TBD minutes. Open V5. Proceed with calibration and tuning of ALD1 per manufacturer's instructions. Use V15 and CL4.

8.4 Close V15 and V5. Switch ALD1 to VENT. Close V4 and V8.

9.0 Basket Lid Test Using Primary System

It is assumed that the basket is loaded, the lid studs have been torqued, and the seal area is free of sodium or its temperature is less than 350°C.

9.1 Attach the BLF to basket lid.

9.2 Open basket lid valve (not numbered) and V20. Allow PV to drop to TBD.

9.3 Close V20 and open V18 and V21. Monitor helium flow with FMH.

9.4 Close V18 and V21 when PH reaches TBD.

9.5 Open V13 and V16. Switch ALD2 to START.

9.6 When ALD2 pressure indicates in the proper range, switch to TEST. Record reading when ALD2 readout stabilizes. This is the "Zero" reading, R0.

9.7 Close V14, open V12. P2 should return to TBD in TBD minutes. When P2 is stable and below TBD Torr, open V14.

9.8 When P2 again stabilizes and ALD2 pressure indicates in the proper range, record ALD2 reading, R1.

9.9 Open V11. When P2 has stabilized and ALD2 pressure indicates in the proper range, record ALD2 reading, R2.

9.10 Observed leak, QO, for normal case, both readings on scale and R2 larger than R1,

QO=CL3*(R1-R0)/(R2-R1).

Correct QO to air equivalent by use of procedures in ANSI N14.5-1977.

9.11 Close V11 and V13. Switch ALD2 to VENT, close V12 and V14. Disconnect BLF from basket lid.

9.12 If R2 and R1 were approximately the same value, or QO is higher than allowed, remove and replace basket lid. Repeat procedure starting at 9.0.

9.13 If resealed and retested basket still exceeds allowable leakage and no problems can be found in the leak detection system, remove basket lid, examine and repair seal area as required.

10.0 Basket Lid Test Using Backup System

It is assumed that the basket is loaded, the lid studs have been torqued, and the seal area is free of sodium or its temperature is less than 350°C.

10.1 Attach the BLF to basket lid.

10.2 Open basket lid valve (not numbered) and V20. Allow PV to drop to TBD.

10.3 Close V20. Open V18 and V21. Monitor helium flow with FMH.

10.4 Close V18 and V21 when PH reaches TBD.

10.5 Open V4.

10.6 Open V5, V6, and V8. Switch ALD1 to START.

10.7 When ALD1 pressure indicates in the proper range, switch to TEST. Record reading when ALD1 readout stabilizes. This is the "Zero" reading, R0.

10.8 Close V6, open V12. P1 should drop to TBD in TBD minutes. When P1 is stable and below TBD Torr, open V6.

10.9 When P1 again stabilizes and ALD1 pressure indicates in the proper range, record ALD1 reading, R1.

10.10 Open V11. When P1 has stabilized and ALD1 pressure indicates in the proper range, record ALD1 reading, R2.

10.11 Observed leak, QO, for normal case, both readings on scale and R2 larger than R1,

QO=CL3*(R1-R0)/(R2-R1).

Correct QO to air equivalent by use of procedures in ANSI N14.5-1977.

10.12 Close V11 and V5. Switch ALD1 to VENT, close V12 and V6. Disconnect BLF from basket lid.

10.13 If R2 and R1 were approximately the same value, or QO is higher than allowed, remove and replace basket lid. Repeat procedure starting at 10.0.

10.14 If resealed and retested basket lid still exceeds allowable leakage and no problems can be found in the leak detection system, remove basket lid, examine and repair seal area as required.

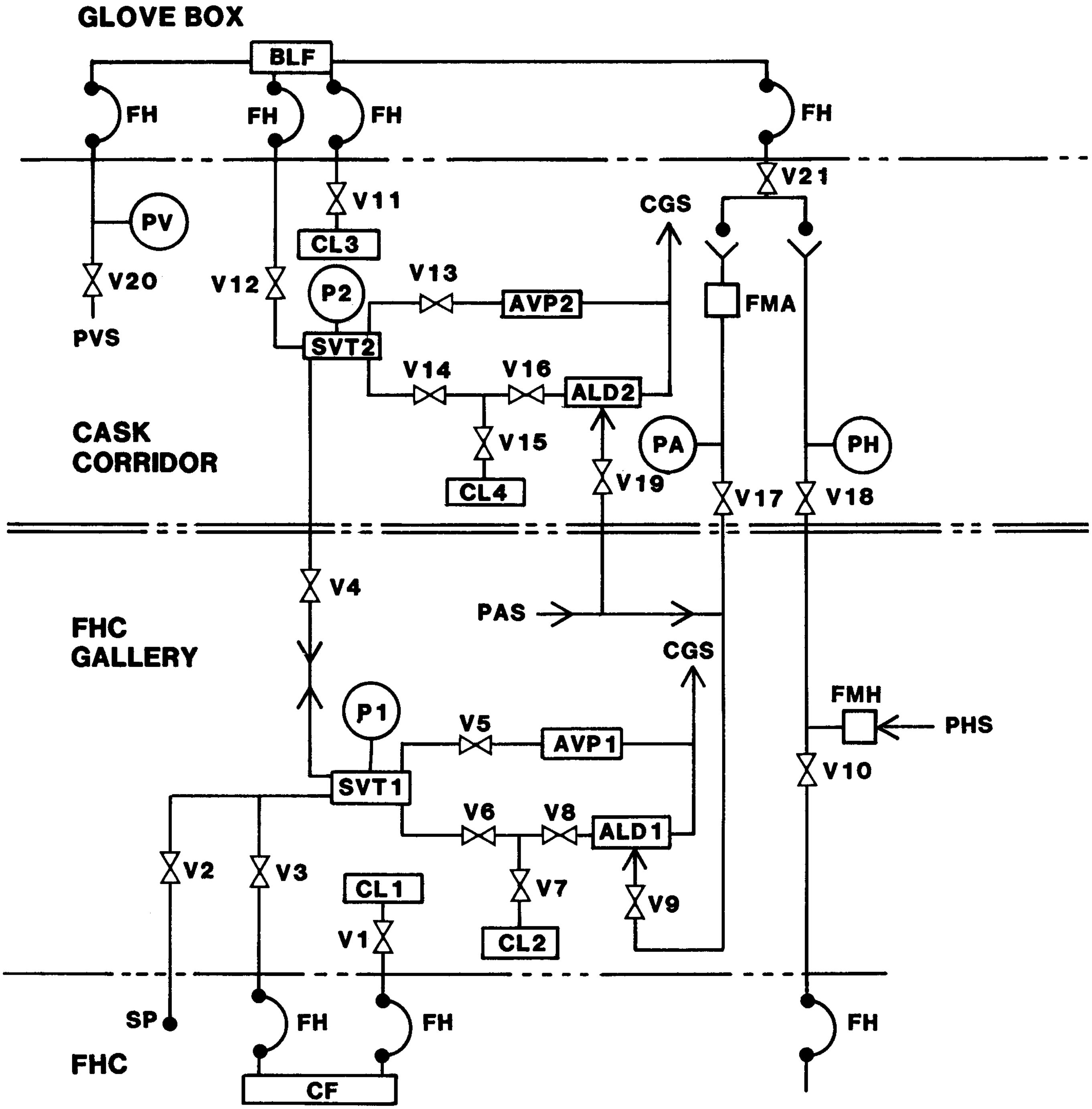

Figure B-1 Leak Detection System Diagram

APPENDIX C
List of Drawings

CRBRP Drawing No. CL	Sandia Drawing No. T	Title
54020	81085	Cask ASSY 2 Level Containment, Monolith
54021	81089	Cask ASSY 2 Level Containment, Basket
54022	81067	Cask ASSY 3 Level Containment, w/Basket
54023	81090	Basket CRBRP
54024	81087	Lid, Basket, CRBRP
54025	81086	Cask Body, Monolith (SHT 1-5)
54026	81091	Cask Body, Basket, 2 Level Containment (SHT 1-5)
54027	81066	Cask Body, 3 Level Containment
54030	78943	Canister Assembly
54031	78944	Body, Canister
54032	78945	Cap, Sealing
54033	78946	Swing Bolt w/Nut Assy
54034	81063	125 Ton Well Car (4 Axle)
54035	81064	150 Ton Depressed Center Flat Car (8 Axle)
54036	81065	Cask Removal
54037	81224	130 Ton Depressed Center Flat Car (6 Axle)

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