ENCLOSURE (2)

WAPD-LP(FE)-220

SAFETY ANALYSIS REPORT FOR PACKAGING
SUPER TIGER SHIPPING CONTAINER
AS ADAPTED FOR LWBR TYPE FUEL RODS

(LWBR Development Program)

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TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF EFFECTIVE PAGES

Page	Issue
Title Page	Rev. 3, Feb. 1983
i thru vii	Rev. 3 Feb. 1983
1-1	Rev. 2, Sept. 1981
1-2 thru 1-4	Rev. 3, Feb. 1983
Figure 1.1	Original
Figure 1.2 thru 1.6	Rev. 3, Feb. 1983
2-1	Rev. 2, Sept. 1981
2-2 thru 2-3	Rev. 3, Feb. 1983
2-4 thru 2-5	Rev. 2, Sept. 1982
2-6	Rev. 3, Feb. 1983
2-7 thru 2-8	Rev. 2, Sept. 1981
2-9	Rev. 3, Feb. 1983
2-10 thru 2-12	Rev. 2, Sept. 1981
2-13 thru 2-14	Rev. 3, Feb. 1983
2-15	Rev. 2, Sept. 1981
2-16 thru 2-23	Rev. 3, Feb. 1983
2-24	Rev. 2, Sept. 1981
2-25	Rev. 3, Feb. 1983
Figure 2.1	Original
Figure 2.2 thru 2.3	Rev. 3, Feb. 1983
3-1	Rev. 3, Feb. 1983
4-1	Rev. 2, Sept. 1981
5-1 thru 5-8	Rev. 3, Feb. 1983
Tables 5.1 thru 5.5	Rev. 3, Feb. 1983
Figures 5.1 thru 5.6	Rev. 3, Feb. 1983
6-1 thru 6-16	Rev. 3, Feb. 1983
Table 6.1 thru Table 6.6	Rev. 3, Feb. 1983
Table 6.7	Rev. 1, Feb. 1981
Table 6.8 thru 6.14	Original
Table 6.15	Rev. 3, Feb. 1983
Figure 6.1 thru 6.5	Rev. 3, Feb. 1983
7-1 thru 7-3	Rev. 3, Feb. 1983
8-1 thru 8-2	Rev. 3, Feb. 1983
8-3 thru 8-4	Rev. 2, Sept. 1981

CHAPTER 1 GENERAL INFORMATION

1.1 Introduction

This Safety Analysis Report for Packaging supports the required revision to the Super Tiger Shipping Container Certificate of Compliance USA/6400/BLF (ERDA-NR) to permit the transport of Large Quantities of U-233 in the form of LWBR type unirradiated fuel rods as a Fissile Class III shipment.

The Super Tiger was designed and tested to the requirements of Code of Federal Regulations (CFR) Title 10, Part 71 to assure nuclear safety during transport. Subsequent evaluations have confirmed that the Super Tiger may not meet all defined transport requirements without specific secondary packaging. This Safety Analysis Report provides the assessment of the required secondary packaging to accomodate the LWBR type fuel rods.

1.2 Package Description

1.2.1 Packaging

The packaging consists of the existing Super Tiger and a new inner containment assembly which restrains the fuel rods in an ordered array within the Super Tiger cavity.

1.2.1.1 Super Tiger Shipping Container

This existing container (Figure 1.1) is a protective overpack which provides physical containment, impact resistance, and thermal resistance for its contents. The containment vessel (cavity) is approximately 76 inches by 76 inches by 172 inches and is constructed of 10 gauge and 3/16 inch thick mild steel. Closure of the containment vessel is by a 1/4 inch thick aluminum plate and silicone rubber gasket bolted to the containment vessel. A capped pressure fitting on the closure plate provides a means for leak testing. The containment vessel is centered and supported in an outer 3/16 inch thick mild steel jacket by approximately 32 inches of polyurethane foam insulation at the forward end and 10 inches on the sides. A side hinged rear access door consisting of approximately 34 inches of polyurethane foam insulation encased in mild steel with a silicone rubber gasket is bolted to the main outer steel jacket during transport. The overall dimensions of the package are approximately 96 inches square by 240 inches long. Set into each corner of the outer container are standard steel tie down fittings. The weight of an empty container is approximately 18,600 lbs and the weight of a fully loaded container is nominally 45,000 lbs.

The access door installation is such that full containment of all Super Tiger contents cannot be assured under all defined transport conditions without special secondary packaging. The Department of Energy Super Tiger used by the Bettis Atomic Power Laboratory is further limited to applications with special secondary packaging due to the presence of approximately 12-3/8" dia. steel pins installed in a random pattern between the steel walls of the inner containment vessel and the outer jacket and other deviations as shown in Figure 1.6.

1.2.1.2 Inner Containment Assembly

The new Super Tiger inner containment assembly (Figure 1.2) consists of a shielded steel storage compartment (Figure 1.3) and a polyurethane foam inner liner (Figure 1.4).

The storage compartment consists of four carbon steel tubes enclosed within two inch thick carbon steel plates. This compartment will accomodate four rod storage containers (Figure 1.5) under all loading conditions.

The multi-section inner liner is fabricated of molded polyurethane foam. This inner liner will shore the storage compartment within the center of the Super Tiger cavity for optimum radiation levels at the outer walls and provide additional shock absorbing features for the rod storage containers. The liner will support the storage compartment during normal transport conditions and distribute impact loads over at least 60% of the applicable Super Tiger inner cavity walls as required under the accident drop criteria.

1.2.2 Operational Features

Shipments in the Super Tiger shipping container are made dry with only natural modes of heat removal. The passive nature of the shipping container design requires no analysis of operational features since no operations are required.

1.2.3 Contents of Packaging

The package will be limited to no more than 50 Kg of fissile material per shipment and it has been determined to be nuclearly safe under all possible loading arrangements within defined transport and accident criteria. The total complement of rods to be transported is summarized in Table 6.2. The core and detailed cell rods will be packaged at approximately 490 seed, 160 PFB, or 140 blanket rods per rod storage container. The shorter BMU rods will be packaged in three inner containers at approximately 180 blanket (two inner containers) and 600 seed (one inner container) per rod storage container. As summarized in Section 6, the most reactive configuration is approximately 200 high zone seed rods per container (with optimum rod spacing) rather than the full complement of rods. This configuration will not exist in actual practice since any partially filled containers will be filled with aluminum shim stock as specified in Paragraph 7.4.

The maximum allowable package fissile material load of 50 Kg is summarized in paragraph 1.2.3.1. The actual shipments will average less than 40 Kg of fissile material per package.

1.2.3.1 Quantity of Radionuclides

1. Fissile Material 50.0 Kg

2. Curie Content by Nuclide:

U-233 (and Daughters)	476.77
U-234	4.81
U-235	6.76×10^{-5}
Ra-228	5.51×10^{-2}
Ac-228	5.51×10^{-2}
Th-232	0.20
U-232	6.52
Th-228	2.89
Th-228 Daughters*	16.70
	508.00 ci

* Ra-224, Rn-220, Po-216, Pb-212, Bi-212, Po-212, Ti-208

1.2.3.2 Chemical and Physical Forms

The fissile material will be in the form of solid high density high integrity UO_2 + Th O_2 pellets retained within Zircaloy fuel rod cladding.

1.2.3.3 Material Density

Refer to Table 6.4.

1.2.3.4 Moderator Ratios

There are no significant quantities of moderators in the rod storage containers under normal transport conditions.

1.2.3.5 Decay Heat

The Super Tiger is currently certified for 30 watts decay heat. The allowable load of 50 Kg of fissile material will generate approximately 28 watts and therefore comply with this limit.

1.2.3.6 Internal Pressure Buildup

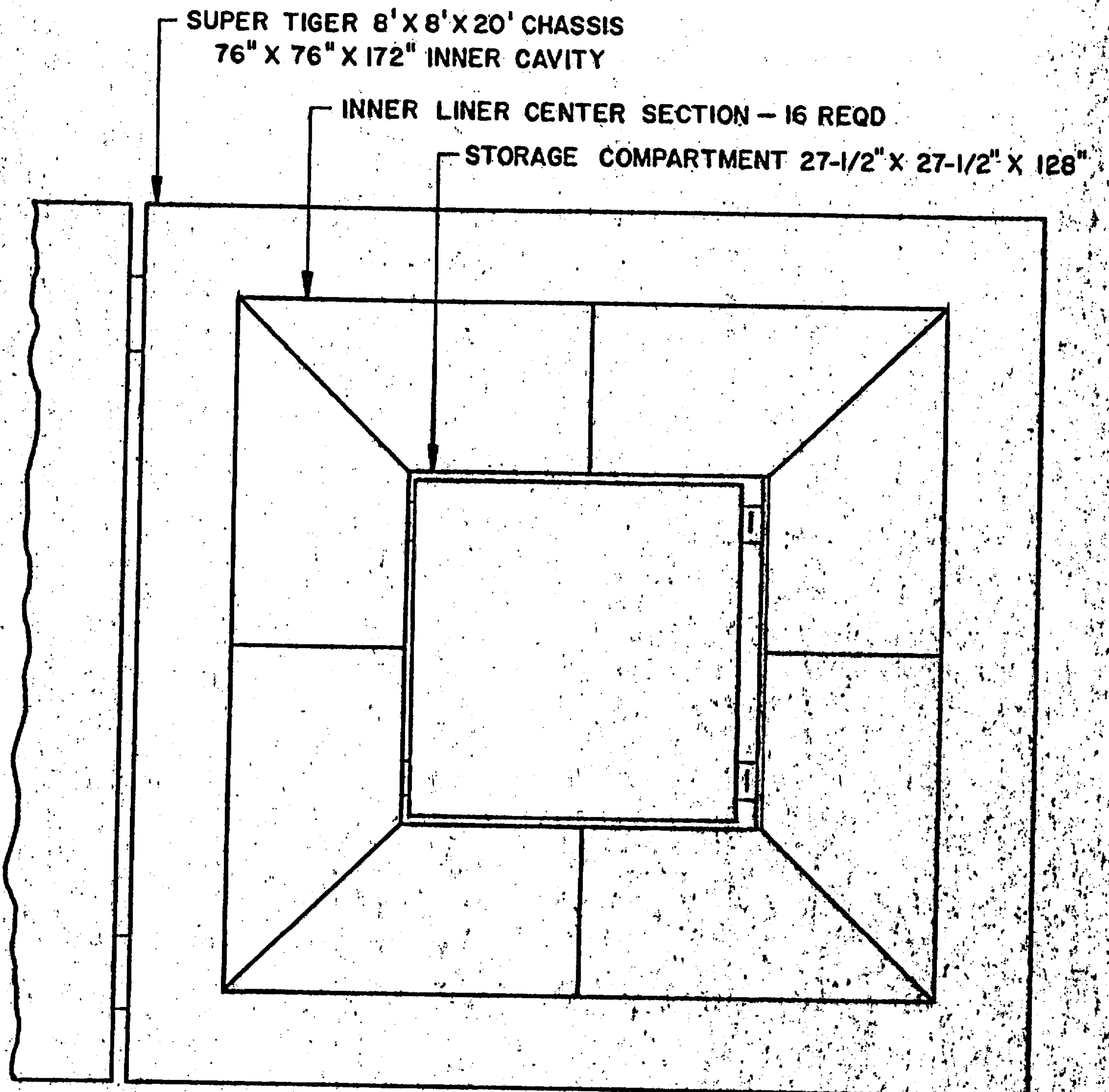
The maximum pressure reached within the sealed container during shipment is 18.3 psia based on a maximum internal air temperature of 200°F as calculated in Chapter 3.

1.3 Appendix

1.3.1 Figures

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 1.1 SUPER TIGER SHIPPING CONTAINER



REAR VIEW
ACCESS DOOR OPENED, CLOSURE PLATE AND TWO REAR SECTIONS OF INNER LINER REMOVED

REFERENCE DWG NO. 1576E84

FIGURE 1.2 SUPER TIGER STORAGE COMPARTMENT INSTALLATION

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 1.3 SUPER TIGER STORAGE COMPARTMENT

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 1.4 SUPER TIGER INNER LINER

- At

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 1.5 LWBR ROD STORAGE CONTAINER

FIGURE WITHHELD UNDER 10 CFR 2.390

ft

FIGURE 1.6 SUPER TIGER SHIPPING CONTAINER AS-BUILT DEVIATIONS

CHAPTER 2. STRUCTURAL EVALUATION

2.1 Structural Design

2.1.1 Discussion

The structural members which contribute to the safe transport of the LWBR fuel rods are the Super Tiger shipping container, the inner liner, the storage compartment, the rod storage containers, and the rod cladding.

2.1.1.1 Super Tiger

The Super Tiger (Protective Packaging Inc. Drawing No.32106) is essentially two right-rectangular steel containers, one within the other, separated by polyurethane foam. The inner container (containment vessel) is approximately 76 inches x 76 inches x 172 inches constructed of 10-gauge and 3/16 inch thick low carbon (mild) steel with welded lap joints. Closure of the containment vessel is accomplished by a 1/4 inch thick aluminum plate which is bolted by 1/2 inch diameter bolts, spaced 10 inch on centers, to a 1 1/4 inch x 1 1/4 inch x 1/4 inch steel angle which is welded to the containment vessel. A silicone rubber seal is bonded to the closure plate. A pressure fitting with cap is provided on the closure plate to provide a means for leak testing. The containment vessel is centered and supported in an outer 3/16 inch thick steel jacket by approximately 32 inches of polyurethane foam insulation on the forward end and 10 inches on the sides, top, and bottom. The outer steel jacket is approximately 96 inches x 96 inches x 240 inches with welded lap joints. All external edges are further reinforced by diagonal gusset plates of 12 gauge steel. Two 1/8 inch thick steel breakaway plates are plug welded to the inner surface of each side of the outer container. The outer container is in two sections, one section in which the containment vessel is formed as described above and the other, essentially a 34 inch thick cover of similar construction, which provides access to the containment vessel. The removable cover is secured to the main body by ten high strength steel bolts through 6 inch ship channels which are welded to the outer jacket. Four dowel pins assure accurate alignment of the cover to the main body. A silicone seal is provided between the ship channels and the cover. Vent holes consisting of 1 1/2 inch diameter pipe flange and plastic plug are provided, two on each side of the container and one on each end. Set into each corner of the outer container are standard I.S.O. (International Organization for Standardization) steel castings welded to the side plates and 3/16 inch thick steel corner reinforcements. A schematic of the Super Tiger is shown in Figure 1.1.

The Super Tiger design was analyzed and prototype tested to the requirements of 10 CFR, Part 71 as documented by Reference 2.1. The Department of Energy-owned Super Tiger to be used for LWBR rod transport has been in extensive use by the Bettis Atomic Power Laboratory for approximately six years.

This shipping container deviates from the original design such that the additional features of the new inner components and transported fuel rods must be considered in order to ensure compliance with the defined transport requirements. The rear cover installation does not ensure that the aluminum closure plate is protected from external pressure changes and the inner containment vessel weld quality does not ensure positive closure. The inner containment vessel walls are not consistantly bonded to the polyurethane foam to ensure a "laminated beam" structure as identified in the analysis of Reference 2.1 and approximately 12-3/8" diameter steel pins have been welded between the inner and outer closure walls as shown in Figure 1.6 to retain the inner walls in position. These pins were apparently installed without formal documentation as part of the subcontractor repair to this shipping container as discussed in Paragraph 2.6.3. The polyurethane foam also may contain voids and density variations such as recently noted in evaluations of other Super Tigers.

2.1.1.2 Inner Liner

The multi-section polyurethane foam inner liner, Figure 1.4, will center the storage compartment within the Super Tiger cavity during normal transport and provide primary impact resistance and load distribution during accidental drop conditions. The molded polyurethane foam weighs approximately five pounds per cubic foot and has a compressive yield strength of approximately 80 pounds per square inch. The multi-section construction will permit the liner to be installed snugly in the Super Tiger cavity in conjunction with the storage compartment and the rear sections can be manually removed to provide access for rod loading and unloading. The inner liner will be subjected to compression loads only and will distribute the shielded rod storage compartment transport loads over at least 60% of the applicable Super Tiger inner cavity impact surface as required on page 105 of Reference 2.1 to assure that the loads imposed during original Super Tiger drop tests are not exceeded. This new inner liner fills the Super Tiger cavity and provides reinforcement for the inner containment vessel walls and cover plate to prevent inward buckling under defined transport and hypothetical accident conditions. The liner also is of sufficient thickness to prevent the storage compartment from impacting on the steel pins in the Super Tiger chassis walls under the accident conditions. The inner liner sections are designed for fabrication from commercially available molded polyurethane stock.

2.1.1.3 Storage Compartment

The storage compartment, Figure 1.3 will retain four rod storage containers for transport. The compartment is fabricated of four 11 3/4 inch OD by 9 inch ID carbon steel tube sections enclosed within four 2 inch thick carbon steel plates for structural integrity and gamma radiation shielding. The ends of the storage compartment are covered by one inch thick carbon steel plates. The front plate is welded in position and the rear plate is attached by side-mounted hinges and two padlocks for ready access and minimum radiation exposure during loading and unloading operations. The storage compartment design is structurally conservative such that the radiation shielding and the rod storage tubes will withstand all normal and accident transport conditions without change in geometric form.

2.1.1.4 LWBR Rod Storage Containers

The rod storage containers, Figure 1.5, are fabricated of 8 5/8 OD by 7 5/8 ID stainless steel tubes. The 1/4 inch thick bottom cover is welded in position and the 2 inch thick top cover is attached with four 1/2 inch self-locking screws. The shorter BMU rods will be packaged in 7 1/2 inch OD by 7 inch ID inner containers at three inner containers per rod storage container.

2.1.1.5 Fuel Rod Cladding

The fuel rod cladding, Drawing 944F403 (Typical), consists of Zircaloy tubing with welded solid Zircaloy end closures. The rods were fabricated, inspected, and maintained to rigid quality assurance standards and no cladding breach is expected during transport operations. The rod cladding is of core quality in that all rods were double helium leak tested and inspected for defects using ultrasonic and x-ray methods. The rod cladding dimensions are provided in Tables 6.9, 6.11, and 6.14.

2.1.2 Design Criteria

2.1.2.1 General

The Super Tiger shipping container was designed to absorb all normal transport and hypothetical accident loads. Impact loads are absorbed by the regional yield failure of the ductile outer shell and the polyurethane liner material. Puncture and fire test accident criteria are met through the regional ultimate failure of the outer shell and the polyurethane liner.

A Super Tiger prototype was analyzed and tested to the performance requirements of Code of Federal Regulations 10CFR71 as documented by Reference 2.1. The Super Tiger contents are subjected only to the impact loads of the defined drop tests since the Super Tiger chassis provides isolation from the other transport parameters. The new polyurethane foam inner liner will absorb additional impact loads through compressive yield and the new storage compartment will withstand all induced impact loads without structural yield or change in geometric form. Energy relationships are used to evaluate the effects of the free drop accidents on the new components. The potential energy of the component is equated to the work of deformation in crushing the polyurethane foam to obtain static equilibrium. The crush area of the foam evaluated at crush depth times the material's crush stress is considered the crush force incident to impact. The crush force divided by the dropped weight represents the peak deceleration loading. The internal stresses within the component are determined on the basis of the calculated deceleration loading and are used to assess the appropriate modes of failure for the defined normal transport and hypothetical accident impact loads.

The compressive yield of the new inner liner is sufficient to support the new storage compartment and contents under accident induced loads such that the additional impact absorbing characteristics of the as-built Super Tiger chassis are of minor significance.

Compressive loads are negligible and the new storage compartment is designed to withstand the bending loads induced during the hypothetical drop test conditons. The only storage compartment members subject to this bending load are the walls of the carbon steel tubes which support the rod storage containers during hypothetical side or bottom drops. The tube walls are analyzed as fixed-end beams subject to outer surface yield failure at the specified tensile yield stress under the induced drop test deceleration loads.

All Super Tiger shipments for this application will consist of LWBR type Zircaloy-clad fuel rods. The LWBR rod cladding was analyzed to the requirements of 10CFR71 as part of the LWBR core module shipments in the LWBR New Fuel Shipping Container as documented by Reference 2.2. The allowable impact loads prior to cladding failure are conservative for the induced impact loads of Super Tiger transport as discussed in paragraph 2.7.1.5.

2.1.2.2 Buckling

The existing Super Tiger shipping container exhibited no buckling during the prototype drop tests. The inner container cavity will be shored in position by the new polyurethane foam inner liner for this application such that buckling of the cavity walls due to poor bonding to the chassis foam liner is prohibited. The new storage compartment has no structural components which are subject to buckling failure as analyzed to the slenderness ratio criterion as defined on Page 5-41 of Reference 2.3.

2.1.2.3 Fatigue

Both the Super Tiger and the new storage compartment were designed to the structural criteria for the hypothetical accidents and repetitive operational loads required to induce fatigue failure are minimal. The inner compartment is completely supported on all sides by the polyurethane inner liner and is not subjected to the direct impact loads of highway transport.

The new inner liner is fabricated of polyurethane foam with a crush strength of approximately 80 psi and the maximum static loading is approximately 6.5 psi. Limited fatigue failure due to repetitive transport shock loads is not critical to the inner liner function; however, any liner sections exhibiting apparent fatigue failure due to the repetitive trips will be replaced with new components.

2.1.2.4 Brittle Fracture

Brittle fracture or material failure at stress levels below the tensile yield stress is limited to certain materials such as carbon steel which exhibit a defined transition temperature where behavior under stress changes from ductile (exhibiting considerable deformation beyond the yield stress) to brittle where failure occurs with negligible elongation.

The existing Super Tiger chassis is fabricated of mild carbon steel; however, brittle fracture is not normally a concern for thin (3/16") sheets as used in the Super

Tiger. Under the new application, the Super Tiger inner compartment will be laminated between the polyurethene foam Super Tiger liner and new inner liner and will be subjected to minimal concentrated stress loads.

The new storage compartment is fabricated of commercially available mild carbon steel components. The thick sections were selected for gamma radiation shielding such that individual fabrication stresses and normal transport loads are negligible.

2.2 Weights and Center of Gravity

The allowable gross weight of the Super Tiger shipping container is 45,000 pounds. The maximum weight of the individual components is as follows:

1.	Empty Super Tiger	19,000 lbs.
2.	Inner Liner	3,000 lbs.
3.	Storage Compartment	15,000 lbs.
4.	Rod Storage Containers (Four containers at 2,000 lbs each	8,000 lbs.
	Total (Maximum)	45,000 lbs.

All components are symmetrical and the center of gravity of the empty or loaded Super Tiger is at the approximate mid-point for all orientations.

2.3 Mechanical Properties of Materials

Definition of Symbols

S_u = Ultimate tensile stress at indicated temperature in pounds per square inch.

S_y = Tensile stress (.2% strain offset) at yield point at indicated temperature in pounds per square inch.

S_c = Static crush stress (compressive yield)

E = Modulus of elasticity in pounds per square inch.

TE_c = Mean coefficient of thermal expansion between temperatures of interest in inches per inch per degree fahrenheit

D = Density of material in pounds per cubic inch.

K_D = Ratio of dynamic to static crush strength.

2.3.1 Material

Structural carbon steel - ASTM A-36 (ASME SA-36)

Component

Storage compartment components

Reference

1980 ASME Code, Section III, appendices

Table	Page
I-5.0	94
I-6.0	99
I-13.1	190

Property	70°F	200°F	Units
S_u	58.0	-	10^3 psi
S_y	36.0	32.8	10^3 psi
E	29.9	29.5	10^6 psi
TE_c	6.41	6.93	10^{-6}/°F
D	.29	.29	lb/in^3

2.3.2 Material

Polyurethane foam

Component

Inner liner sections

Reference

MIL-P-26514 Type I, Class 1

Property	70°F	200°F	Units
S_c	80	80	psi
D	5.0	5.0	lb/ft^3
K_D	1.0	-	-

2.3.3 Material

Steel - ASTM A193 Gr B8C.
(ASME SA-193, AISI Type 347 18-8 Stabilized)

Component Misc. Thread Fasteners

Reference

ASTM Specification Minimum Values degraded with temperature to the solution treated A193 Gr B8C material, Table 1.7.3. of Section III Appendices of 1977 ASME Code

Property		70°F	200°F	Units
S_u	(1)	115	112.5	
	(2)	105	102.5	10^3 psi
S_y	(1)	80	77.5	10^3 psi
	(2)	65	62.5	
E		28.3	27.7	10^6 psi
TE_c		-	9.34	10^{-6} psi
D		.29		$\#/in^3$

(1) Diameters > .25 to 1.0
(2) Diameters > 1.0 to 1.25

2.4 General Standards for All Packages

The shipping package is in compliance with the general standards for all packaging specified in 10CFR71.31 as demonstrated in the following paragraphs.

2.4.1 Chemical and Galvanic Action

The Super Tiger is fabricated of primed and painted carbon steel and has been in operational use for approximately six years with no evidence of undesirable corrosion effects. The new storage compartment is fabricated of thick carbon steel and the steel components will not contact metallic surfaces other than the stainless steel rod transport containers. No operational components of the shipping package are subject to critical chemical or galvanic damage. The package will be used to ship rods for long term storage or U233 recovery and the rod cladding will not be adversely affected due to contact with the storage containers.

2.4.2 Positive Closure

The Super Tiger door is secured by 10-one inch diameter steel bolts torqued to 150-200 foot/pounds. The inner seal plate is secured by 36-one half inch diameter steel bolts torqued to 35-45 foot/pounds. The rear section of the polyurethane foam inner liner must be removed to gain access to the storage compartment. The hinged storage compartment door is secured by two padlocks. Each of the four loaded rod storage containers must be individually removed from the storage compartment and opened for access to the rods. These combined features prevent inadvertent entry to the shipping package.

2.4.3 Lifting Devices

Not applicable. The Super Tiger will remain mounted on the flat-bed trailer during all transport operations and the side-hinged access door is manually operated. The standard lifting/tiedown fittings fabricated into the Super Tiger corners and previously certified will not be used for this application.

2.4.4 Tiedown Devices

10CFR71.31(d) requires that the tiedown fittings be capable of reacting a load of two times the package weight vertically, ten times the weight in the direction of travel, and five times the weight laterally without generating stress in any package material in excess of its yield stress. Failure of any fitting under excessive loads must not impair the ability of the package to meet the other general package requirements. The Super Tiger is mounted on the flat bed trailer by four 1 1/2 inch diameter steel bolts attached to the Standard ISO (International Organization for Standardization) corner fittings fabricated into the bottom of the Super Tiger. These fittings were previously analyzed for the Super Tiger certification as discussed on page 21 of Reference 2.1. Failure of the tiedown device during excessive load conditions, as in a hypothetical 30 foot drop, would not compromise the integrity of the inner containment as discussed on page 110 of Reference 2.1. The corner fittings are mounted in the outer Super Tiger shell such that bolt, fitting, or installation failure would leave the inner closure intact.

2.5 Standards for Type B and Large Quantity Packaging

The shipping package is in compliance with the standards for type B and large quantity packaging specified in 10CFR71.32 as demonstrated in the following paragraphs.

2.5.1 Load Resistance

The package must be capable of withstanding a uniform load equal to five times the loaded package weight applied along any major axis without generating stresses in excess of the material yield strength. The Super Tiger meets this requirement as discussed on page 114 of Reference 2.1. No significant reduction in this capability is expected due to the partial lack of bonding between the inner cavity walls and the chassis foam liner. The new foam inner liner will be shored snug against the cavity walls to preclude wall buckling and the container chassis will continue to react to this load as a short (20 foot) beam with a composite large (eight foot) thickness.

2.5.2 External Pressure

The package must be adequate to assure that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 pounds per square inch gauge. This requirement was previously analyzed for the Super Tiger certification as discussed on pages 19, 116, and 143 of Reference 2.1. There is no assurance that the Super Tiger inner chassis will now retain a positive seal under differential external pressures because of the poor welds, incomplete cavity wall bonding, and insufficiently sealed access door; however, massive chassis, cavity wall, or cover plate failure will now be prevented by the new inner liner and storage compartment and loss of contents would be prevented by the fuel rod cladding. The rod cladding was designed to withstand operating pressures of approximately 2000 psi at 500°F and the cladding integrity will be retained during all hypothetical accident conditions such that no fuel materials would be released as a result of an extended or intermittent 25 psi external pressure. The rod storage containers, storage compartment structure, and container chassis would also retain individual rods within the package.

2.6 Normal Conditions for Transport

The shipping package is in compliance with the standards for normal conditions of transport specified in 10CFR71.35 as demonstrated in the following paragraphs.

2.6.1 Heat

The package must be assessed for the effects of direct sunlight at an ambient temperature of 130°F in still air. This requirement was not specifically analyzed for the Super Tiger certification; however, as discussed in Paragraph 2.7.3, the Super Tiger prototype was subjected to the 1475°F thermal test with no adverse effect on the operational capability. No operational components are subject to ambient temperature malfunction and the insulational nature of the polyurethane foam liner limits the internal temperature change.

2.6.2 Cold

The package must be assessed for the effects of an ambient temperature of -40°F in still air and shade. This requirement was not specifically analyzed for the Super Tiger Certification; however, no adverse effects are expected due to the lack of temperature sensitive operational components and the insulational nature of the foam liner as discussed in paragraph 2.6.1.

2.6.3 Pressure

The package must be assessed for the effects of atmospheric pressure equal to 0.5 standard atmospheric pressure. This requirement was previously analyzed for the Super Tiger certification as discussed on page 118 of Reference 2.1. The structural integrity of the Super Tiger would be retained; however, the fuel materials would also be retained by the rod cladding as discussed in Paragraph 2.5.2 in the event of a Super Tiger containment failure. It is noted that the existing Super Tiger was damaged while being returned empty from Idaho to Bettis after its initial shipment. The inner steel liner separated from the polyurethane foam apparently due to the reduced internal pressure resulting from sealed shipment from a lower to higher atmospheric pressure. The containment boundary seal was not ruptured during this incident and no further incidents of this nature have occurred in the six years of extensive use since the container was repaired. The inner cavity is now vented to atmosphere during empty transport, is always filled to capacity during sealed shipments, and is always vented prior to removal of the aluminum closure plate. For this rod transport application, the new polyurethane foam inner liner will provide a protective buffer to prevent wall collapse due to extreme pressure variations.

2.6.4 Vibration

The package must be assessed for the effects of vibration normally incident to transport. This requirement was not specifically analyzed for the Super Tiger certification; however, no Super Tiger operational features are sensitive to vibration induced loads. The polyurethane foam Super Tiger liner and inner liner will also dampen any vibration induced loads as discussed in paragraph 2.1.2.3.

2.6.5 Water Spray

The package must be assessed for the effects of a water spray sufficiently heavy to keep the exposed surface continually wet during a 30 minute period. This requirement was not analyzed for the Super Tiger certification; however, the Super Tiger has been stored outside during the approximately six years of operational use with no evidence of water penetration into the storage compartment or external damage other than minor surface rusting. Water leakage into the inner cavity would not jeopardize the structural integrity of the package and fuel materials would be retained by the rod cladding as discussed in Paragraph 2.5.2. The storage compartment was evaluated for total flooding in Chapter 6 and the package would remain nuclearly safe even under massive leakage conditions.

2.6.6 Free Drop

The package must be assessed for the effects of a one foot free drop on a flat unyielding horizontal surface in a position of expected maximum damage. This requirement was not specifically analyzed for the Super Tiger certification; however, the analysis for the 30 foot drop test as discussed on pages 11 and 67 of Reference 2.1 can be applied to this requirement. Maximum damage to the Super Tiger shipping container was expected during a corner drop due to the smaller cross section of material to absorb the impact loads. A one foot corner drop would result in a considerably lower crush depth and G loading than the approximate 47 inch crush depth and 25 G loading for a 30 foot drop as calculated in Reference 2.1. The additional energy absorbing qualities of the Super Tiger outer shell would also significantly reduce the crush depth as confirmed by the 14 inch crush depth for the prototype 30 foot drop test as discussed on page 3 of Reference 2.1. As noted on page 51 of Reference 2.1, a total of four 40 inch drop tests and one 30 foot drop test produced no noticeable effect on the prototype inner containment boundary; therefore, none would be expected for a one foot corner drop.

The storage compartment and contents will not be damaged in a 30 foot drop as discussed in paragraph 2.7.1; therefore, no damage is expected in a one foot corner drop; however, the polyurethane foam inner liner would be subjected to compressive yield during the one foot drop. Maximum inner liner yield would occur during an end drop due to the reduced effective cross-sectional area. (Corner drop loads would be distributed over the side and end areas by the rigid storage compartment and no localized corner yield would occur as for the outer Super Tiger corner.) As calculated below, the maximum end drop crush depth would be limited to 7.4 inches and the maximum side (bottom) drop crush depth would be limited to 1.1 inches even if all of the loaded storage compartment energy was absorbed by the inner liner.

From the energy balance where Potential Energy = Internal Energy

$$W(H + D_c) = K_D\, S_c\, A_c\, D_c \quad .$$

Then

$$D_c = \frac{WH}{K_D S_c A_c - W}$$

where

D_c = material crush depth (inches)

W = Weight of loaded storage compartment (23,000 pounds max)

H = Drop height (12 inches)

K_D = Dynamic crush strength to static crush strength factor (approx. 1.0 for foam)

S_c = Static crush strength (80 pounds/inch^2 for foam)

A_c = Crush area* (756 inches of foam for end drop)
(3520 inches of foam for side/bottom drop)

*Conservative crush area under the 27.5 inch x 27.5 inch x 128 inch storage compartment ignoring the wider area under compressive yield due to the approximate 45° shear plane as discussed in Paragraph 2.7.1.2.

$$D_c = \frac{23{,}000 \times 12}{1 \times 80 \times 756 - 23{,}000} = 7.4 \text{ inches max for end drop}$$

$$D_c = \frac{23{,}000 \times 12}{1 \times 80 \times 3520 - 23{,}000} = 1.1 \text{ inches max for side or bottom drop}$$

In summary, the Super Tiger shipping container corner would be slightly damaged during a one foot corner drop and the inner liner would be crushed a maximum of 7.4 inches during a one foot end drop. Neither drop would damage the storage compartment or the containment boundary. An in-process shipment could be completed; however, the Super Tiger chassis and the polyurethane foam inner liner would be evaluated for possible repair prior to subsequent shipments.

2.6.7 Corner Drop

This multiple one foot corner drop analysis requirement is not applicable for packages with a gross weight over 110 pounds.

2.6.8 Penetration

The package must be assessed for the effect of the impact of the hemispherical end of a 13 pound 1 1/4 inch diameter steel cylinder dropped from 40 inches on any exterior location. This requirement was not specifically analyzed for the Super Tiger certification. If the 1 1/4 inch diameter cylinder penetrated one of the 1 1/2 inch diameter vent holes in the outer Super Tiger shell, the cylinder would not penetrate through the 10 inches of polyurethane foam to contact the inner containment shell. From the energy balance as discussed in paragraph 2.6.6, $D_C = WH/K_D S_C A_C W$

where

D_C = material crush depth (inches)
W = Weight of cylinder (13 pounds)
H = Drop Height (40 inches)
K_D = Dynamic crush strength factor (1.0)
S_C = Super Tiger foam crush strength (80 lbs/in^2)
A_C = Crush area = x 0.62^2 = 1.21 in^2 (conservative crush area ignoring the wider area under compressive yield due to the approximate 45° shear plane as discussed in Paragraph 2.7.1.2.)

Then: D_C = 13 x 40/1 x 80 x 1.21 x 13 = <u>0.4 inches</u>

No other external components are vulnerable to the missile penetration.

2.6.9 Compression

This package compression analysis requirement is not applicable to packages exceeding 10,000 pounds in weight.

2.7 Hypothetical Accident Conditions

The shipping package is in compliance with the standards for sequentially applied hypothetical accident conditions specified in 10 CFR 71.36 as demonstrated in the following paragraphs.

2.7.1 Free Drop

The Super Tiger shipping container and the polyurethane foam inner liner will absorb all of the impact loads for a 30 foot free drop in any alignment and the storage compartment, payload, and containment boundary will not be damaged as demonstrated in the following paragraphs.

2.7.1.1 Super Tiger Shipping Container

A Super Tiger prototype was analyzed and tested for a 30 foot free drop as discussed on pages 11, 28, and 67 of Reference 2.1. The analysis for the various impact orientations is summarized as follows:

Orientation of Impact	Regional Crush Strength (psi)	Peak (G's)	Duration of Crush Event (sec)	Crush Depth (in)
(1) Flat, end	100	19.7	.0688	18.39
(2) Flat, side	100	50.6	.0264	7.14
(3) Edge, 240"	200	39.4	.0540	18.79
(4) Edge, 96"	200	24.9	.0870	30.12
(5) Corner	200	25.0	.1240	47.21

This analysis considered the impact absorbing features only of the polyurethane foam liner. The additional impact absorbing features of the outer steel shell would tend to reduce the crush depth and increase the peak "G" loads for the corner and edge drops as shown by the actual prototype 30 foot corner drop. The corner of the outer steel shell indented less than 14 inches compared to the 47 inches as calculated for the foam only. The non-conservative nature of these calculated G loads for the edge and corner drops is not considered significant for the current application. The Super Tiger prototype was successfully tested to the most stringent 30 foot corner drop requirement and the new components are structurally conservative for these angular impact loads. The calculated G loads for the flat drops are considered realistic since the crushing of the outer shell is not a factor.

The previously identified non-specification parameters such as poor welds, inconsistant foam density, erratic foam to metal bonding, and chassis wall pins are not considered significant for this application. The new foam inner liner reinforces the steel cavity wall to compensate for the lack of bonding to the chassis foam and absorbs the payload impact loads to compensate for variations in chassis foam compressive strength. The inner liner sections are fabricated from commercially available polyurethane stock manufactured under controlled process conditions to ensure compliance with specification requirements. Although the chassis welds are potentially porous, there are no cracks; therefore, massive structural failure would not occur during the 30 foot drop. Although total fuel containment could not be assured by the container chassis, structural integrity would be maintained sufficiently to retain the storage compartment and rods and the rod cladding would in turn retain the fuel material. The steel pins in the chassis wall could penetrate the inner cavity walls during side or corner drops; however, the inner liner foam is of sufficient thickness to prevent the pins from impacting on the rod storage compartment.

2.7.1.2 Inner Liner

The new polyurethane foam inner liner will retain the 27.5 inch x 27.5 inch x 128 inch storage compartment within the center of the 76 inch x 76 inch x 172 inch Super Tiger cavity. During a hypothetical 30 foot drop, the deceleration energy of the storage compartment will be absorbed by the combined inner liner foam and Super Tiger liner foam. The polyurethane foam tends to fail in compression along an approximate 45° shear plane as shown in Figure 2.1 such that the deceleration energy is absorbed by the compression of an obelisk volume of foam under the applicable storage compartment surface. This foam compression feature is discussed on page 125 of Reference 2.1. As shown in Figure 2.1, this compression failure characteristic also tends to distribute the storage compartment impact load over the applicable Super Tiger inner wall as required on page 105 of Reference 2.1. The storage compartment load would be distributed over approximately 84% of the inner wall during an end drop and approximately 73% of the side wall during a side drop as compared to the minimum of 60% required by Reference 2.1.

Assuming the storage compartment deceleration energy to be absorbed by the crushing of the obelisk section of combined inner liner and Super Tiger liner foam under the storage compartment, the maximum crush depth and G loads can be determined. From the energy balance where potential energy = internal energy:

$$W(H+D_C) = K_D S_C A_C D_C$$

Then

$$D_C = \frac{W(H + D_c)}{K_D S_C A_C - W}$$

where:

D_c = Foam crush depth (inches)

W = Weight of loaded storage compartment (23,000 pounds max.) (the deceleration energy of the inner liner sections above the storage compartment would tend to be absorbed by the sections beside the storage compartment)

H = Drop height (360 inches)

K_D = Dynamic crush strength to static crush strength factor (approximately 1.0 for foam)

S_c = Static crush strength (80 lbs/in^2) (Conservative assumption for the combined 80 lbs/in^2 inner liner foam and the 100 lbs/in^2 Super Tiger chassis foam).

A_c = Effective crush area (V_c/D_c)

V_c = Effective crush volume

V_c for an obelisk (frustrum of rectangular pyramid) = $1/6\ D_c[AB + (A + A_1)(B + B_1) + A_1B_1]$ where A and B are the lower sides and A_1 and B_1 are the upper sides of the obelisk (Reference page 2-13 of Reference 2.3).

For an end drop, A_1 = 27.5 inches and B_1 = 27.5 inches. For a side drop, A_1 = 27.5 inches and B_1 = 128.0 inches.

Dimensions A and B are a function of D_c for the 45° shear plane such that for an end drop, $A = A_1 + 2\ D_c$ and $B = B_1 + 2\ D_c$ and for a side drop, $A = A_1 + 2\ D_c$ and $B = B_1$ (since the inner liner end sections are not subject to the side drop compression loads).

For simplification in calculating V_c, D_c is assumed to be 32 inches for an end drop and 19 inches for a side drop such that:

V_c = 124,459 and A_c = 3889 for an end drop
V_c = 110,884 and A_c = 5836 for a side drop

The crush depth for these assumed crush areas is verified as follows:

$$D_c = \frac{W(H + D_c)}{K_D S_c A_c - W} = \frac{23{,}000 \times (360 + 32)}{1 \times 80 \times 3889 - 23{,}000} = \underline{31.3 \text{ inches for an end drop}}$$

$$D_c = \frac{W(H + D_c)}{K_D S_c A_c - W} = \frac{23{,}000 \times (360 + 19)}{1 \times 80 \times 5836 - 23{,}000} = \underline{19.6 \text{ inches for a side drop}}$$

From Force (F) = Mass (M) x Deceleration (a) = W/g x a.

Where G = a/g (Ratio of force on a body to the body weight during deceleration)/

Then F = WG and G = F/W

For $F = K_d\ S_c\ A_c$

Then $G = K_d\ S_c\ A_c/W$

Maximum G would occur at the instant of maximum crush depth where:

A_c = $(27.5 + (2 \times 32))^2$ = 8372 inch^2 for an end drop

A_c = $(27.5 + (2 \times 19))128$ = 8384 inch^2 for a side drop

For conservatism, assume the storage compartment deceleration load to be entirely reacted by the chassis liner. Therefore the maximum G load in each orientation would be:

1 x 100 x 8372/23,000 = 36.4 G (end drop)

1 x 100 x 8384/23,000 = 36.5 G (side drop)

By similar calculation, the maximum storage compartment deceleration load for a 240" edge drop would be 42.8 G. The Super Tiger chasis will be subjected to less external damage and the new storage compartment will be subjected to lower G loads during a 30 foot drop due to the lower crush strength and reduced effective crush area of the new inner liner foam. As shown in the following paragraphs, the storage compartment and contents will withstand the peak Super Tiger G loads summarized in Paragraph 2.7.1.1 such that they will readily withstand the reduced loads imposed by the inner liner.

The Super Tiger chassis walls are 10" thick and the inner liner side sections are 24" thick for a total thickness of 34". The maximum foam side drop crush depth is 19.6" such that the 10" long steel pins in the chassis walls would only penetrate within 4.4" of the storage compartment. The 24" thick inner liner would absorb the entire 19.6" crush depth as required such that the chassis foam crush strength is not critical for storage compartment protection during the side and corner drops. The chassis ends are 34" thick and the inner liner end sections are 21" thick for a total thickness of 55". The maximum foam end drop crush depth is 31.3" such that both foam components would be required to absorb the storage compartment impact loads. No steel pins are installed on the chassis ends and the chassis foam in these areas appear to be of approximate specification density such that the storage compartment also will be fully protected during the end drops.

2.7.1.3 Storage Compartment

The storage compartment will accommodate the loaded rod storage containers and retain structural integrity during the hypothetical 30 foot drop in all orientations. The compartment is fully enclosed in the polyurethane foam inner liner such that all deceleration loads at all drop orientations are evenly reacted by the foam compression and no extreme bending loads or concentrated impact loads are imposed on the outer surface. The thick-section storage compartment components were selected for nuclear safety and radiation shielding such that the design is structurally conservative.

2.7.1.3.1 Side Drop-Tube Wall Bending and Compression

Assume that one loaded storage compartment tube section and one half of the upper shield plate is fully supported by the lower tube section under a 50.6 G maximum deceleration load as shown in Figure 2.3.

The maximum static load is:

One loaded storage container = 2000 lbs

Two tube sections 152.4 lbs/ft x 10.5 ft x 2 = 3200 lbs

1/2 plate section 81.6 lbs/ft^2 x 10.5 ft x 0.98 ft = 840 lbs

6,040 lbs total

The maximim applied deceleration load per one linear inch during a 30 ft side drop = 6040 lbs x 50.6 G/126 inch = 2426 lbs

From Reference 2.4, page 220, Table 17, Ref. No. 1;

The maximum bending moment at "X" = 0.3183 WR and the maximum bending moment at "Y" = -0.1817 WR where W = 2426 lbs (for a one inch tube section) and R = 11.75 in/2 = 5.875 in therefore M_x = 0.3183 x 2426 x 5.875 = 4538 in-lbs and MY = -0.1817 x 2426 x 5.875 = -2590 in-lbs (i.e. tension at the outer diameter/compression at the inner diameter).

From Reference 2.3, page 5-23, the maximum fiber stress due to the bending moment = MC/I where $I = bh^3/12 = 1x1.375^3/12 = 0.217$

and $C = h/2 = 0.6875$

Therefore the maximum fiber stress at "X" = 4538x0.6875/0.217 = 14,376 lbs/in^2 and the maximum fiber stress at "Y" = -2590x0.6875/0.217 = 8,205 lbs/in^2 (due to the bending moment) and 2426 lbs/2x1 in x 1.375 in = 882 lbs/in^2 (due to the compression load) = 8205 + 882 = 9,087 lbs/in^2 (at the inner diameter) (compared to S_y = 32,800 lbs/in^2)

From Reference 2.4, Page 220, Table 17, Ref. No. 1 (with no correction for hoop stress or shear stress);

The deflection at "Y" = $0.137\ K_x\ WR^3/EI$

and the deflection at "X" = $0.149\ K_y\ WR^3/EI$

where: $K_x = 1.05$, $K_y = 1.03$

$W = 2426$ lbs

$R = 5.875$ in.

$E = 29.5 \times 10^6\ lbs/in^2$

$I = 0.217\ in^4$

$D_x = 0.137 \times 1.05 \times 2426 \times 5.875^3/29.5 \times 10^6 \times 0.217$ = 0.01 in

$D_x = -0.149 \times 1.03 \times 2426 \times 5.875^3/29.5 \times 10^6 \times 0.217$ = -0.01 in (i.e. Decrease in diameter)

These calculations are conservative since the lower tube section is restrained between the adjacent (equally loaded) tube section and the two inch thick side shield plate such that lateral deflection and induced bending loads are limited. The deflection is negligible in comparison to the 0.375 inch gap between the 8.625 inch OD rod storage containers and the 9.00 inch ID tube sections such that no storage compartment loads are transferred to the rod containers.

2.7.1.3.2 **Edge Drop/Corner Drop - Tube Bending and Compression**

The tube bending and compression loads during any edge or corner drop will be less than the calculated side drop loads since the impact loads will be distributed over all lower surfaces and the calculated G loads for those drop orientations (paragraph 2.7.1.2) are less than the specified 50.6 G Super Tiger side drop load.

2.7.1.3.3 **Shielding Installation**

Assume one 1820 pound side section of the steel radiation shield to be entirely supported by the two .50 in. x 126 in. welds during a 30 foot side drop.

Maximum deceleration load = 1820 lbs x 50.6 G = 92,092 lbs

Minimum weld cross section = .707 x .50" x 126" x 2 welds = 89 inches^2

Maximum weld shear stress = 92,092/89 = 1,035 lbs/in^2

(Compared to allowable weld shear stress = 50% S_y = 16,400 lbs/in^2)

2.7.1.3.4 **Cover Installation**

Assume the 184 pound front cover to be entirely supported by four .25 inch diameter padlock pins and four .25 in diameter hinge pins as shown on Drawing 1919F67 during a 30 foot side drop.

Maximum deceleration load = 184 lbs x 50.6 G = 9310 lbs

Minimum pin cross section - 3.14 x .12^2 x 8 pin sections in shear = .36 in^2

Maximum pin shear = 9310/.36 = 25,860 lbs/in^2

(Compared to allowable shear stress of 50% S_y = 38,750 lbs/in^2)

The 184 pound rear cover is supported by the 102 inch x .50 inch fillet weld which would be subject to a negligible shear load of 18450.6/102 x .05 x .707 = 258 lbs/in^2 during a 30 foot side drop.

Both covers would be subjected only to flat compression loads during a 30 foot end drop since the combined storage compartment and storage container inertia loads would be distributed over the effective foam crush area.

2.7.1.4 Rod Storage Containers

The 8.625 in OD x 0.5 in wall stainless steel rod storage containers are enclosed within the 9.0 inch ID x 1.375 inch wall carbon steel tubes of the storage compartment such that the storage containers walls are subjected primarily to compressure loads only during 30 ft drops in all orientiations. From Reference 2.4 Page 232, Table 17, Ref. No. 14, it is confirmed that the stresses and deformation of the container walls are negligible during a 30 ft side drop (Approximately 250 lbs/in^2 stress and 0.015 in change in diameter).

2.7.1.5 Rod Cladding

The rod cladding was analyzed for the 30 foot free drop as summarized in Section 7.1.4 of Reference 2.2. The calculated allowable G loadings for the various impact orientations is summarized as follows:

(1) End Drop (seed rods)	428 G
(2) End Drop (blanket rods)	360 G
(3) Side Drop (seed rods)	291 G
(4) Side Drop (blanket rods)	260 G

The G loadings under which the rod cladding integrity will be maintained during Super Tiger transport are considered comparable to these limits for module transport as calculated in Reference 2.2 due to the similarity in analysis. Although the rods were supported laterally at approximately 17 inch intervals by the grids during module transport, the analysis considered the extreme condition of all upper rods in the module array impacting on the bottom rod during a 30 foot side drop. These quantities of rods were comparable to the quantities of similar rods which would be stacked over a single rod in the rod storage containers (24 seed, 14 PFB, 12 blanket, 28 BMU seed, 11 BMU blanket). The rods would be restrained from buckling during the end drops by the other rods in the storage containers.

No further analysis is required for the rod cladding since the maximum G loadings imposed by the Super Tiger shipping container are considerably less than the allowable G loadings for the rods.

2.7.2 Puncture

The package must be assessed for the effects of a 40 inch free drop on a 6 inch diameter by at least 8 inch long rigidly supported mild steel bar. This requirement was analyzed and subjected to prototype testing for the Super Tiger certification as documented on pages 12, 36, and 69 of Reference 2.1. For the selected configuration, the outer shell and polyurethane liner absorbed all impact damage and no damage was evident for the inner shell or cover plate. The outer chassis shell was not penetrated and the local indentation was limited to approximately 2 1/2" during the prototype test. Even if the puncture mechanism impacted one of the 10" long steel pins in the side of the Super Tiger chassis, the pin would only penetrate 2 1/2" into the 24" thick inner liner foam such that the storage compartment would not be affected. The chassis containment boundary would be ruptured; however, the fuel material would remain fully contained by the storage compartment and rod cladding. A sequential puncture accident on a Super Tiger side impacted during a 30' side drop still would not impact the steel pin into the storage compartment surface.

2.7.3 Thermal

The package must be assessed for the effects of exposure to a radiation environment of 1475°F for 30 minutes. This requirement was analyzed and subjected to prototype testing for the Super Tiger certification as documented on pages 19 and 51 of Reference 2.1. Damage was restricted to the outer shell and polyurethane foam and temperature rise inside the container was less than 80°F; therefore, no further analysis is required for the new inner liner or storage compartment as summarized in Chapter 3.

2.7.4 Water Immersion

The package must be assessed for the effects of immersion under three feet of water for at least eight hours. This requirement was not specifically analyzed for Super Tiger certification; however, the requirement is satisfied by the external pressure analysis as documented on page 19 of Reference 2.1 and discussed in Paragraph 2.5.2. Three foot total immersion would place the bottom of the Super Tiger at an 11 foot immersion and subject to a surface pressure of 4.77 pounds per square inch compared to the analysis for 25 pounds per square inch. The Super Tiger containment boundary could be ruptured under the previous accident criteria such that the rod storage area could become flooded. The fuel materials would remain enclosed by the rod cladding and all combinations of total and partial water flooding are evaluated in Section 6; therefore, the container would remain nuclearly safe and no loss of fuel materials would result even while the container was being drained.

2.7.5 Summary of Damage

The Super Tiger shipping container inner and outer shells and polyurethane liner would suffer some damage under the sequential free drop, puncture, and thermal test conditions. The Super Tiger chassis containment boundary could be ruptured due to as-built deviations in the structure; however, the fuel materials would remain fully contained by the rod cladding and the new storage compartment. The new polyurethane inner liner would be subjected to compressive yield failure during the free drop conditions; however, the storage compartment and contents would not be damaged under any of the hypothetical accident conditions. No storage compartment components will be subjected to loads exceeding the allowable yield stresses and the rod storage configuration will not change. The Super Tiger prototype testing was conducted under the specified sequential accident conditions and no significant accumulative damage is expected for the new components. The "free drop" and "penetration" conditions are the only "normal conditions of transport" as discussed in Section 2.6 which could significantly affect this accumulative damage. These conditions were not included in the analysis since both a one foot free drop and a partial penetration of the 45,000 pound Super Tiger container would be treated as an accident and corrective action would be taken prior to continued use. The free drop crush damage would be concentrated in the smaller area of the inner liner which could be readily inspected and replaced as required. (The combined inner liner and chassis liner are of sufficient thickness to accomodate the accumulated crush damage from both a one foot drop and a 30 foot drop as calculated pending repair.) Under no conditions would a trip be continued without corrective action in the unlikely event of partial penetration of one of the Super Tiger vent holes by the defined penetration missile.

2.8 Special Form

This requirement is not applicable since special form is not claimed for the rod shipments.

2.9 Fuel Rods

The fuel rod cladding was analyzed in Paragraph 2.7.1.5 and determined to retain structural integrity during the hypothetical 30 foot drop. The rods were designed and tested to withstand operational pressures of 2000 psi at 500°F such that induced pressures due to shipping container boundary failure and compartment flooding as discussed in this chapter are insignificant.

2.10 Appendix

2.10.1 References

2.1 Mechanics Research Inc. Report No. C2378 "Engineering Evaluation of the Super Tiger Overpack Designed for the Shipment of Large Quantities of Hazardous Materials," dated March 4, 1970.

2.2 Bettis Atomic Power Laboratory Report No. WAPD-LC(CEM)-65 "Safety Analysis Report for Packaging, LWBR New Fuel Module Shipping Container," dated November 1973. Associated Certificate of Compliance USA/9784/BLF(ERDA-NR), dated March 14, 1975.

2.3 Marks Standard Handbook for Mechanical Engineers, Eighth Edition.

2.4 Formulas for Stress and Strain, Raymond J. Roark, Warren C. Young, Fifth Edition, McGraw Hill Book Company.

2.10.2 Figures

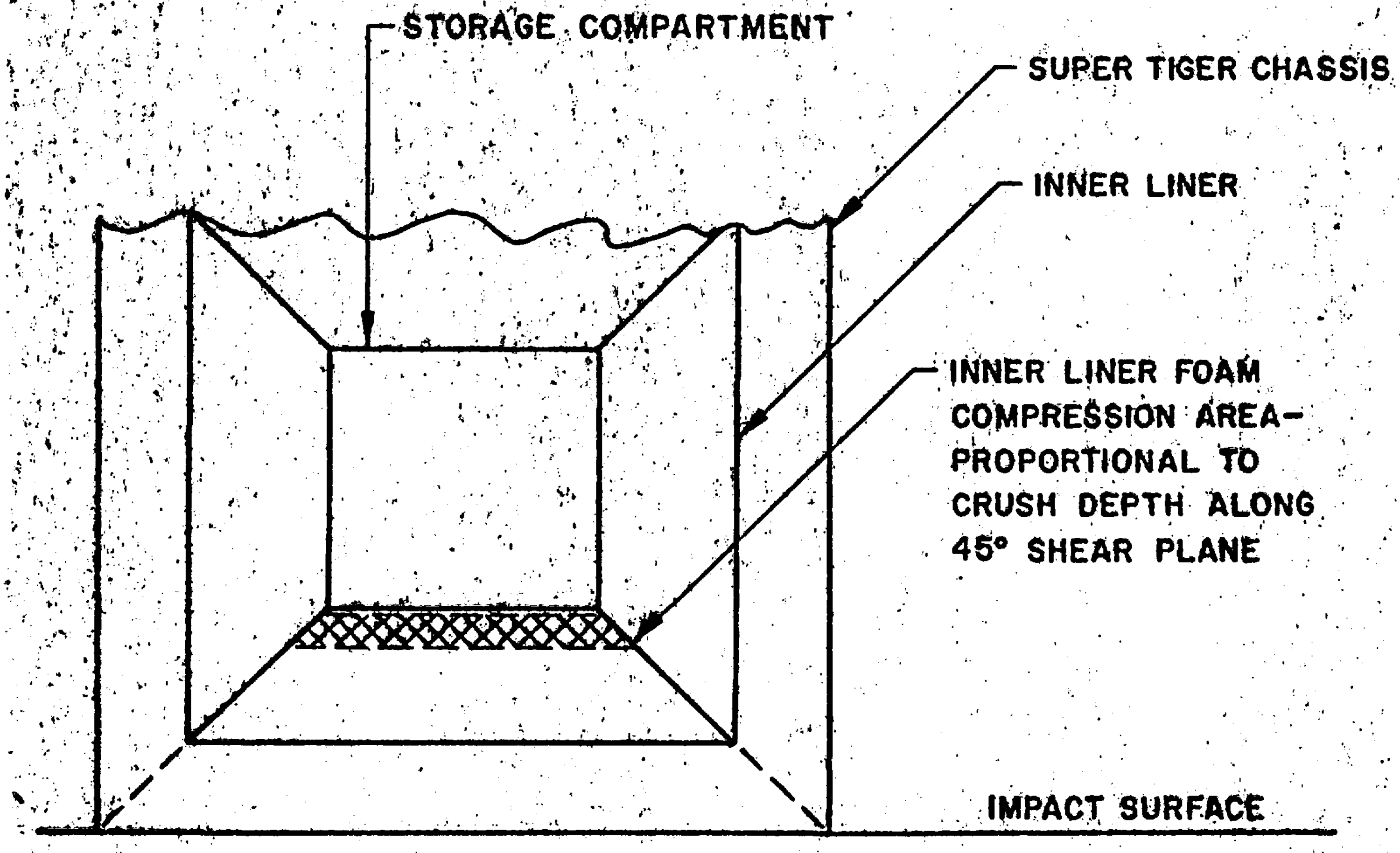


FIGURE 2.1 INNER LINER COMPRESSION-FLAT IMPACT

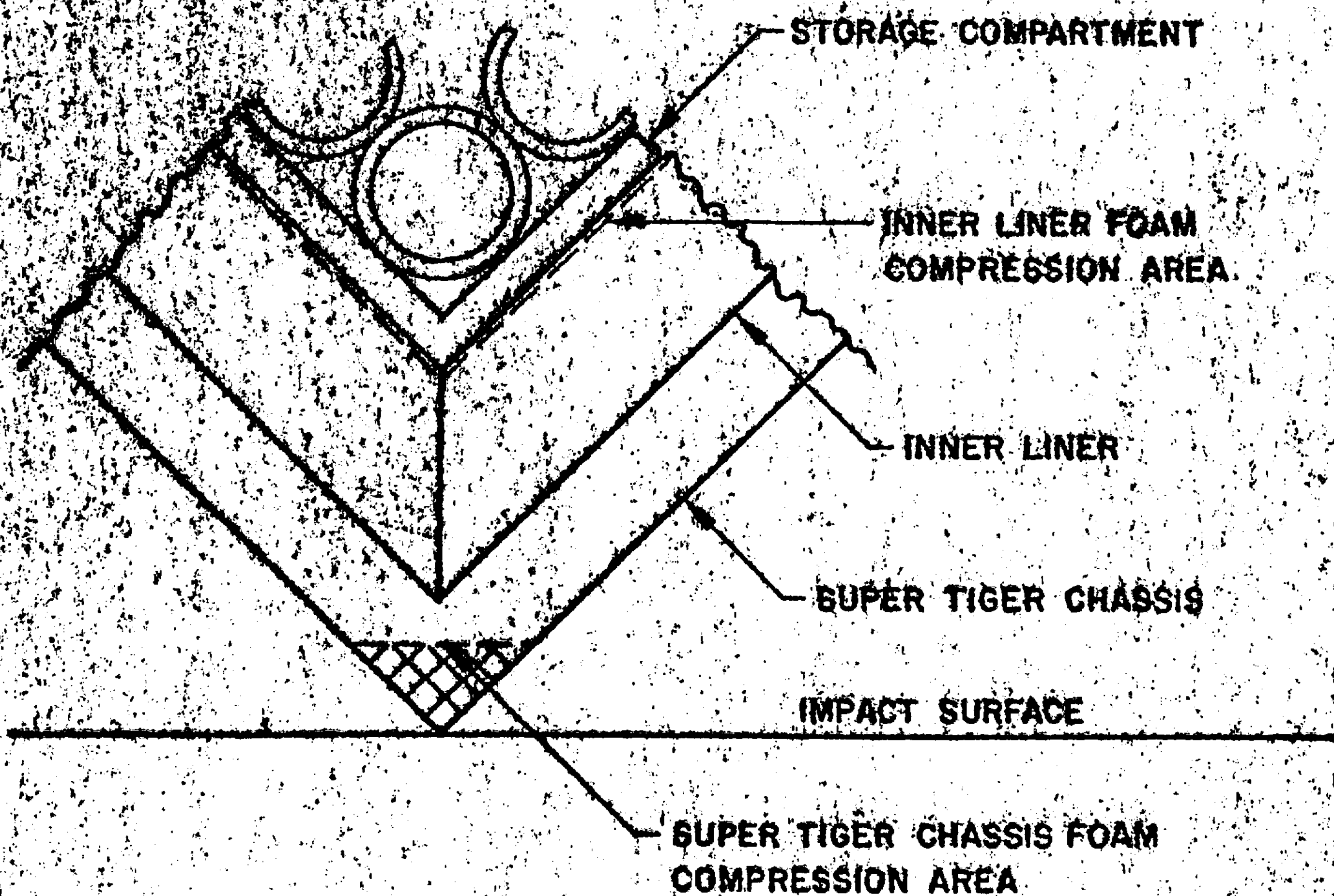


FIGURE 2.2 INNER LINER COMPRESSION—ANGULAR IMPACT

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 2.3 STORAGE COMPARTMENT TUBE WALL BENDING LOADS.

CHAPTER 3 THERMAL EVALUATION

3.1 Discussion

The Super Tiger shipping container was analyzed for the effects of an external radiation environment of 1475°F for 30 minutes as documented on pages 19 and 84 of Reference 2.1. It was determined that the temperature rise of the internal payload would be limited to less than 10°F. Prototype testing under more extreme conditions, as documented on page 51 of Reference 2.1, verified that internal (payload) temperatures did not reach the 150°F minimum threshold for the temperature recording instruments (80°F above ambient). Fire damage was limited to the outer shell and the outer six inches of the polyurethane liner. The Super Tiger was not specifically analyzed for normal thermal conditions of transport; however, no solar induced thermal loads would exceed the payload temperatures noted above and the insulational features of the polyurethane foam Super Tiger liner and new inner liner would inhibit extensive internal temperature rise.

The current rated thermal heat capacity of the Super Tiger shipping container as documented in the Certificate of Compliance is 30 watts and the maximum heat generation due to radioactive decay of a full load of LWBR rods (up to 50 Kg of fissile material) is approximately 28 watts as defined in Reference 2.2. Even with no dissipation of internally generated heat due to the insulation features of the polyurethane foam in the Super Tiger liner and the new inner liner, internal temperature rise is minimal. The 15,000 pound steel mass of the storage compartment at a nominal specific heat of 0.1 BTU/lb-°F could absorb the 28 watts with a temperature rise of only 1.5°F per day.

Detailed thermal evaluation is unnecessary based on the above assessment. The Super Tiger shipping container is currently certified for the defined thermal conditions and the maximum possible internal temperatures are well within temperature ranges for the internal component mechanical properties as defined in paragraph 2.3. Maximum internal temperature due to radioactive decay of the contents would not exceed the design temperature of 200°F even if the container was loaded at an ambient temperature of 70°F and a nominal four day shipment was extended to 85 days while no internal heat was being dissipated.

Maximum internal pressure could occur under the specified hypothetical condition when the enclosed air in the sealed container is heated from the ambient 70°F (530°R) to 200°F (660°R) as follows:

$$P_{max} = P_{amb} \frac{T_{max}}{T_{amb}} = 14.7 \text{ psi } \frac{660^0}{530^0 R} = 18.3 \text{ psia}$$

CHAPTER 4 CONTAINMENT

4.1 Discussion

The Super Tiger shipping container containment boundary as designed consisted of the 3/16 inch thick mild steel inner shell and the 1/4 inch thick aluminum closure plate with full length silicon rubber gasket. The closure plate is secured to the inner shell with 36-1/2 inch diameter steel bolts torqued to 35-45 foot pounds. A pressure fitting with cap on the closure plate provides a means for leak testing. The new rod transport application is compatible with the original container design criteria as summarized below:

(1) The existing Super Tiger chassis will be used without modification and no new containment penetrations are incorporated (Reference Para. 2.1.1.1).

(2) Shipments will continue to be made dry with only natural modes of heat removal (Reference Para. 1.2.2).

(3) The center of gravity of the loaded Super Tiger will remain near the geometric center of the container (Reference Para. 2.2).

(4) The impact loads of the new storage compartment will be distributed over the applicable surface area of the Super Tiger cavity (Reference Para. 2.7.1.2).

(5) Acceptable internal temperatures and pressures will be generated during transport (Reference Chapter 3).

Since this containment boundary is no longer reliable due to as-built Super Tiger deficiencies, total fuel material containment for this application will be provided by the container chassis in conjunction with the new inner components. The fuel rod claddding will retain the fuel materials during all defined normal transport and accumulative accident conditions as discussed in Chapter 3. The new storage compartment will retain structural integrity under all accident conditions and the new inner liner will absorb most of the drop test impact loads to prohibit massive Super Tiger chassis failure. The composite storage compartment and Super Tiger chassis will therefore insure containment of all rods. The container also will remain nuclearly safe under the worst case loading conditions and all possible flooding conditions as discussed in Chapter 6.

CHAPTER 5 SHIELDING EVALUATION

5.0 General

This chapter describes the shielding analysis performed for the shipment of UO_2 - ThO_2 fuel rods in the Super Tiger container. This analysis shows that radiaton levels at three feet from the container surface following the hypothetical accident condition described in Chapter 2 will be substantially below the 1000 mrem/hr limit of Title 10 of the Code of Federal Regulations.

5.1 Discussion and Results

The shielding calculations were explicitly performed for the normal transport conditions and conservatively extrapolated from these results to predict the accident condition radiation levels. The actual radiation levels will be monitored and recorded during loading of the Super Tiger, and this will provide definitive assurance that all radiation requirements are satisfied under normal transport conditions. The results of normal transport condition calculations provide a basis for planning and general assurance that the intended shipments can satisfy the requirements. Conservatively predicted accident condition radiaton levels, based on a worst-case shipment, are about a factor of 20 below the 10 CFR 71 limits.

In the Super Tiger a two inch thick carbon steel radiation shield and 1 3/8 inch thick carbon steel tube of the storage compartment is supplemented by the two 3/16 inch carbon steel Super Tiger walls and 1/2 inch thick stainless steel rod storage container walls for a minimum total of 4 1/4 inches of steel.

All critical dimensions were included in the shield model and the maximum dose rates, as summarized in Table 5.1, were determined using the Bettis RCP01 computer program. This method has been verified with the Bettis SPAN-4 computer program. As noted in Table 5.1, the most limiting radiation levels occur at the two meter distance from the sides of the container. The maximum dose rates occur at the mid-section of the container. The dose rate at the ends of the container are considerably lower due to the small exposed fuel cross section, the additional distance to the fuel, and the additional shielding of the Zircaloy rod endclosures. The dose rate in the cab of the towing vehicle is below the two mrem/hr allowed by 49CFR173.393.

The shipping container is designed to accommodate four storage containers of LWBR rods. The calculated dose rates as summarized in Table 5.1 are based on a full shipment of high zone power flattening blanket (PFB) rods, although no single shipment is expected to consist entirely of this type rods. The specified maximum dose rates could theoretically be exceeded if four storage containers of LWBR core high zone seed rods (2056 rods) or experimental physics high zone BMU rods (2508 rods) were shipped at one time; however, these quantities exceed the actual available quantities to be shipped. In actual practice, the types and quantities of rods comprising each shipment will be selected to stay below the maximum allowed dose rate levels for transport. Applicable dose rate levels will be recorded during all shipping container loading operations and in no case will a shipment be initiated with a dose rate exceeding allowable levels.

5.2 Source Specification

The radiation levels associated with the Super Tiger fuel shipments are predominantly due to gammas associated with the alpha decay of U-232 and its daughters. All of the fuel rods to be shipped contain uranium with approximately 8 parts per million U-232. The U-232 reactions reach a peak activity approximately 11 years after purification (solvent extraction) and the shielding evaluation is based on this peak activity since all of the fuel will be near that age by the time shipments are initiated.

5.2.1 Gamma Source

The predominant gamma source in the unirradiated fuel shipments is the photons that are given off as a result of alpha decay of U-232 and its daughter products. The level is time dependent and depends upon the fuel age since separation which is assumed to be 3000-4000 days resulting in peak radiation levels. The daughter products are assumed to be in equilibrium such that each decay of U-232 is accompanied by a decay of each of its daughters. The U-232 content of the LWBR fuel rods vary from 7.1 to 8.5 atoms of U-232 per million atoms of fissile uranium. The U-232 content of the experimental physics rods is approximately 8 parts U-232 per million parts of fissile fuel. Based on a U-232 to U-233 atom ratio of 8×10^{-6} the disintegration rate of U-232 is calculated to be 6.34×10^{6} disintegrations/second per gram of fissile fuel. An average of 2.394 photons with an average energy of .6511 Mev accompany each disintegration. The energy distribution of the gamma source is given in Table 5.2.

5.2.2 Neutron Source

A natural source of neutrons occurs in the $^{233}U\text{-}ThO_2$ fuel rods as a result of alpha decay of the fuel atoms. The alpha particles react with O^{18} atoms in the rods and produce neutrons. The decay rates and atomic concentrations of the fuel rods, at a fuel age of peak activity, are such that approximately 80% of the source results from U-233 decay and less than 20% from U-232 decay. The neutron production rate attributable to the U-233 decay is based on experimental measurements (Reference 5.1) which resulted in 6.3 ± 1.5 neutrons/sec per gram of U-233 fuel. The natural neutron source level in the Super Tiger shipping container under normal transport conditions with four storage containers of 5.2 w/o high zone core seed rods (514 rods/container) is calculated to be 1.4×10^{6} neutrons/sec. This is a loading configuration that would exceed the fissile content of any actual intended shipment and is estimated may marginally exceed maximum allowable gamma dose rates. The neutron source level includes U-233 and U-232 components and a factor of 2 for subcritical multiplication under typical loading conditions. Under accident conditions this level could become 6.9×10^6 neutrons/sec based on a subcritical multiplication factor of 10.0 (K-effective = 0.90).

5.3 Model Specification

The entire Super Tiger shipping container was modeled for the shielding analysis as shown in Figures 5.1 and 5.2. These Figures are predominantly to scale.

5.3.1 Description of Radial and Axial Shielding Configuration

All parts of the Super Tiger shipping container were represented in detail in the RCP01 calculations. The geometrical detail was somewhat greater than that used in the criticality calculations discussed in Section 6.3.1. The RCP01 shielding calculational model included the following approximations:

(1) Carbon steel was used to represent the rod storage containers instead of stainless steel,

(2) The geometry of the gamma detectors was such that the gamma dose rates were average values over large volumes of material,

(3) The density of polyurethane material was reduced to 1.0 lb/ft^3 as a conservatism, and

(4) The BMU fuel rod metal end caps were conservatively omitted. Figures 5.1 and 5.2 show a longitudinal view of the shielding configuration. The materials used in the calculations are listed. Figures 5.3 and 5.4 show a cross-sectional view based on the RCP01 geometry. The detector regions in contact with and 2 meters from the container walls are shown. Each detector region is about 2 feet square. The surface detectors are 3 inches thick, the detectors 2 meters from the container sides are 6 inches thick, and the detectors 2 meters from the front and back container ends are 12 inches thick. The reported surface radiation level is that of the combined average of the two surface detectors to reduce statistical uncertainty. Similarly the radiation at the two side detectors at 2 meters has been combined. However, the radiation at either end of the container is treated separately since the shielding is not symmetric front to back.

5.3.2 Shield Regional Densities

The atom densities for the constituent nuclides for all shielding materials are listed in Table 5.3. The detector materials are based on air with its density increased by a factor of approximately 1200. The fuel material listed is typical but varied from case to case. A complete list of the fuel rods to be shipped are listed in Table 6.2.

5.4 Shielding Evaluation

5.4.1 Basic Methods

Expected radiation levels for both accident and normal transport conditions were based on explicit evaluation of the latter only. This procedure is permitted due to the geometry and integrity of the Super Tiger shipping configuration. For normal conditions, dose rates were calculated at six locations:

(1) In contact with the sides of the container (2 locations),

(2) 2 meters from the sides of the container at the longitudinal and elevational center of the fuel (2 locations),

(3) 2 meters from front of Super Tiger (these dose rates were also used as towing vehicle cab dose rates although the cab is expected to be at least 5 meters in front of Super Tiger), and

(4) 2 meters from the back of Super Tiger.

The detector locations are shown in Figure 5.1 and in Figure 5.2.

The maximum allowable dose rate under hypothetical accident conditions is 1000 mrem/hr at three feet from the shipping container surface as specified in 10 CFR Part 71. Under worst-case accident conditions, the shielded storage compartment loaded with fuel rods could crush approximately 19.6 inches of the 34 inches of total polyurethane foam during a 30 foot side drop as calculated in Paragraph 2.7.1.2. This would place the storage compartment at a distance of approximately 51 inches from the specified dose rate point for hypothetical accident conditions as compared to the normal transport location of approximately 34 inches from the storage compartment outer wall. As discussed in Section 5.4.3, the maximum calculated normal transport dose rate on contact with the outer wall is 50 mrem/hr. This dose rate was conservatively assumed to be the maximum dose rate at three feet from the container surface under hypothetical accident conditions. This assumption is justified since the storage compartment and contents will remain intact and restrained within the Super Tiger chassis under hypothetical accident conditions as determined in Section 2.7. The storage compartment and contained rods would be at least four feet from the specified dose point location (i.e., at least one foot inside the

Super Tiger outer shell after a 19.6 inch displacement) after a 30 foot side drop compared to the normal transport location approximately three feet inside the Super Tiger outer shell. The polyurethane foam provides minimal radiation shielding and any shielding loss due to foam displacement during a 30 foot drop would be insignificant.

The increases in radiation level that would result from the 6 inch diameter puncture and the 1/2 hour fire are both negligible. Only the outer wall would be punctured. The thickness of this wall is 3/16 inch relative to a total iron and steel shielding material thickness of 4-1/4 inches. A 3/16 inch loss in steel shielding is estimated to increase the dose rate by less than 15%. In addition, the area of the puncture is small relative to the total area through which radiation would pass to reach any point outside the container. The 1/2 hour fire would result in the loss of approximately 20 percent of the polyurethane. It is estimated that if all this material were lost then the dose rate would increase by less than 10 percent. Thus the 6 inch diameter puncture and the loss of 20 percent polyurethane would result in insignificant increases in radiation levels which is more than compensated for by not including the distance fall-off effect.

5.4.2 Computer Programs and Nuclear Data

The computer program RCP01 (Reference 5.2) was used to determine gamma absorption rates and gamma fluxes at detector locations. These were then converted to dose rates as discussed in Paragraph 5.4.3. The RCP01 method was selected since it utilized calculational models consistent with the criticality evaluations of Chapter 6. The geometry packages or descriptions were essentially the same in both cases. That is, to run a gamma photon calculation from a neutron transport calculation setup requires only a change in cross-sectional libraries and a control parameter.

The cross-sectional library and source spectrum used with the RCP01 calculations (Table 5.2) is based on XAP (Reference 5.3) which is the standard Bettis repository of nuclear data.

The flux to dose conversion factors used to convert the RCP01 gamma fluxes to dose rates are a function of energy and are listed in Table 5.4.

The SPAN-4 program, a point kernal computer program for shielding, (Reference 5.4) was selected to corroborate the RCP01 calculations. The gamma energy structure utilized by the SPAN-4 calculations is consistent with that used for previous LWBR fuel shielding calculations. Iron buildup factors were used except for the cab locations where the major shielding material is the thorium fuel at the ends of the rods. For this location, lead buildup factors were used. For the SPAN-4 calculations, attenuation factors, cross-sections, and flux to dose conversion factors were supplied by the SPAN-4 library.

5.4.3 Gamma Dose Rate Calculations

The gamma dose rates were calculated using the three-dimensional Monte Carlo program RCP01. The RCP01 data were used to determine these rates by two methods: (1) the first by normalizing detector gamma absorption rates to those of a similar RCP01 calculation of measured dose rates of an explicit geometry fuel rod array in a single 100 gallon drum, and (2) by converting the RCP01 calculated gamma fluxes to dose rates using conversion factors and normalizing to the source level specified in Section 5.2.1. The radiation levels reported in Tables 5.1 and 5.5 are those obtained using the first method. The second method predicted dose rates of 10% to 40% lower than those of the first method.

An earlier shipping arrangement consisting of twenty rectangular boxes, rather than the currently proposed four cylindrical containers, within the Super Tiger had been extensively analyzed with RCP01 both for reactivity and radiation considerations. For that earlier geometry, revision 2 of this document, the SPAN-4 Program was used to calculate radiation levels to provide confirmation of the adequacy of the RCP01 procedure. Although the RCP01 vs. SPAN-4 comparison does not represent the current shipping geometry, it does validly indicate that both programs predict consistent radiation levels. Figure 5.5 contains a summary of ten RCP01 calculations and three SPAN-4 calculations. The dose rate at the container surface and at 2 meters from the surface mid-point is plotted versus the fraction of the gammas that leak outside the carbon steel shield walls (RCP01) multiplied by the source strength in terms of grams of U-232 in the container. These 10 cases vary as to shield thickness, number of fuel rods present, and geometry of the detector located at 2 meters from the container wall.

Calculated dose rates are listed in Table 5.5 for three normal condition transport cases corresponding to the current shipping geometry. The reported values are 95% confidence upper bound data. Each case conservatively represents a high loaded configuration -- high total fissile content. In fact, there exists insufficient rods to actually make up case 1 or case 2 shipments. It is anticipated each real shipment will be composed of both high-zoned and low-zoned rods so as to minimize the total fissile content and consequent radiation. Case 3 represents an upper estimate of any shipment actually anticipated, and it is conservatively predicted case 3 would be about a factor of 2 lower than any 49 CFR radiation limits. Case 3 was chosen as the normal transport condition given in Table 5.1.

Cases 1 and 2 are conservatively predicted to only marginally exceed the 49 CFR maximum allowable limits. Case 1 predicts the highest dose rates in the cab, while case 2 predicts the highest dose rates on-contact with and 2 meters from the container surface. Case 2 is loaded entirely (2056 rods) with high zoned LWBR seed rods, while there are only 624 of these rods available to be shipped. The 95% confidence upper bound predicted dose rates 2 meters from the container side and on-contact are 10.4 and 49.1 mrem/hr respectively. The dose rate limit is 10 mrem/hr at 2 meters from the container surface. Case 1 is loaded entirely (2508 rods) with 12 w/o BMU seed rods centered between 42 inch BMU blanket rods, while there are only 2184 of these BMU seed rods available. The case 1 95% confidence upper bound predicted dose rate 2 meters from the front of the container is 5.2 mrem/hr. The maximum allowable dose rate in the vehicle cab is 2 mrem/hr and it is expected the vehicle cab will be at least 5 meters from the front of the Super Tiger. It is estimated that 5.2 mrem/hr at 2 meters would correspond to 2 mrem/hr at 5 meters (based on an inverse square law relationship relative to a point source centered within the Super Tiger) and this would just match the allowable maximum. The actual dose rates for each shipment will be measured, however, to assure compliance with required dose rate limits.

The predicted accident condition dose rate, case 4 listed in Table 5.5, was conservatively extrapolated from the normal transport condition on-contact calculation of case 2. No credit has been taken for additional attenuation due to increased distance. Jusfification for this procedure was discussed in Paragraph 5.4.1. The accident condition dose rate at 3 feet from the container surface is predicted to be less than 50 mrem/hr relative to the 1000 mrem/hr dose rate limit.

5.4.4 Neutron Dose Rate Calculations

Neutron dose rates were generated by comparison with the explictly-calculated neutron dose rates for PWR Core 2 blanket modules in shipping containers. Based on the relative neutron source strength of the Super Tiger for the case specified in Section 5.2.2, which is lower than the PWR blanket shipment by a factor of approximately 2000, and geometrical considerations, the maximum neutron rate dose at the surface of the Super Tiger package is estimated to be less than 0.2 mrem/hr relative to a corresponding gamma dose rate of about 50 mrem/hr. In addition, an independent assessment directly relating the neutron source and consequent neutron flux to the neutron dose rate obtains a conservative estimate of less than 0.5 mrem/hr at the Super Tiger surface. Thus the neutron contribution to the total radiation level is insignificant for the current analysis of LWBR fuel rod shipments in the Super Tiger. Nonetheless, the neutron dose rate of each shipment will be specifically monitored and recorded. Under accicent conditions, the neutron contribution would still be less than 5% of the estimated total dose rate.

5.5 Appendix

5.5.1 References

5.1 WAPD-TM-601, Measured Natural Neutron Source in $U^{233}O_2$-ZrO_2 and $U^{233}O_2$-ThO_2, April 1967.

5.2 RCP01-A Monte Carlo Program for Solving Neutron and Photon Transport Problems in Three-Dimensional Geometry with Detailed Energy Description, WAPD-TM-1267, August 1978.

5.3 XAP-A Multigroup Cross Section Library System, WAPD-TM-823(L), February 1971.

5.4 SPAN4-A Point Kernal Computer Program for Shielding, WAPD-TM-809(L), Volumes 1 and 2, October 1972.

5.5.2 Tables

5.5.3 Figures

WP: LWB82240N

TABLE 5.1

SUMMARY OF MAXIMUM DOSE RATES*

Normal Transport Conditions
4 Storage Containers, 169 HZ PFB Rods per Container, 676 Rods, 42.6 K_g U-fissile

	On Contact With Package Surface	2 Meters From Package Surface	In Vehicle Cab
	32 mrem/hr	5.1 mrem/hr	0.3 mrem/hr
49 CFR Limit	200 mrem/hr	10 mrem/hr	2 mrem/hr

Hypothetical Accident Conditions
4 Storage Containers, 514 5.2 w/o Seed Rods per container, 2056 Rods, 71.1 K_g U-fissile

	3 Feet From Container Surface Top, Sides, Bottom
Gamma	49.1 mrem/hr
10 CFR71 Limit	1000 mrem/hr

NOTE: Since the Super Tiger will be shipped exclusive use, the limits in 49CFR173.393(j) will be used: 200 mrem/hr on contact, 10 mrem/hr at 2 meters from the side of the vehicle, and 2 mrem/hr in the cab. Due to the size of the Super Tiger, the dose rate at 2 meters from the package will be used. The listed vehicle cab dose rates were calculated at two meter distance from the front of the container rather than the estimated actual five meter distance. The package will never be loaded to exceed the 49 CFR dose rate limits for transport.

*The total dose rate and that due just to gamma may be considered equal since the neutron contribution is estimated (see Section 5.4.4) to be much less than 5% of the total under any conditions.

TABLE 5.2

GAMMA CROSS SECTION LIBRARY FOR SHIELDING CALCULATIONS

Isotope	XAP* ID
Carbon	C(4)
Hydrogen	H(4)
Iron	Fe(4)
Oxygen	O(4)
Thorium	TH(4)
Uranium	U(4)
Zirconium	Zr(4)
Nitrogen	N(4)

* XAP (Reference 5.4) is the Bettis Atomic Power Laboratory Repository for Cross-Sectional Data.

Energy Distribution of Gamma Source
(Cumulative Number of Photons per Disintegration by Multigroup

57 Multigroup Structure (Energy at Top of Multigroup)	Cumulative Spectrum
.280+7	0.3477
.260+7	0.3477
.240+7	0.3477
.220+7	0.3485
.180+7	0.3648
.160+7	0.3680
.140+7	0.3680
.120+7	0.3771
.100+7	0.3779
.90+6	0.4255
.80+6	0.5117
.70+6	0.5117
.60+6	0.9262
.50+6	0.9328
.40+6	0.9732
.30+6	1.8424
.20+6	1.8507
.15+6	1.8938
10+6	1.9117
.50+5	2.3944

TABLE 5.3

PACKAGE REGION DENSITIES USED IN GAMMA DOSE RATE ANALYSIS
(CASE 3 OF TABLE 5.5)

		Material Density (gm/cc)	Atoms/cc ($x10^{24}$)	Total Mass (Kilograms)
LWBR 2.8 w/o PFB Fuel	Pellets	9.812		
	Uranium	0.274	.7075-3	44.9
	Oxygen	1.189	.44756-1	239.3
	Thorium	8.349	.21671-1	1690.8
Fuel Rod Cladding (Zirc 4)		6.55	0.429-1	408.2
Super Tiger Container and Inner Containers (Iron)		7.9	0.849-1	11719.
Polyurethane		0.0160		
	Hydrogen	0.0012	.774-3	44.5
	Carbon	0.0148	.774-3	530.4
Detectors		1.489		
	Oxygen	0.345	0.1289-1	137.3
	Nitrogen	1.143	0.4873-1	454.4

TABLE 5.4

GAMMA RAY NUMBER FLUX TO DOSE RATE CONVERSION FACTORS

Energy (E) Mev	Factor*
.10	.000160
.20	.000371
.30	.000596
.40	.000815
.50	.001022
.60	.001222
.70	.001410
.80	.001593
1.00	.001923
1.25	.002294
1.50	.002652
1.75	.002971
2.00	.003272
2.20	.003500
2.50	.003840
2.75	.004103
3.00	.004359
3.50	.004854
4.00	.005332
4.50	.005814
5.00	.006265
5.50	.006732
6.00	.007176
6.50	.007176
7.00	.008050
7.50	.008482
8.00	.008912
8.50	.009350
9.00	.009801
10.00	.010710

* Yields dose rate in mr/hr if flux is in gammas/cm^2-sec.

TABLE 5.5

SUMMARY OF CALCULATED GAMMA* DOSE RATES (millirems/hour)

	On Contact With Package Surface	2 Meters From Package Sides	2 Meters From Package Front	2 Meters From Package Rear
CASE 1: 4 containers of BMU 12 w/o seed (2508 rods) + 2 w/o blanket (768 rods) total [illegible] kg U-fissile	<41.0 (29.5)	<8.1 (4.7)	<5.2 (2.3)	<0.9 (0.3)
CASE 2: 4 containers of 5.2 w/o LWBR seed (2056 rods) total 71.1 kg U-fissile	<49.1 (39.6)	<10.4 (7.4)	<1.2 (0.4)	<0.4 (0.2)
CASE 3: 4 containers of 2.8 w/o LWBR PFB (676 rods) total 42.6 kg U-fissile	<32.0 (22.8)	<5.1 (2.7)	<0.3 (0.1)	No Estimate
49 CFR Limit	200	10	2 in the vehicle cab	
CASE 4: Hypothetical Accident Condition - same as Case 2 except inner assembly shifted within 5 inches of Super Tiger inner wall		<49.1 at 3 feet from container		
10 CFR71 Limit		1000		

*The reported dose rates are 95% confidence upper bound values. The corresponding best estimate values are those given in parentheses. The neutron radiation is not included since it is estimated to contribute much less than 5% to the total dose rate under any conditions.

WP: LWB82240N

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 5.1 LONGITUDINAL CROSS SECTION OF SUPER TIGER

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 5.2
DETAILED LONGITUDINAL CROSS SECTION OF SUPER TIGER.

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE 5.3
LONGITUDINAL CROSS SECTION OF FUEL

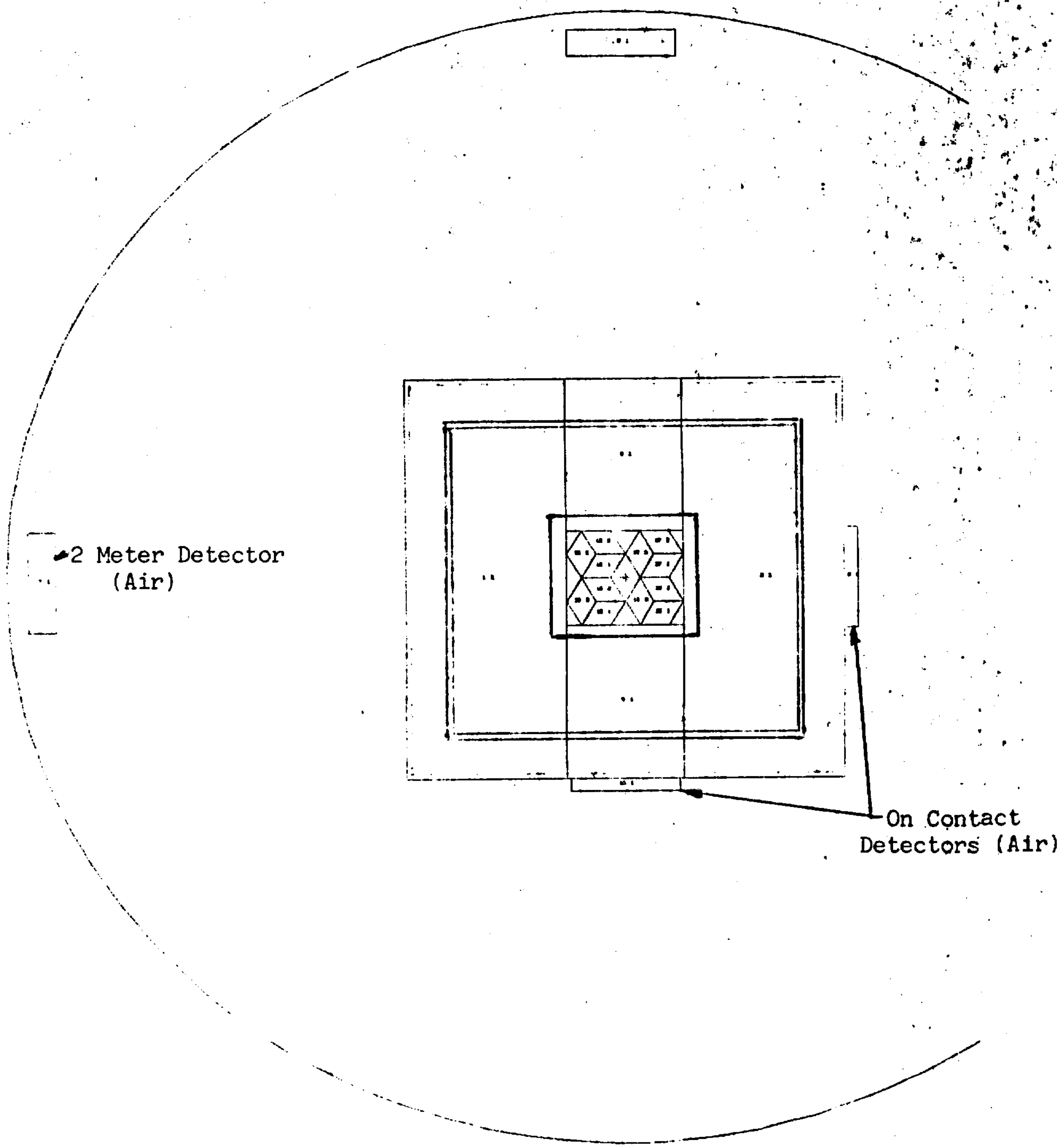


FIGURE [illegible].4

COMPUTER PLOT-RADIAL CROSS SECTION OF SUPER TIGER

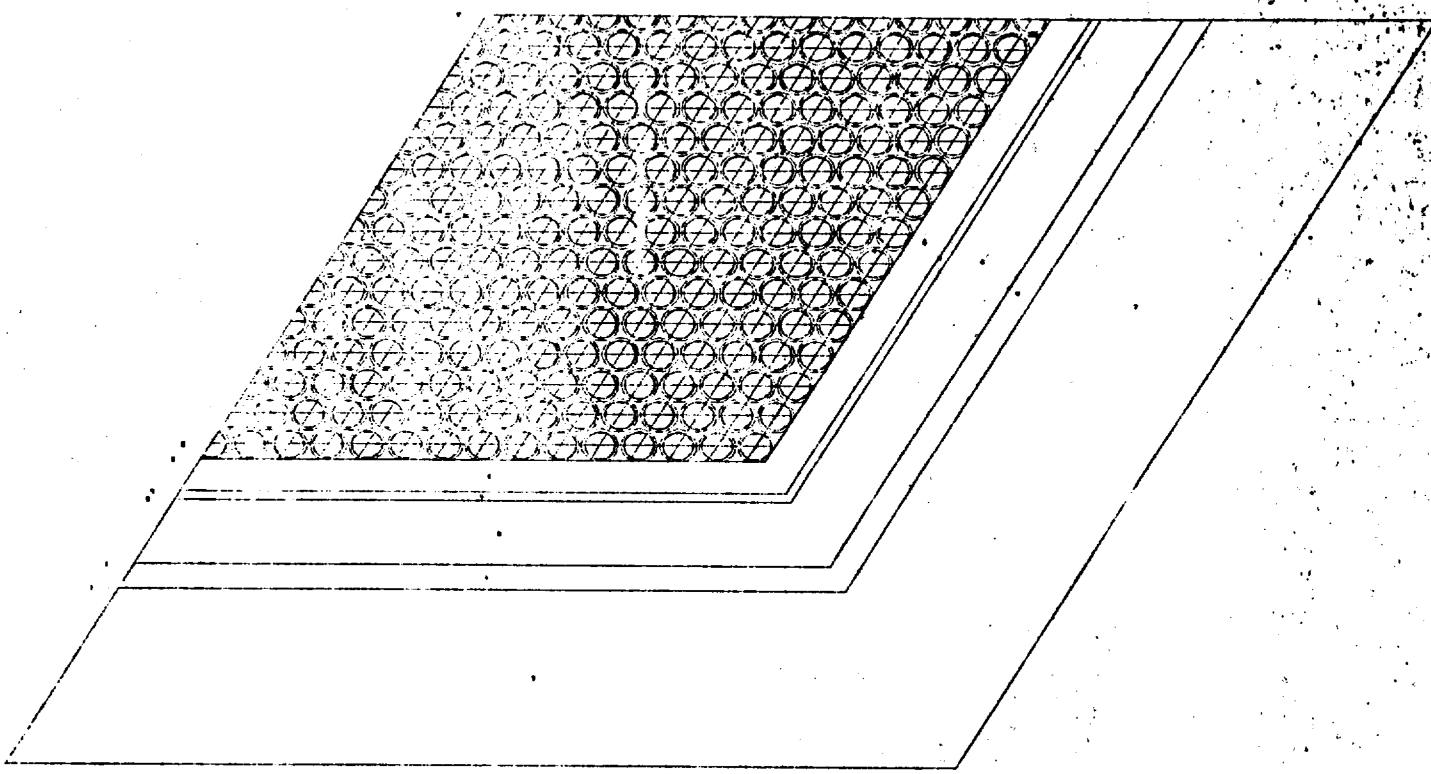


FIGURE 5.5

COMPUTER PLOT-RADIAL ONE THIRD CROSS SECTION OF FUEL PORT

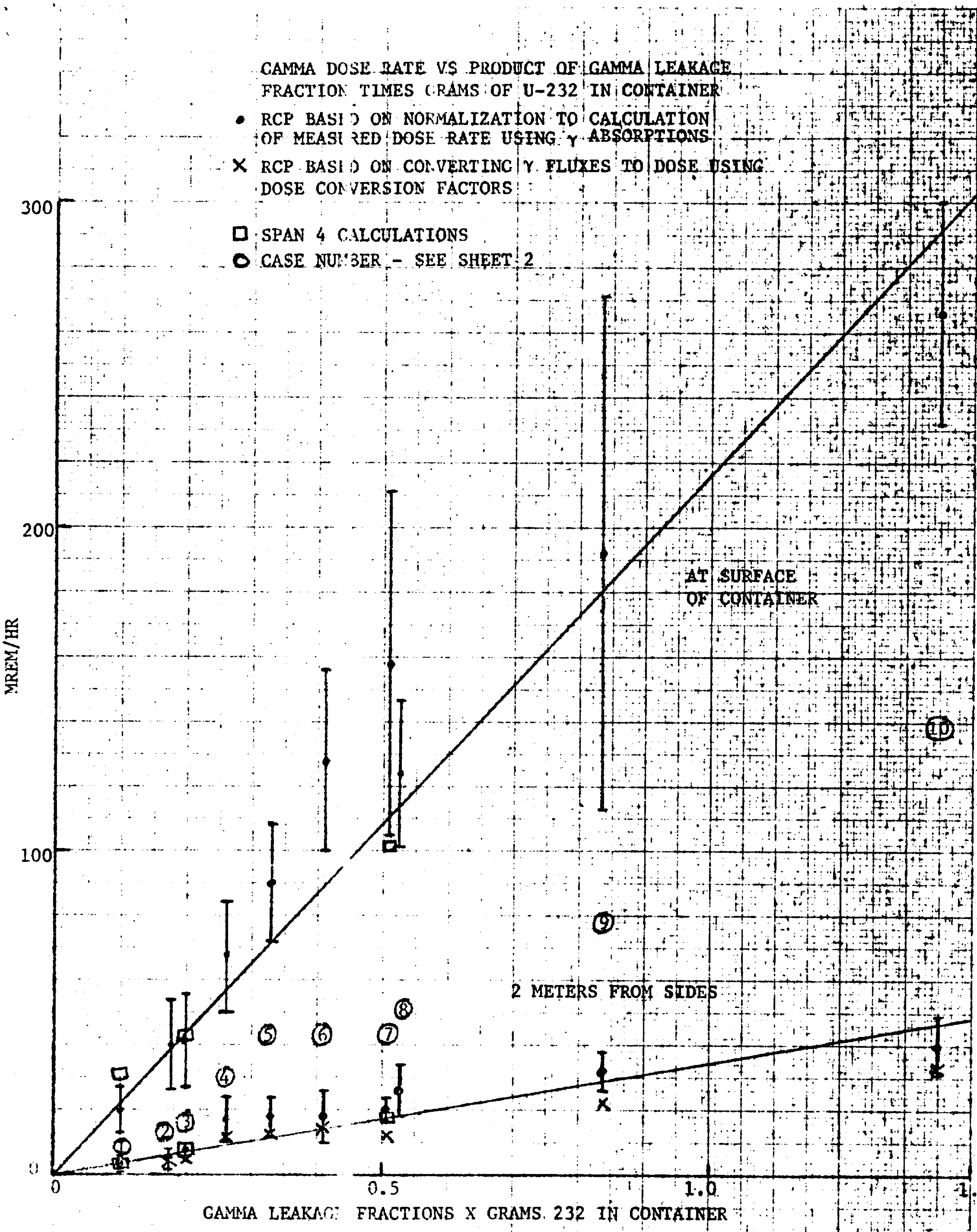


FIGURE 5.6

SUMMARY OF CALCULATED DOSE RATES VERSUS LEAKAGE FROM CONTAINER X 10^4

46 1320

LIST OF CASES FOR CALCULATED DOSE RATES

Case	Type Fuel	Rods/ Box*	$K_g U_{233}$	Shield Thickness	2 Meter Detector**
1	Low Zone Reg. Blkt.	8	10.5	1 3/4 inch	Annulus
2	Hi Zone Reg. Blkt.	8	29.1	2 3/4 inch	3 x 30 x 36
3	Low Zone Reg. Blkt.	8	21.0	1 3/4 inch	Annulus
4	5.6 w/o Seed	16	45.3	2 3/4 inch	3 x 30 x 36
5	Hi Zone Reg. Blkt.	8	29.1	1 3/4 inch	3 x 30 x 36
6	Hi Zone Reg. Blkt.	15	54.6	1 3/4 inch	3 x 30 x 36
7	5.6 w/o Seed	16	45.3	1 3/4 inch	Annulus
8	5.6 w/o Seed	16	45.3	1 3/4 inch	3 x 30 x 36
9	5.6 w/o Seed	70	198.2	1 3/4 inch	Annulus
10	Hi Zone Reg. Blkt.	8	29.1	0	3 x 30 x 36

* All fuel rod lengths 84 inches except for Case 1 which was 42.5 inches.
** Detector geometry was either a 36 inch high, 3 inch thick annulus or 36 inch high, 3 inch thick, 30 inch wide rectangular region.

FIGURE 5.6 Sheet 2

CHAPTER 6 CRITICALITY EVALUATION

6.0 General

This chapter describes the criticality evaluations that were performed for shipments of UO_2-ThO_2 fuel rods in the Super Tiger container. The evaluations were performed in accordance with 10CFR71 for fissile class III shipments. Under normal conditions of transport with two containers in contact and reflected on all sides by water, the K-effective is very conservatively < 0.55. Under worst case accident conditions, the maximum K-effective will not exceed 0.91. The conditions of these calculations are summarized in Table 6.1.

6.1 Discussion and Results

This section provides a brief description of the fuel rods to be shipped and their normal arrangement in the storage containers. The significant criticality design features, the adequacy of the criticality evaluations, and a summary of the criticality evaluations are discussed.

6.1.1 Description of Fuel Rods to be Shipped

Table 6.2 contains a compilation of the UO_2-ThO_2 fuel rods that are to be shipped in the Super Tiger container. These rods are from three sources, the LWBR core spare rods, the Detailed Cell critical experiments, and the BMU critical experiments. They will be loaded in cylindrical stainless steel storage containers and shipped at four containers per shipment in the Super Tiger. The expected maximum number of rods per storage container for each rod type is also listed in Table 6.2. The rods will be tightly packed in the storage containers and aluminum shims will be used to fill empty spaces in partially loaded containers.

6.1.2 Significant Criticality Design Features

All fuel shipments will be maintained in a subcritical condition during normal as well as worst case accident conditions. This is guaranteed by the design and integrity of the shipping container. The shipping container storage compartment is constructed of thick cross section carbon steel components which tend to decouple the four fuel ports should they become flooded during accident conditions. Under normal conditions, the fuel ports are unmoderated and separated from the weakly moderating polyurethane material, which is packed around the outside of the shipping compartment, by the composite 3 3/8 inch thickness of the shipping compartment and storage containers. For hypothetical accident conditions in which the container becomes flooded with water, subcritical conditions are maintained. This is guaranteed by the integrity of the Super Tiger fuel port structure and rod storage containers, which will prohibit significant changes in the fuel rod configurations.

The storage containers that fit within the four fuel ports will each be loaded entirely with fuel rods and/or aluminum shims to obtain a tightly packed array. There are strict administrative constraints, inspections, and procedures to assure that the fuel rod array is not loosely packed. In particular, a minimum 70% of the storage container cross section area will be occupied by fuel rods and/or aluminum shims to positively restrict the available free space that could become flooded under accident conditions. This minimum 70% criterion translates into a specified minimum number of rods (or rods plus equivalent cross sectional area of shims) for each rod type.

6.1.3 Adequacy of the Criticality Evaluations

The criticality evaluations for normal and postulated accident conditions were based on explicit-geometry three-dimensional eigenvalue (K-effective) calculations with the Monte Carlo program RCP01 (Reference 6.1). The nuclear cross-sectional data is the same as used in the Light Water Breeder (LWBR) nuclear calculational model. This program and these data have been used extensively in analyzing critical experiments (References 6.2 and 6.3) and the operating LWBR (References 6.4 and 6.5), both of which utilized the same type fuel rods.

The assurance that the critical facility fuel inventories are correct is based on the fact that these fuels have been used in critical experiments whose analysis accurately predicted criticality. The assurance that the spare LWBR fuel inventories are correct is based on the demonstrated effectiveness of the extensive LWBR manufacturing quality control and the fact that calculation of the LWBR core accurately predicted criticality. The assurance that other important materials such as the carbon steel fuel port shipping compartment and the stainless steel rod storage containers are as specified is based on the quality and administrative controls that will be utilized in the procurement and construction of the shipping container components.

6.1.4 Summary of Criticality Evaluation for Normal Conditions and Accident Conditions

The criticality evaluations were based on using the most reactive fuel rods, the 12 w/o BMU seed rods and the 5.6 w/o Detailed Cell seed rods. It is intended that no actual Super Tiger shipment will consist entirely of high zoned fuel rods. Rather, each shipment will contain combinations of the available fuel rod types and enrichment chosen deliberately to minimize the shipment total fissile content and consequent reactivity and radiation levels. Hence, the criticality evaluations involve more severe loading conditions than any actually anticipated.

A conservative criticality evaluation was made for two identical undamaged Super Tiger containers in contact with each other and entirely surrounded by water. An earlier proposed (Revision 2 of this document) shipping configuration of twenty rectangular fuel ports, rather than the current four cylindrical fuel ports, was the basis for this evaluation. Six of the fuel ports were loaded with a total of 7128 BMU 12 w/o seed rods and the other 14 fuel ports with a total of 3920 Detailed Cell 5.6 w/o seed rods, corresponding to about 232 kg total fissile content per Super Tiger container. Such a loading significantly exceeds the fissile content and total number of rods that physically could be contained in the currently proposed shipping configuration. The number of rods also exceeds the total number of all available seed rods to be shipped. The K-effective of the calculation summarized above was 0.527 ± 0.014, where the uncertainty is the 95% confidence interval.

The criticality evaluation of the Super Tiger configuration for worst case hypothetical accident conditions consider the multiple accident premise that the following four unlikely conditions exist concurrently:

1) Thirty foot drop and high temperature thermal exposure. Neither of these conditions result in any loss of integrity or perturbed configuration of the Super Tiger inner shipping containment structure and fuel ports. This has been discussed in Section 2.7. The possible shifting of the inner containment structure and partial loss (about 20%) of polyurethane due to these accidents were evaluated for the earlier proposed shipping configuration and determined to have no statistically significant effect on reactivity.

2) Optimum water moderation and reflection due to flooding. The most reactive situation occurs when the entire Super Tiger container is externally reflected and the four fuel ports are internally flooded, but the inner shipping containment enclosing the four fuel ports is itself dry.

3) The four fuel ports are all loaded with identical most reactive rods. The high-zoned 5.6 w/o Detailed Cell seed rods with 84 inch enriched fuel stack length and the 12 w/o BMU seed rods with 28 inch enriched fuel stack length have both been evaluated as the most reactive rods. The 28 inch BMU seed rods have 42 inch BMU blanket rods of 2 w/o enrichment loaded at either end of the storage container.

4) Each of the four fuel ports is loaded with a wetter lattice, fewer number of rods, and hence higher reactivity, than that permitted by administrative constraints and loading procedures.

These four accident conditions more than satisfy the 10CFR71.40(b) requirements. Either condition 3 or 4 above would satisfy the unlikely most reactive configuration requirement. The conditions 3 and 4 together would be most unlikely. The 95% confidence upper bound K-effective of .91 corresponds to the four combined hypothetical conditions listed above.

Table 6.1 shows a summary of the required Fissile Class III Transport Conditions, and the degree to which they are met in the Super Tiger shipments. The maximum K-effective values are conservative since no bias contribution has been included. The RCP calculated K-effective values for the BMU critical experiments were greater than unity (Section 6.5), and the bias would thus act to decrease K-effective.

6.2 Package Fuel Loadings

Table 6.2 provides the fissile loadings of the various types of fuel rods to be shipped. The total Super Tiger loading will vary from shipment to shipment because of the many types of rods. Table 6.3 summarizes the fuel loading input to RCP calculations for the normal and hypothetical accident conditions.

6.3 Model Specification

This section describes the detailed three-dimensional geometry and the materials which were input to the RCP computer program to calculate K-effective for the various conditions.

6.3.1 Geometry

6.3.1.1 Fuel Rods and Storage Containers

All fuel rods to be shipped in the Super Tiger will be enclosed in cylindrical stainless steel storage containers 8 5/8 inch outside diameter and 7 5/8 inch inside diameter. These containers are sealed at one end with a 1/4 inch thick stainless steel plate and at the other with a 2 inch thick stainless steel plate. The inside length of these storage containers is 122 1/2 inches. The Detailed Cell and LWBR Core rods will fit directly into these containers. The BMU inner containers are cylindrical stainless steel 7 1/2 inch O.D. and minimum 1/4 inch thickness with stainless steel end plates of 1/4 inch at one end and 1 inch thickness at the other end. The inside length of these inner containers is 29 inches for the seed rods and 43 1/4 inches for the blanket rods. Three BMU inner containers - one seed container centered between a blanket container at either end - will be stacked within the larger basic storage container. This loading array restriction for BMU inner containers does not strictly apply in the case of the lowest enriched (5/2 w/o) BMU seed rods; in which case, more than one BMU seed container may be loaded within the basic storage container.

The cylindrical storage containers are represented in the RCP calculations as hexagonal structures of equivalent cross sectional area. The container ends are not described in the calculations; this is true for the inner BMU containers and the basic storage containers. The fuel rod pellets, pellet to cladding gap, and cladding are explicitly described on a uniform triangular pitch within the hexagonal storage containers. However, the fuel rod endclosures, axial plenum if present, as well as any thoria above and below the enriched fuel stack length are not described in the RCP calculations. A thick water reflector region terminates either end of the fuel rod region for simplicity in the calculations. Figures 6.1 and 6.2 show a 1/3 section of a fuel port and storage container with fuel rods as represented in the RCP calculations. Fuel rod parameters are given in Tables 6.9 through 6.15.

6.3.1.2 Carbon Steel Fuel Ports and Shipping Compartment

Centered within the Super Tiger is a square shipping compartment with carbon steel walls 2 inches thick and 23 1/2 inches inside dimensions. This shipping compartment contains the four cylindrical carbon steel fuel ports which are 11 3/4 inch outside diameter and 9 inch inside diameter. The inside length of the fuel ports and shipping compartment is 126 inches with a 1 inch thick carbon steel plate attached at both ends. The cylindrical fuel ports are represented as hexagonal, concentrically enclosing the storage containers. The square shipping compartment is represented as rectangular to accomodate the boundaries of the hexagonally represented fuel ports. The shipping compartment end plates are not included in the RCP geometry description.

6.3.1.3 Super Tiger Container and Surroundings

The overall Super Tiger container itself is 8 feet square and 20 feet long. It essentially consists of two carbon steel shells 3/16 inch thick each separated by about 10 inches of polyurethane foam. About 2 feet of polyurethane separate the Super Tiger inner wall from the shipping compartment. Figure 6.3 shows the RCP geometry description cross section of the Super Tiger container and the shipping compartment and the four hexagonally represented fuel ports. A 1/3 section of a fuel port is shown in Figures 6.1 and 6.2.

6.3.2 Package Regional Densities

The material densities, atomic number densities, and masses for materials in the criticality evaluations are listed in Table 6.4. Section A of the table lists parameters corresponding to Case A-2 of Table 6.6 for the Detailed Cell seed rods. Section B lists parameters corresponding to Case B-2 of Table 6.6 for the BMU rods.

6.4 Criticality Evaluation

This section describes the calculational method and nuclear data used, the selection of worst case accident conditions, and results of criticality analyses.

6.4.1 Calculational Method and Nuclear Data

Effective multiplication constants for Super Tiger fuel configurations were calculated using the Monte Carlo program RCP01 (Reference 6.1). This computer code provided eigenvalue (K-effective) calculations of the Super Tiger with various hypothetical fuel loading configurations. Most of the nuclear data is the same as used in the LWBR nuclear design calculational model (Section IV.B of Reference 6.7). This program and these data have been verified as a package by calculations of critical experiments and the LWBR as discussed in Section 6.5.

6.4.1.1 Description of the RCP01 Computer Program and Nuclear Data Used

The RCP01 computer program solves the neutron transport equation using Monte Carlo techniques. An initial source shape guess is provided to start an iterative procedure which results in converged source and neutron flux distributions consistent with the eigenvalue, or K-effective, of the system. Uncertainties in terms of 95 percent confidence intervals are based on the iterative procedure. The three-dimensional geometry capability of the program is described in detail in Reference 6.1. This program has sufficient capability to permit all of the significant details of the Super Tiger system loaded with fuel rods to be represented explicitly.

The nuclear data used in conjunction with the RCP01 program is based on the LWBR nuclear calculational model wherever possible. These data are prepared for use in the RCP01 program by combining neutron cross-section libraries for each of the nuclides present in the calculation into a composite library. Table 6.5 lists the identification of these individual libraries in terms of their XAP names. XAP (Reference 6.8) is the Bettis repository of nuclear cross-sectional data. Three of the libraries shown are for nuclides that were either not present in the LWBR model or were of lesser importance relative to the K-effective benchmark calculations used to verify the data. These are indicated in the Table.

6.4.1.2 Basis for Selecting RCP01 and Nuclear Data Used in Criticality Analyses

The RCP01 program was selected as the computer program for criticality evaluations for the following reasons:

(1) It permits explicit representation of all significant geometry features in three dimensions.

(2) It was the program used to calculate the $^{233}UO_2$-ThO_2 benchmark experiments that are used as a basis for design assurance of this evaluation.

(3) It is widely used at BAPL for all types of benchmark calculations and has been accepted as an analytical standard.

(4) It is a convenient package which is familiar to the BAPL nuclear design community and provides a compact package of input and output parameters as well as pictorial descriptions that are easily checked.

The nuclear data package listed in Table 6.5 was selected for the following reasons:

(1) The data for fuel rod materials, the rod cladding, and the water are the same as used in the LWBR nuclear design model which is based on extensive investigations into the nuclear properties of these materials and successful criticality analyses.

(2) The materials which are not a part of the LWBR nuclear design model are based on ENDF/B libraries which are nationally accepted as best-data. These libraries are all for well known materials which have uncomplicated cross sections.

6.4.2 Fuel Loading Optimization

6.4.2.1 Worst Case Accident Conditions

The normal shipping configurations for the available fuel rods listed in Table 6.2 do not result in maximized reactivity should the storage containers become flooded with water. These configurations are maintained by loading procedures which specify tightly packed arrays of the fuel rods within each storage container. It is further intended that each shipment will include combinations of fuel rod types and enrichments to deliberately miminize the shipment total fissile content and associated potential reactivity and radiation levels.

The worst case accident condition considers the following four unlikely events to exist concurrently:

1) Free drop and high temperature thermal exposure of the total Super Tiger container.

2) External water reflection and internal water moderation in a manner to maximize reactivity.

3) Each of the four fuel ports is loaded with most reactive rods. Both full length 5.6 w/o Detailed Cell seed rods and the 12 w/o BMU 28 inch seed rods centered between 2 w/o BMU 42 inch blanket rods have been considered as most reactive rods.

4) Each of the four fuel ports is loaded with a wetter lattice, i.e., fewer number of rods and hence greater reactivity, than that permitted by administrative constraints and loading procedures.

6.4.2.2 Optimization Calculations

Calculations of an earlier proposed shipping arrangment demonstrated that relocation of the internal shipping container within the Super Tiger due to a drop accident and partial loss of the polyurethane foam due to fire would have negligible reactivity effect. Thus the above condition (1) has not been explicitly included in the current reactivity calculations.

Current survey calculations and those for an earlier proposed shipping configuration both demonstrate that total flooding internally and externally does not result in the most reactive condition. Calculations indicate that external water reflection of the total Super Tiger container and internal flooding of the fuel rod arrays within the four fuel ports while the square internal shipping compartment itself otherwise remains dry results in the most reactive flooding condition. Other flooding configurations where the internal shipping compartment and fuel ports are totally flooded or where only a single fuel port is flooded are less reactive due to increased neutron moderation and consequent capture in structural materials or due to increased net neutron leakage respectively. Calculations also demonstrate that no reactivity increase would result in the event that all or part of the polyurethane foam within the package became replaced with water under hypothetical accident conditions.

High zoned seed rods, both 5.6 w/o Detailed Cell and 12 w/o BMU, have been examined as the most reactive of the available fuel rod types. Results of reactivity calculations are presented in Figures 6-4 and 6-5 indicating the reactivity increases as the number of fuel rods per port decreases under conditions of optimum water moderation and not including any aluminum shims. The reactivity would be reduced when aluminum shims are included to compensate for any decreased number of fuel rods. In practice each fuel port will be fully loaded to achieve a tightly packed array of fuel rods and/or aluminum shim stock. This will be assured by strict administrative controls, inspections, and procedures. Survey calculations indicate it would be necessary to fill each fuel port with high zoned seed rods to only about one third capacity, roughly 200 seed rods per port, including no aluminum shims and under conditions of optimum water moderation, before maximum reactivity near or above critical (k-effective = 1.0) would result.

6.4.3 Criticality Results

Table 6.6 lists the conditions and results for various RCP01 reactivity calculations. The first two sets of calculations, Cases A and B represent accident conditions of flooding and most reactive credible loading configurations to satisfy the 10 CFR 71.40(b) requirements. The last two calculations, Cases C1 and C2, represent non-accident conditions of two identical Super Tiger containers in contact and externally reflected by water to satisfy the 10CFR71.40(a) requirements.

6.4.3.1 Accident Conditions

The Case A calculations of Table 6.6 involve Super Tiger shipment configurations loaded entirely with high-zoned 5.6 w/o Detailed Cell seed rods. It is expected about 500 seed rods will physically fit in each fuel port and 437 rods is the minimum number permitted without the addition of shims. Cases A-1, A-2, and A-3 represent loading configurations of 547, 469, and 397 high-zoned seed rods per fuel port without including any aluminum shims and under optimum water moderation conditions. In the calculations the fuel rods are conservatively described as 104 inch enriched fuel stack height rather than the true 84 inch height. It is a further conservatism to consider all the rods as full length 5.6 w/o enrichment since only 334 of this type rod exist. The other available seed rods have lower enrichment and/or shorter enriched stack lengths. These calculations are plotted in Figure 6-4. For conservatism, the minimum credible number of rods per fuel port without any shims is assumed to be 415, which is 5% lower than the minimum allowed by strict administrative constraints. It is shown in Figure 6-4 that the 95% confidence upper bound k-effective is about 0.91 for this minimum credible number of high zoned detailed cell seed rods in each of the four fuel ports.

The Case B calculations of Table 6.6 involve Super Tiger shipment configurations loaded entirely with 28 inch length BMU 12 w/o seed rods, centered between 91 BMU 2 w/o blanket rods of 42 inch length at either end. It is expected that about 600 such seed rods will fit in each fuel port. (More precisely, this number of rods fits within the short BMU seed rod inner container which itself fits within the basic storage container which then fits into the fuel port. The shipping array within the basic storage container is restricted to one BMU seed container centered between two BMU blanket containers for the 12 w/o or the 9/5 w/o BMU seed rods. The lowest enriched 5/2 w/o BMU seed rods are not restricted to a single seed container per basic storage container). There are 2184 of these 12 w/o BMU seed rods available to be shipped, although it is not expected they will all be included in any single shipment. Cases B-1, B-2, and B-3 respectively represent loading configurations of 631, 547, and 469 high zoned BMU seed rods per BMU seed container without any aluminum shims and under optimum water moderation conditions. The minimum number is 546 BMU seed rods per BMU seed container that is permitted without the addition of shims. For conservatism, the minimum credible number of rods per port without shims is assumed to be 518, which is 5% lower than the 546 minimum permitted. The Case B calculations are plotted in Figure 6-5, which shows the 95% confidence upper bound k-effective is about 0.90 for such a minimum credible number of high zoned BMU seed rods (without shims) in each of the four fuel ports.

6.4.3.2 Non-Accident Conditions

The two calculations Cases C1 and C2 of Table 6.6 are based on an earlier proposed shipping arrangement. That involved twenty rectangular fuel ports within the Super Tiger container rather than the currently proposed four cylindrical fuel ports. However, these calculations adequately demonstrate that two identical shipments in contact and externally surrounded with water, even grossly overloaded,remain subcritical, thus satisfying the 10CFR71.40(a) requirement. The containers are internally dry. It is anticipated no shipments in actual practice will contain more than about 40 kg of total fissile loading and, in any case, are restricted to no more than 50 kg.

Case C1 represents a hypothetical condition of substantial overloading. This case contains a total of 7128 high-zoned BMU seed rods and 3920 high-zoned detailed cell seed rods, which corresponds to about 232 kg total fissile content, in the single Super Tiger container. It would not be physically possible to obtain such a high loading in the currently proposed shipping arrangement. Nevertheless, the calculated K-effective is less than 0.55 for two such containers in contact and totally surrounded by water.

Case C2 is more realistic in total fissile content, about 46kg per Super Tiger container. In this case, the calculated maximum K-effective is less than 0.20.

6.5 Critical Benchmark Experiments

6.5.1 Benchmark Experiments and Applicability

The calculational method and neutron cross section data discussed in Section 6.4.1 have been used extensively in analyzing critical experiments. Those experiments were constructed using the same BMU and Detailed Cell rods that are to be shipped in the Super Tiger. The experimental configurations are described in detail in References 6.2 and 6.3. The calculated K-effectives of seven Detailed Cell and three BMU experiments were presented in Table VIII-1 of Reference 6.7 and are summarized here in Table 6.7.

The BMU experimental configurations for which results are included below did not include any that contained fuel rods with the highest fissile content (12 w/o UO_2). However, experiments were conducted using these rods, as discussed in Reference 6.2 at that time but RCP calculations were not performed for them since this fuel loading density was much higher than the maximum established for the final LWBR design (5.2 w/o U fissile) and was of limited interest. Additional calculations have therefore been performed now for the experimental core configuration designated as BMU-1A and shown in Figure 2 of Reference 6.2. The only fissile fuel contained in this experiment was the 12 w/o UO_2 BMU seed rods.

6.5.2 Details of Benchmark Calculations

The benchmark critical experiments were calculated in exact geometric detail. Each fuel rod was described explicitly except that in some cases the clad was homogenized with the void region separating the pellet and clad. All structural materials within the boundaries of the fuel lattices were described in detail including hafnium control blades and steel grids. Paragraph 6.6.1, contains the fuel rod parameters used in these calculations.

The RCP setup for the BMU-1A calculation involved using that of the BMU-1B calculation and converting the fuel pellet number densities to those of the BMU-1A. An additional change involved lowering the positions of the hafnium control blades to the BMU-1A measured height.

The nuclear cross-sectional libraries used in the benchmark calculations are listed in Table 6.8. The nuclide identifications are those given to the libraries as contained in the Bettis nuclear data repository XAP. A justification of the most important of these libraries is included in Section IV.B of Reference 6.7.

6.5.3 Results of the Benchmark Calculations

The calculated eigenvalues (K-effectives) of the benchmark experiments and their weighted average, as discussed in Section VIII-B of Reference 6.7, are contained in Table 6.7. These results show that the RCP calculated K-effectives are greater than 1.0 for the four BMU cores while three of the Detailed Cell values are greater than unity with four less than unity.

The benchmark calculations presented here confirm the calculational model and cross-sectional data used for criticality analyses of the Super Tiger shipping configurations since the same procedure and data were used in obtaining the benchmark results. In addition the experiments were performed using the same fuel rods that are to be shipped. Since the calculated eigenvalues for the four BMU configurations are greater than unity and 12 w/o UO_2 seed rods from these assemblies determine the most limiting accident configurations, no reactivity bias was applied to the criticality calculations of the Super Tiger hypothetical accident calculations based on benchmark experiments. The calculational model is thus conservative.

6.6 Appendix

6.6.1 Fuel Rod Geometry and Composition

A summary of fuel rod geometries and material composition for fuel rods to be shipped in the Super Tiger container are included below.

LWBR Core Fuel Rods

Tables 6.9 and 6.10 contain as-built properties of the LWBR core rods. These tables are extracted from Tables II-1, II-2, and A-11 of Reference 6.4.

Detailed Cell Fuel Rods

Tables 6.11, 6.12, and 6.13 include properties of the Detailed Cell fuel rods. The tables are extracted from Tables A-1, A-2, and A-3 respectively of Reference 6.3.

BMU Fuel Rods

Tables 6.14 and 6.15 include properties of the BMU fuel rods. These tables are extracted from Appendix A and Appendix B respectively of Reference 6.2.

6.6.2 References

6.1 WAPD-TM-1267, RCP01-A Monte Carlo Program for Solving Neutron and Photon Transport Problems in Three-Dimensional Geometry with Detailed Energy Description dated August 1978.

6.2 WAPD-TM-1117, BMU Series of ^{233}U Fueled Critical Experiments dated January 1975.

6.3 WAPD-TM-1101, ^{233}U Oxide-Thorium Oxide Detailed Cell Critical Experiments dated October 1974.

6.4 WAPD-TM-1326, Summary of the Nuclear Design and Performance of the Light Water Breeder Reactor (LWBR) dated June 1979.

6.5 WAPD-TM-1336 Results of Initial Nuclear Tests on LWBR, dated June 1979.

6.6 10 CFR, Part 71, Packaging of Radioactive Material for Transport and Transportation of Radioactive Material under Certain Conditions.

6.7 WAPD-TM-1314, The Calculational Model used in the Analysis of Nuclear Performance of the Light Water Breeder Reactor (LWBR) dated August 1978.

6.8 WAPD-TM-823(L) XAP - A Multigroup Cross Section Library System dated February 1971.

6.6.3 Tables

6.1 Demonstration that the Super Tiger Shipments meet the Requirements of 10 CFR 71

6.2 Rod Transport Summary

6.3 Summary of Assumed Fuel Loadings for Normal and Accident Conditions

6.4 Densities, Number Densities, and Masses used in RCP01 calculations

6.6.3 Tables (Cont'd)

Figures

TABLE 6.1

DEMONSTRATION THAT THE SUPER TIGER SHIPMENTS MEET THE REQUIREMENTS OF 10CFR71

10CFR Paragraph	Specific Requirement	Demonstration That Shipment Meets This Requirement	Ref. Para. 6.4.1
71.40(a)	The undamaged shipment would be subcritical with an identical shipment in contact with it and with the 2 shipments closely reflected on all sides by water.	RCP01 calculation of 2 Super Tiger loaded containers in contact and reflected by H_2O, but internally dry shows keffective <0.54.	Table 6.6 Case C-1
71.40(b)	The shipment would be subcritical if each package were subjected to the hypothetical accident conditions specified in Appendix B of part 71, which are the free drop, thermal, and water immersion conditions in the sequence listed in Appendix B, with close reflection by water on all sides of the array and with the packages in the most reactive arrangement and with the most reactive degree of interspersed hydrogenous moderation which would be credible considering the controls to exercise over the shipment.	RCP01 calculation of 1 Super Tiger, internally partially flooded, externally H_2O reflected, with the most reactive credible fuel loading configuration shows k-effective <0.91	Table 6.6 Cases A and B Figure 6.4 Figure 6.5

TABLE 6.2

ROD TRANSPORT SUMMARY
(Four Containers per shipment-max.)

	Rod Inventory				Transport Data		
	Qty	Binary Stack Length (inches)	$U_{fissile}$/ Rod (grams)	$U_{fissile}$ Total (Kgs)	Max Rods Per Cont.	Max U_F/ Cont. (Kgs)	Approx. No. of Cont.
LWBR Core Seed							
Low Zone(4.3 w/o)	583	42	14.36	8.37	490	7.0	1.2
	289	56	19.14	5.53	490	9.4	0.6
	167	70	23.94	4.00	490	11.7	0.3
High Zone(5.2 w/o)	624	84	34.56	21.56	490	16.9	1.3
LWBR Core Blanket							
Low Zone(1.2 w/o)	436	42	16.46	7.18	140	2.3	3.1
Med. Zone(1.7 w/o)	201	56	30.33	6.10	140	4.2	1.4
	237	84	45.66	10.82	140	6.4	1.7
High Zone(2.0 w/o)	200	70	45.45	9.09	140	6.4	1.4
	259	84	54.66	14.16	140	7.7	1.9
LWBR Core Power Flattening Blanket (PFB)							
Low Zone(1.7 w/o)	220	42	18.96	4.17	160	3.0	1.4
Med. Zone(2.0 w/o)	169	56	30.73	5.19	160	4.9	1.1
	67	84	46.43	3.11	160	7.4	0.4
High Zone(2.8 w/o)	131	70	52.56	6.89	160	8.4	0.8
	771	84	63.04	48.61	160	10.1	4.8

TABLE 6.2 (Continued)

	Rod Inventory				Transport Data		
	Qty	Binary Stack Length (inches)	$U_{fissile}$/ Rod (grams)	$U_{fissile}$ Total (Kgs)	Max Rods Per Cont.	Max U_F/ Cont. (Kgs)	Approx. No. of Cont.
Experimental Physics Detailed Cell							
Seed (3.8 w/o)	153	42	12.29	1.88	490	6.0	0.3
	73	56	16.30	1.19	490	8.0	0.1
	67	70	20.30	1.36	490	9.9	0.1
Seed (5.6 w/o)	334	84	35.39	11.82	490	17.3	0.7
Blanket (1.0 w/o)	81	42	12.35	1.00	490	1.7	0.6
Blanket (1.5 w/o)	44	56	26.36	1.16	140	3.7	0.3
Blanket (1.9 w/o)	47	70	38.72	1.82	140	5.4	0.3
	48	84	48.75	2.34	140	6.8	0.3
Blanket (1.5 w/o)	47	84	39.36	1.85	190	5.5	0.3
PFB (1.5 w/o)	47	42	17.02	.80	160	2.7	0.3
PFB (1.9 w/o)	30	56	28.67	.86	160	4.6	0.2
PFB (2.6 w/o)	34	70	47.06	1.60	160	7.5	0.2
	188	84	56.12	10.55	160	9.0	1.2
PFB (1.9 w/o)	9	84	42.22	.38	160	6.8	0.1

TABLE 6.2 (Continued)

	Rod Inventory				Transport Data		
	Qty	Binary Stack Length (inches)	$U_{fissile}$/ Rod (grams)	$U_{fissile}$ Total (Kgs)	Max Rods Per Cont.	Max U_F/ Cont. (Kgs)	Approx. No. of Cont.
Experimental Physics BMU							
Seed (2/5 w/o)	2187	28**	3.91	8.55	600*	2.3*	3.6*
Seed (5/9 w/o)	2525	28***	7.83	19.77	600*	4.7*	4.2*
Seed (12 w/o)	2184	28	13.16	28.73	600*	7.9*	3.7*
Blanket (2 w/o)	145	14	8.62	1.25	90*	0.8*	1.6*
	265	28	17.43	4.62	90*	1.6*	2.9*
	1349	42	26.02	35.10	90*	2.3*	15.0*
						Sub Total	11 Containers
Bettis Total	14211			291.41 Kg		Total	38 Containers

* Quantities per inner container to be shipped at two BMU blanket containers and one BMU seed container per rod storage container.
** 14 inches each of 2 w/o and 5 w/o.
*** 14 inches each of 5 w/o and 9 w/o.

Summary

Full Length Rods: 2290 Seed, 1665 PFB, 1600 Blanket = 5556 Rods, 193.39 Kg fissile, 27 rod storage containers (8.2 Kg fissile/container-ave)

Short Length Rods: 6896 Seed, 1759 Blanket = 8655 Rods, 98.02 Kg fissile, 11 rod storage containers (8.9 Kg fissile/container-ave)

TABLE 6.3

SUMMARY OF INPUT FUEL LOADINGS FOR NORMAL AND ACCIDENT CONDITIONS
(kilograms per Super Tiger Container)

A.	Hypothetical Accident Condition Case A-3 of Table 6.6 All Detailed Cell Fuel	70.2 kg U-Fissile	1051.1 kg Thorium
B.	Hypothetical Accident Condition Case B-3 of Table 6.6 All BMU Fuel	41.0 kg U-Fissile	1034.9 kg Thorium
C.	Normal Condition (hypothetically grossly overloaded) Case C-1 of Table 6.6		
	BMU Fuel	92.7 kg U-Fissile	706.2 kg Thorium
	Detailed Cell Fuel	139.8	2568.1
	Total	232.5	3274.3

TABLE 6.4
DENSITIES, NUMBER DENSITIES AND MASSES USED IN RCP01 CALCULATIONS

	Material Density (gm/cc)	Atoms/cc ($x 10^{24}$)	Total Mass (kilograms)
A. Hypothetical Accident Conditions			
(Detailed Cell, Case A-3 of Table 6.6)			
Detailed Cell Fuel (5.6 w/o)(1)	9.609		
U-233	0.5272	.1363-2	70.1
U-234	0.78-2	.2004-4	1.04
U-235	0.56-3	.1431-5	0.07
U-238	0.18-2	.4482-5	0.0
Oxygen	1.165	.4383-1	141.3
Thorium	7.907	.2053-1	1051.1
Fuel Rod Cladding (Zirc 4)	6.55	0.429-1	201.1
Fuel Storage Containers (SS304)	8.0	0.885-1	4620.1
Super Tiger Shipping Containers (Iron)	7.9	0.8492-1	6622.8
Polyurethane	0.064		
Hydrogen	0.0049	0.2965-2	101.2
Carbon	0.0591	0.2965-2	1221.1
Water(3)	1.0		
Hydrogen	0.111	0.668-1	30.1
Oxygen	0.889	0.334-1	241.3
B. Hypothetical Accident Conditions (BMU, Case B-3 of Table 6.6)			
BMU Fuel (12 w/o)(2)	8.3870		
U-233	0.8532	0.2205-2	41.0(4)
U-234	0.75-2	0.1932-4	0.36
U-235	0.24-3	0.6023-6	0.01
U-238	0.88-2	0.2234-4	0

TABLE 6.4 (Continued)

	Material Density (gm/cc)	Atoms/cc (x 10^{24})	Total Mass (kilograms)
B. (Continued)			
Oxygen	1.0160	0.3826-1	135.9
Thorium	6.5010	0.1688-1	1034.9
Fuel Rod Cladding (Zirc 4)	6.55	0.429-1	158.7
Fuel Storage Containers (SS 304)	8.0	0.885-1	5074.8
Super Tiger Shipping Containers (Iron)	7.9	0.8492-1	6622.8
Polyurethane	0.064		
Hydrogen	0.0049	0.2965-2	101.2
Carbon	0.0591	0.2965-2	1221.1
Water(3)	1.0		
Hydrogen	0.111	0.668-1	22.4
Oxygen	0.889	0.334-1	179.5

FOOTNOTES:

(1) Weight percent U-total
(2) Weight percent UO_2
(3) Mass in fuel ports only. Reflector mass not included.
(4) The masses for BMU fuel are for the total of 28 inch 12 w/o seed plus 42 inch 2 w/o blanket above and below the seed.

TABLE 6.5

CROSS SECTION LIBRARIES FOR RCP01 CALCULATIONS

Isotope		Identification[1] of Fast Group Cross Section Set	Identification[1] of Thermal Group Cross Section Set
U-234		E1043U234M	E1043U234M
U-233		U233(14)	U233LWB2B
Zr[2]		Zr(25)	Zr(25)
Zr4 Residual[3]		Zr4RRDA2B	Zr4RRDA1B
Th232		TH232LWB3B	TH232LWB3B
H		M242H	T001H
O		O(25)	E1013016V2
FE**		FE(16)	FE(16)
SS304[4]*		(A merge of the following isotope cross-section sets):	
	CR	CR(8)	CR(8)
	FE	FE(16)	FE(16)
	MN	MN(4)	MN(4)
	SI	E1151SI	E1151SI
	NI	NI(8)	NI(8)
Carbon**		E1165C12	E1165C12

NOTES:
(1) These are the ID's of the neutron cross-section sets in the Bettis nuclear data storage system known as "XAP", Reference 6.8.
(2) This is the pure element Zirconium portion of the Zircaloy-4 alloy.
(3) This is the sum of the alloying elements, tin, iron etc., in the alloy Zircaloy-4.
(4) This is a merge of the cross-section sets for the alloying elements listed weighted by their isotopic fractional incidence in SS304.
* This element is relatively unimportant for criticality evaluations in LWBR and the Benchmark experiments discussed in Section 6.5.
** These elements are not used in LWBR or Benchmark critical analyses.

TABLE 6.6

RESULTS OF RCPO1 CALCULATIONS

NOTES:
1) The indicated uncertainties represent the 95% confidence level.
2) Case A and B results include optimum water moderation and reflection; i.e., the Super Tiger container externally water reflected and the four fuel ports internally flooded.
3) Case A and B results do not include the effects of aluminum shims that will be used to obtain a tightly packed array in any instance that is not fully loaded and tightly packed with fuel rods. Including the aluminum shims would reduce the reactivity relative to that calculated.

A: Each of the four fuel ports loaded with high-zoned Detailed Cell seed rods, 5.6 w/o U-total (6.36 W/o UO_2), represented as 104 inch enriched fuel stack length.

Case A-1: 547 rods/port, k-effective = 0.5771 ± 0.0136
96.7 kg total fissile content

Case A-2: 469 rods/port, k-effective = 0.7915 ± 0.0133
82.9 kg total fissile content

Case A-3: 397 rods/port, k-effective = 0.9060 ± 0.0258
70.2 kg total fissile content

B: Each of the four fuel ports loaded with BMU high zoned 12 w/o UO_2 28 inch stack length seed rods centered between 91 BMU 2 w/o UO_2 42 inch stack length blanket rods at either end.

Case B-1: 631 seed rods/port, k-effective = 0.7120 ± 0.0249
49.5 kg total fissile content

Case B-2: 547 seed rods/port, k-effective = 0.8481 ± 0.0157
45.1 kg total fissile content

Case B-3: 469 seed rods/port, k-effective = 0.9252 ± 0.0140
41.0 kg total fissile content

C: Two Super Tiger container in contact side by sideand externally reflected by water but internally dry. these cases represent an earlier proposed shipping concept (revison 2 of this document) that involved twenty rectangular fuel ports centered in a rectangular array within the Super Tiger container.

Case C-1: Six fuel ports each loaded with 1188 BMU 12 w/o seed rods and fourteen fuel ports each loaded with 280 Detailed Cell 5.6 w/o seed rods.
k-effective = 0.5270 ± 0.014
232.5 kg total fissile contents per container

Case C-2: Twenty fuel ports each loaded with 64 Detailed Cell 5.6 w/o seed rods.
k-effective = 0.172 ± 0.011
45.7 kg total fissile content per container

TABLE 6.7

EIGENVALUES FROM CRITICAL ASSEMBLIES

	RCP	Corrections** to RCP	Corrected RCP	(1σ)
BMU CORES				
BMU1C (410°F)	1.0061	+0.0000	1.0061	(0.0017)
BMU-2-4 (power flattened)	1.0048	+0.0000	1.0048	(0.0018)
BMU1B	1.0069	+0.0000	1.0069	(0.0019)
BMU1A	1.0079	+0.0000	1.0079	(0.0072)
DETAILED CELLS				
Seed Position (inches)*				
14.0	1.0015	+0.0006	1.0021	(0.0017)
-3.5	0.9978	+0.0012	0.9990	(0.0017)
-26.35	0.9985	+0.0003	0.9988	(0.0015)
+3.5 (477°F)	0.9969	+0.0007	0.9976	(0.0015)
+17.8	1.0026	+0.0010	1.0036	(0.0017)
-2.0	1.0006	+0.0009	1.0015	(0.0018)
-14.0	0.9948	+0.0008	0.9956	(0.0015)
$1/\sigma^2$ weighted average			1.0011	(0.0036)

* The seed position is with respect to the position where the seed is aligned with the blanket.

** Corrections for small reactivity effects not included in the calculations such as U-235 fission.

TABLE 6.8

CROSS SECTION LIBRARIES FOR BENCHMARK CALCULATIONS

U-233	U-233(14)	U233LWB2B
Th-232	Th232LWB3B	Th232LWB3B
U-234	E1043U234M	E1043U234M
U-235	M718U235	T034U235
U-238	U238RDA1B	U238RDA1B
Hydrogen	M242H	T001H
Oxygen	O(25)	E1013016V2
Zirc2*		
SS304	M578SS304	T578SS304
ThIMP**		
ThUIMP***		

* Special Zircaloy-2 deck constructed for material used in benchmark rods, base data is XAP zirconium.

** Special library for impurity materials in BMU ThO_2 fuel pellets.

*** Special library for impurity materials in BMU UO_2-ThO_2 fuel rods.

TABLE 6.9
AVERAGE AS-BUILT LWBR CORE FUEL CHARACTERISTICS

	Pellet OD (in)	Pellet Length (in)	Percent of Theoretical Density	U-Fissile (w/o)*	U-Fissile (grams/in.)	Rod Length (in)	Rod O.D. (in)	Clad Thickness (in)
Seed								
Thoria	0.2556	0.530	98.01	None	None	718.37-	0.3063	0.02217
Low zoned	0.2520	0.444	97.71	4.337	0.3416	119.14		
High zoned	0.2520	0.615	97.55	5.202	0.4114			
Standard Blanket								
Thoria	0.5106	0.616	97.80	None	None	121.88-	0.5717	0.02808
Low zoned	0.5105	0.531	98.61	1.214	0.3920	122.12		
Medium zoned	0.5105	0.868	98.22	1.668	0.5421			
High zoned	0.5105	0.785	98.11	2.005	0.6498			
Power Flattening Blanket								
Thoria	0.4696	0.447	98.06	None	None	121.88-	0.5274	0.02642
Low zoned	0.4695	0.870	98.03	1.654	0.4537	122.12		
Medium zoned	0.4695	0.786	98.04	2.009	0.5509			
High zoned	0.4696	0.701	97.91	2.739	0.7492			

$$\text{*U-Fissile (w/o)} = \frac{\text{U-233} + \text{U-235}}{UO_2 + ThO_2} \times 100$$

U Isotopic Composition

U-232	<0.001 w/o
U-233	98.23
U-234	1.29
U-235	0.09
U-236	0.02
U-238	0.37

TABLE 6.10

LWBR URANIUM ISOTOPIC WEIGHT PERCENT BY FUEL COMPOSITION

	U-232	U-233	U-234	U-235	U-236	U-238
Seed						
Low zoned	0.00075	98.3088	1.2899	0.07947	0.01775	0.30333
High zoned	0.00070	98.3679	1.2742	0.06711	0.01397	0.27610
Standard Blanket						
Low zoned	0.00084	98.3037	1.3289	0.08805	0.02411	0.25442
Medium zoned	0.00082	98.3218	1.3144	0.08078	0.02101	0.26118
High zoned	0.00082	98.2597	1.3504	0.10466	0.03032	0.25412
Power Flattening Blanket						
Low zoned	0.00082	98.3074	1.3193	0.08665	0.02258	0.26323
Medium zoned	0.00079	98.2260	1.3620	0.11257	0.03247	0.26613
High zoned	0.00070	98.0419	1.2433	0.09690	0.02648	0.59072

TABLE 6.11
PHYSICAL DIMENSIONS OF FUEL COMPOSITIONS AND FUEL ATOM DENSITIES

DETAILED CELL AT 27°C
CELL DIMENSIONS IN INCHES

5.6 w/o Seed

Pellet Diameter	0.2501
Pellet Length	0.711
1/2 (Pellet OD-Pellet Dish) Diameter)	0.025
End Dish Depth	0.008
Rod OD	0.3051 ±0.0007
Rod ID	0.257
Pitch	0.3685 ±0.0002

3.8 w/o Seed

Pellet Diameter	0.2503
Pellet Length	0.591
1/2 (Pellet OD-Pellet Dish Diameter)	0.025
End Dish Depth	0.008
Rod OD	0.3054 ±0.0005
Rod ID	0.257
Pitch	0.3685 ±0.0002

1.542 w/o Power Flattening Blanket

Pellet Diameter	0.4646
Pellet Length	0.658
1/2 (Pellet OD-Pellet Dish Diameter)	0.050
End Dish Depth	0.015
Rod OD	0.5278 ±0.0005
Rod ID	0.470
Pitch	0.6308 ±0.0002

0.963 w/o Regular Blanket

Pellet Diameter	0.5056
Pellet Length	0.740
1/2 (Pellet OD - Pellet Dish Diameter)	0.050
End Dish Depth	0.015
Rod OD	0.5725 ±0.0004
Rod ID	0.511
Pitch	0.6308 ±0.0002

1.532 w/o Regular Blanket

Pellet Diameter	0.5053
Pellet Length	0.860
1/2 (Pellet OD-Pellet Dish Diameter)	0.050
End Dish Depth	0.015
Rod OD	0.5723 ±0.0008
Rod ID	0.511
Pitch	0.6308 ±0.0002

1.901 w/o Regular Blanket

Pellet Diameter	0.5053
Pellet Length	0.908
1/2 (Pellet OD-Pellet Dish Diameter)	0.050
End Dish Depth	0.015
Rod OD	0.5725 ±0.0005
Rod ID	0.511
Pitch	0.6308 ±0.0002

TABLE 6.11 (continued)

1.928 w/o Power Flattening Blanket

Pellet Diameter	0.4648
Pellet Length	0.778
1/2 (Pellet OD-Pellet Dish Diameter)	0.050
End Dish Depth	0.015
Rod OD	0.5277 ±0.0005
Rod ID	0.470
Pitch	0.6308 ±0.0002

2.564 w/o Power Flattening Blanket

Pellet Diameter	0.4647
Pellet Length	0.898
1/2 (Pellet OD-Pellet Dish Diameter)	0.050
End Dish Depth	0.015
Rod OD	0.5280 ±0.0005
Rod ID	0.470
Pitch	0.6308 ±0.0002

NOTE: Seed rod length: 104.08"
PFB/blanket rod length: 104.88"

TABLE 6.12
DETAILED CELL AT 27°C ISOTOPIC
WEIGHT PERCENT MEASURED

5.6 w/o Seed (Type 1)

Isotope	w/o Uranium
^{233}U	98.112
^{234}U	1.448
^{235}U	0.0039
^{236}U	0.0067
^{238}U	0.3295

3.8 w/o Seed (Types 2 to 4)

Isotope	w/o Uranium
^{233}U	98.201
^{234}U	1.472
^{235}U	0.0745
^{236}U	0.0066
^{238}U	0.2461

0.963 w/o Regular Blanket (Type 1)

Isotope	w/o Uranium
^{233}U	96.637
^{234}U	1.058
^{235}U	0.5883
^{236}U	0.0089
^{238}U	1.7053

1.532 w/o Regular Blanket Types 2 and 5)

Isotope	w/o Uranium
^{233}U	98.108
^{234}U	1.447
^{235}U	0.1051
^{236}U	0.0067
^{238}U	0.3331

1.901 w/o Regular Blanket (Types 3 and 4)

Isotope	w/o Uranium
^{233}U	96.994
^{234}U	1.1522
^{235}U	0.4710
^{236}U	0.0084
^{238}U	1.3721

All Power Flattening Blanket Binary Regions

Isotope	w/o Uranium
^{233}U	98.201
^{234}U	1.472
^{235}U	0.0745
^{236}U	0.0066
^{238}U	0.2461

TABLE 6.13
DETAILED CELL AT 27°C, W/O UO_2 W/O U-TOTAL AND
PELLET FRACTION OF THEORETICAL DENSITY

Composition	w/o UO_2	Measured w/o U-Total	Pellet Fraction of Theoretical Density
5.6 w/o Seed (Type 1)	6.362	5.594	0.9547
3.8 w/o Seed (Types 2 to 4)	4.321	3.799	0.9698
0.963 w/o Regular Blanket (Type 1)	1.096	0.9633	0.9646
1.532 w/o Regular Blanket (Types 2 and 5)	1.742	1.532	0.9608
1.901 w/o Regular Blanket (Types 3 and 4)	2.162	1.901	0.9598
1.542 w/o Power Flattening Blanket (Type 1)	1.754	1.542	0.9711
1.928 w/o Power Flattening Blanket (Types 2 and 5)	2.192	1.928	0.9718
2.564 w/o Power Flattening Blanket (Types 3 and 4)	2.916	2.564	0.9598

TABLE 6.14

BMU FUEL AND ROD DIMENSIONS

Fuel	Pellet Stack Length Inches	Rod Length Inches	Rod Ends Inches	Void Length Inches	Measured Rod O.D. Inches	Rod+ I.D. Inches	Measured Pellet Diameter Inches
12 w/o Seed	27.80 ± 0.07	28.16	0.17	0.04	0.2506	0.2130	0.2062
(5/9) w/o Seed	--	28.16	0.17	0.04	0.2502	0.2126	
5 w/o	13.89 ± 0.01						0.2068
9 w/o	13.90 ± 0.07						0.2069
(2/5) w/o Seed	--	28.16	0.17	0.04	0.2492	0.2126	
2 w/o	13.900 ± 0.001						0.2067
5 w/o	13.900 ± 0.001						0.2068
2 w/o Blanket	42.013 ± 0.0007	42.46	0.20	0.06	0.6240	0.5510	0.5432
(2/0) w/o Blanket	--	42.46	0.20	0.06	0.6240	0.5510	
2 w/o	14.008 ± 0.001						0.5432
0 w/o	28.00*						0.5432*
(2/0) w/o Blanket	--	42.46	0.20	0.06	0.6240	0.5510	
2 w/o	28.004 ± 0.001						0.5432
0 w/o	14.00*						0.5432*

* Value not measured

\+ Rod ID calculated from measured OD and nominal wall thickness

TABLE 6.15
COMPOSITION OF BMU FUEL

Fuel	Fuel Density g/cm^3	Measured w/o^{T}U*	Measured w/o$^T UO_2$*
12 w/o Seed	8.387	10.37	11.79
9 w/o Seed	8.453	8.453	7.8258.900
5 w/o Seed	8.478	8.478	4.3514.948
2 w/o Seed	8.494	8.494	1.7191.955
2 w/o Blanket	8.493	1.724	1.961

ISOTOPIC COMPOSITION OF BMU FUEL

Fuel	^{233}U	^{234}U	^{235}U	^{238}U
12 w/o Seed				
w/o Uranium	98.094	0.863	0.027	1.015
9 w/o Seed				
w/o Uranium	98.16	0.914	0.017	0.934
5 w/o Seed				
w/o Uranium	97.909	0.877	0.024	1.190
2 w/o Seed				
w/o Uranium	98.082	0.867	0.026	1.025
2 w/o Blanket				
w/o Uranium	97.966	0.859	0.026	1.159

---

* weight percent total uranium

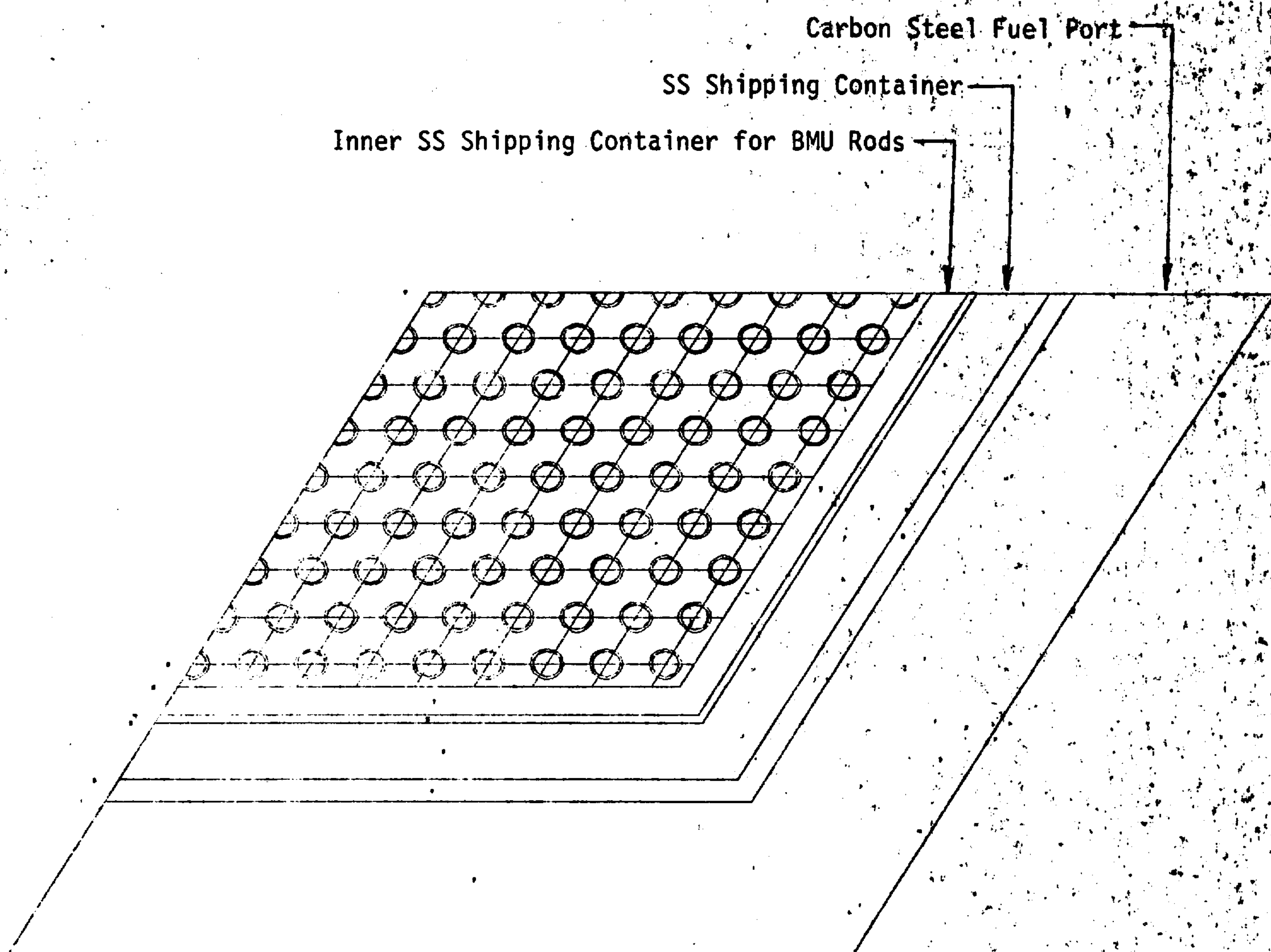


FIGURE 6.1

RADIAL ONE THIRD CROSS SECTION OF FUEL PORT AND STORAGE CONTAINER, BMU

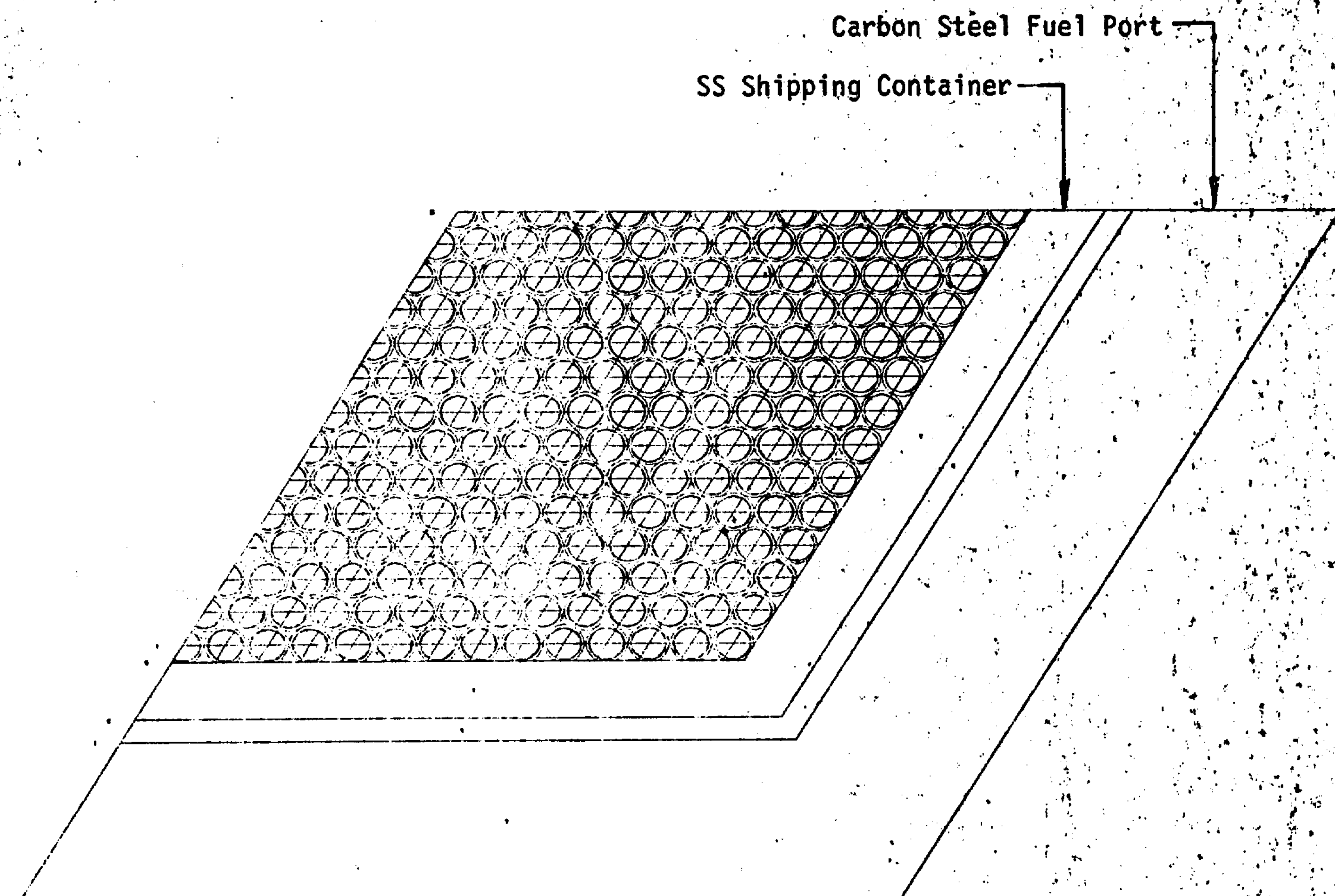


FIGURE 6.2

RADIAL ONE THIRD CROSS SECTION OF FUEL PORT AND STORAGE CONTAINER,
DETAILED CELL

FIGURE 6.3

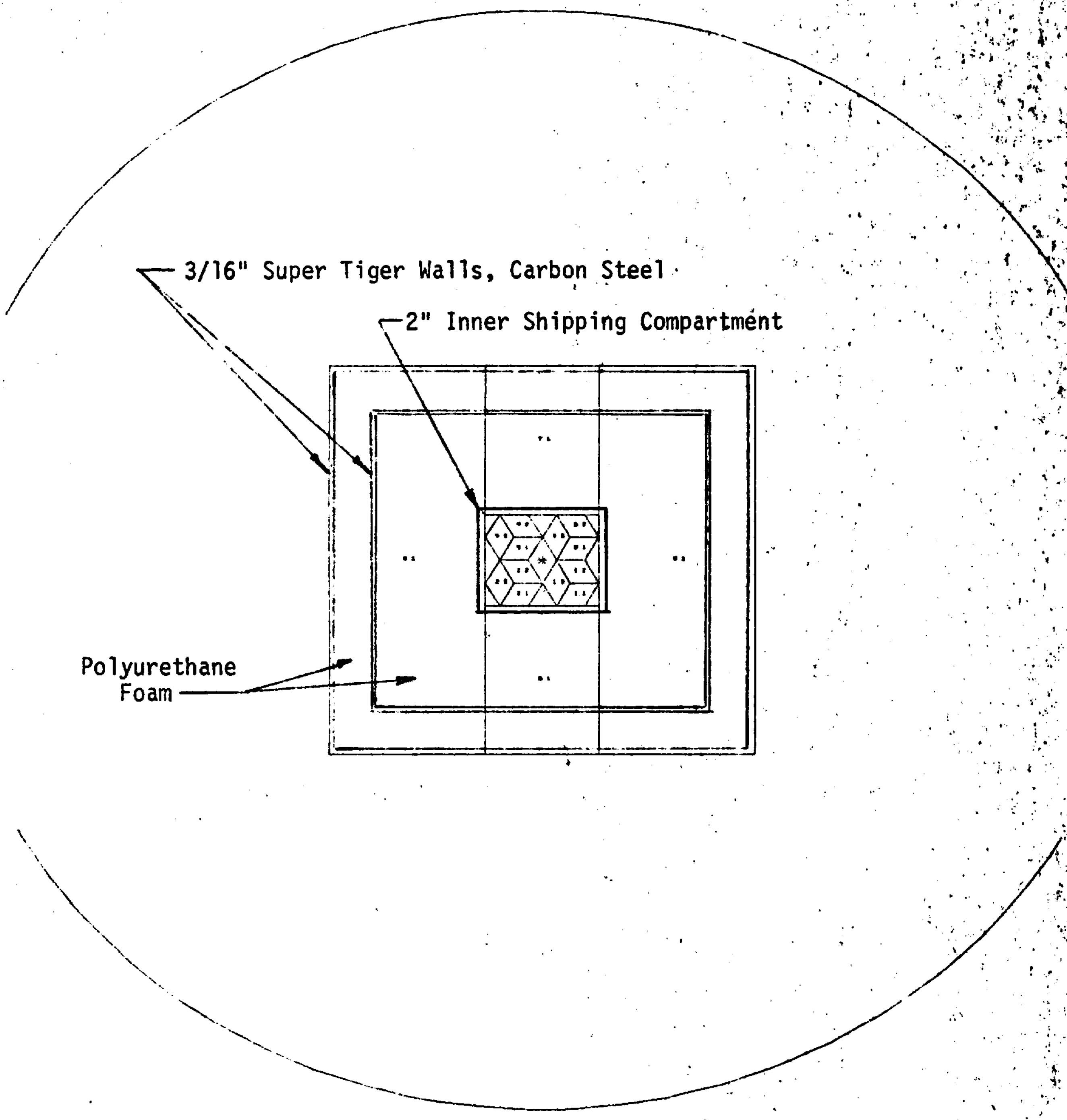


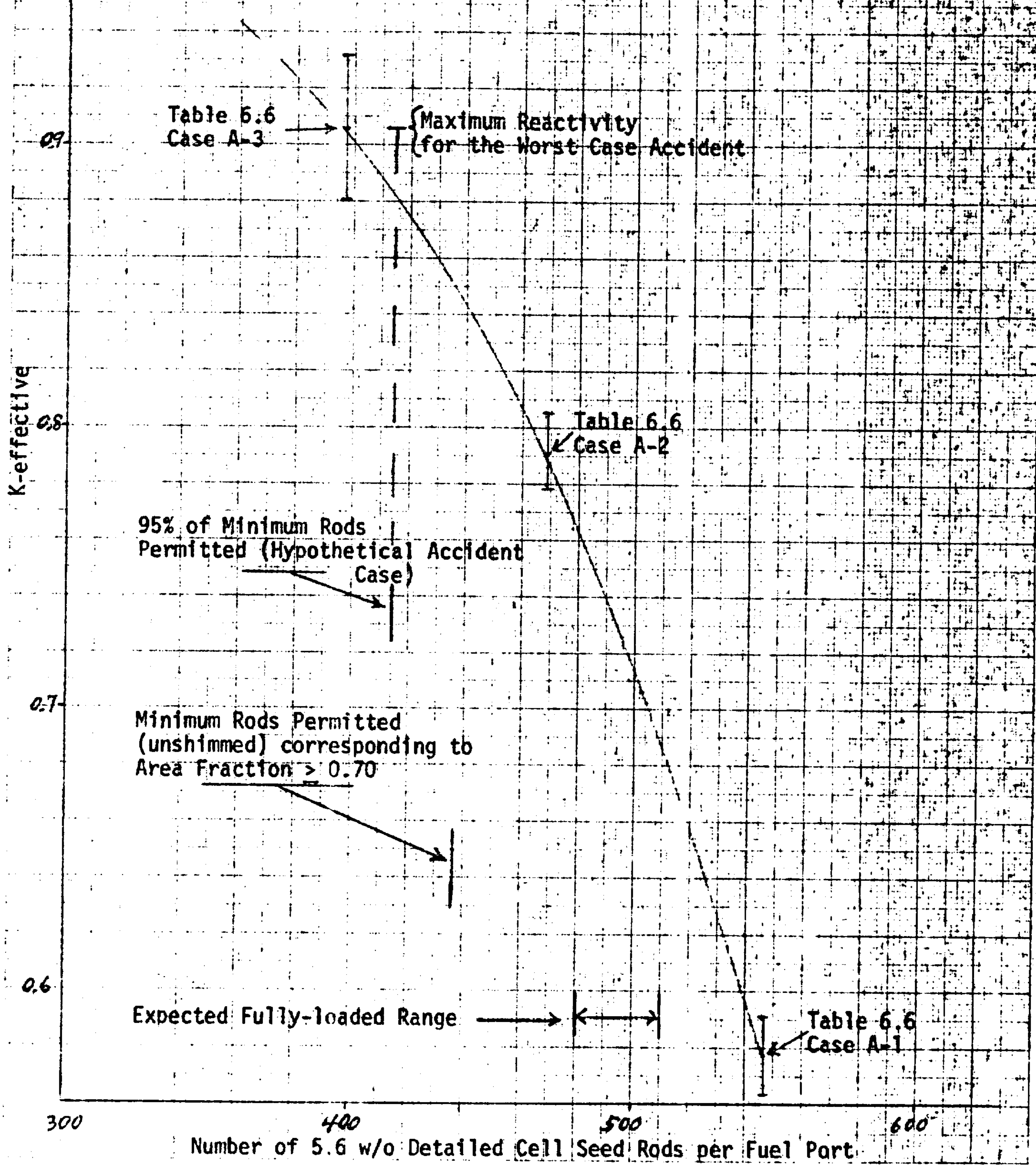
FIGURE 6.3

RADIAL CROSS SECTION OF SUPER TIGER AND FOUR FUEL PORTS

FIGURE 6-4

Super Tiger K-effective
as a function of
Number of 5.6 w/o Detailed Cell Seed Rods per Fuel Port
Optimum Water Moderation and Reflection
and not including any Aluminum Shims

Uncertainty is 95% Confidence Level



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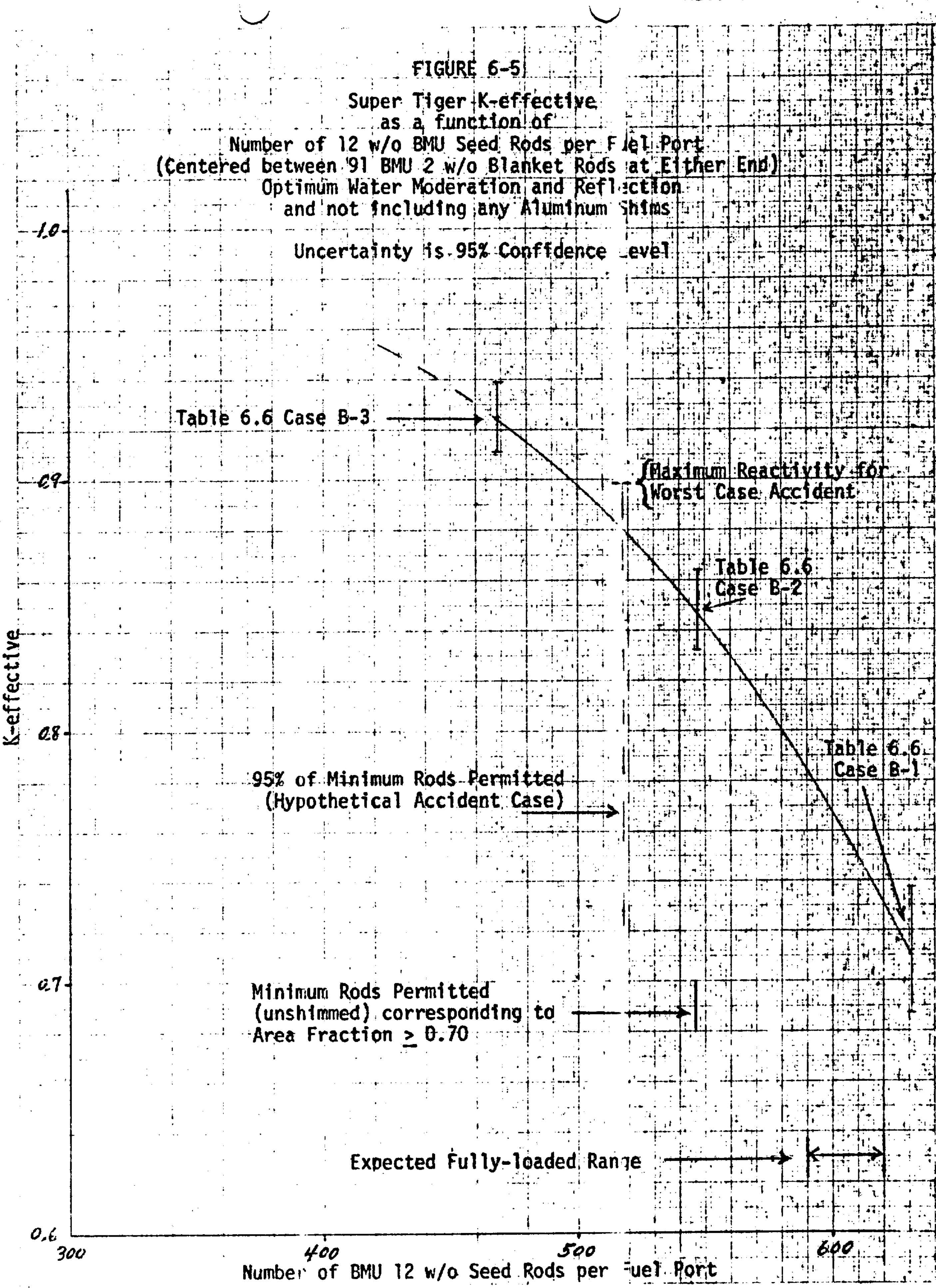

FIGURE 6-5

Super Tiger K-effective as a function of Number of 12 w/o BMU Seed Rods per Fuel Port (Centered between 91 BMU 2 w/o Blanket Rods at Either End) Optimum Water Moderation and Reflection and not including any Aluminum Shims

Uncertainty is 95% Confidence Level

CHAPTER 7 OPERATING PROCEDURES

7.0 Introduction

All of the rods to be transported will be shipped in LWBR rod storage containers (Figure 1.5). The Super Tiger shipping container will be installed on a flatbed trailer and the inner containment assembly will be preinstalled prior to the start of shipments. A fork-lift loading device will be used to install the four loaded rod containers in the shipping container for each shipment.

7.1 Procedures for Loading the Package

The complete loading sequence will be documented by formal procedure summarized as follows:

(1) Confirm that the shipping container/trailer maintenance program has been completed as defined in Paragraph 8.2.

(2) Confirm that any loading devices have been load tested and serviced for operation.

(3) Prepare the Super Tiger for loading be removing the 10-one inch bolts and manually opening the door, performing a leak test as defined in Paragraph 8.2.2, removing the 36-one half inch bolts and removing the inner seal plate, removing the rear section of the inner liner, and unlocking and opening the storage compartment door.

(4) Perform a radiation survey of the storage area and a contamination survey of the accessible portion of the Super Tiger inner compartment.

(5) Rope off and post the area around the Super Tiger and the open storage area door as a High Radiation Area.

(6) Using the fork-lift loading device, lift the selected rod storage container and insert it at least 70% into the selected Super Tiger port.

(7) Using the fork-lift loading device, push the rod storage container the rest of the way into the Super Tiger port.

(8) Repeat steps (6) and (7) to complete the Super Tiger load. Periodically record all Super Tiger external radiation levels and terminate loading if any level approaches the allowable transport limit (200 mrem/hr on contact with any external surface, 10 mrem/hr at 2 meters from any external surface, and 2 mrem/hr in the truck cab).

(9) Prepare the Super Tiger for transport by locking the storage compartment door, installing the rear sections of the inner liner, installing the inner seal plate with the

36-one inch bolts, performing a leak test as defined in paragraph 8.2.2 and closing and securing the Super Tiger door with the 10-one inch bolts.

(10) Close and secure the storage area and retain the Super Tiger/trailer under armed security escort until the shipment is initiated.

7.2 Procedures for Unloading the Package

The complete unloading sequence will be formally documented with the significant shipping container provisions summarized as follows:

(1) Position the shipping container/trailer for unloading and prepare for unloading by removing the 10-one inch bolts and manually opening the door, removing the 36-one half inch bolts and removing the inner seal plate, removing the rear section of the inner liner, and unlocking and opening the storage compartment door.

(2) Perform a contamination survey of the accessible portions of the shipping container as the above operations are in process.

(3) Install the Bettis supplied eyebolt in the threaded hole of the rod storage container to be extracted.

(4) Using a fork-lift or other suitable vehicle, extract the rod storage container on to a suitable fork-lift mounted unloading rack.

(5) Using an overhead crane, raise the rod storage container to the vertical position and place in a suitable retainer rack.

(6) Replace the eyebolt with a suitable rod storage container handling tool (long eyebolt or equivalent).

(7) Using a overhead crane, transfer the rod storage container to the storage location.

(8) Repeat steps 3 through 7 for the remaining rod storage containers.

7.3 Preparation of an Empty Package for Transport

The preparation for empty transport will be performed to a written checklist summarized as follows:

1. Perform a contamination survey of the accessible portion of the Super Tiger inner compartment.

2. Close and lock the storage compartment door.

3. Install the rear sections of the inner liner.

4. Install the inner seal plate with the 36-one half inch bolts.

5. Remove the leak test valve to assure that the Super Tiger cavity is vented for empty transport.

6. Close and secure the Super Tiger door with the 10-one inch bolts.

7. Confirm that the trailer has been currently serviced and inspected for Highway use.

8. Confirm that the Super Tiger tiedown bolts are secured.

NOTE: The empty Super Tiger/trailer may be transported by commercial carrier.

7.4 Transport Limits

All Super Tiger loading procedures will include provisions for ensuring that the following limits are maintained:

1. No shipment to exceed 50 Kg of U_{233}.

2. All rod storage containers are filled to capacity with rods or aluminum shim stock (at least 70% of the cross sectional area filled with rods or shims).

3. No rod storage container to include more than one BMU rod container of 5/9 w/o or 12 w/o rods.

4. Each rod storage container gross weight is not over 2000 pounds.

5. Gross shipping container and trailer weights are within allowable transport limits.

6. No recorded external beta-gamma <u>and</u> neutron radiation dose rates to exceed 200 mrem/hr <u>on</u> contact with any external surface, 10 mrem/hr at 2 meters from any external surface, and 2 mrem/hr in the truck cab.

CHAPTER 8 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.0 Introduction

As a Prime Contractor in the Naval Nuclear Propulsion Program, Bettis Atomic Power Laboratory maintains a quality assurance program in accordance with the applicable requirements of MIL-Q-9858 and MIL-I-45208. The application of this quality assurance program to the design, procurement, and use of fissile material shipping container components has been summarized in numerous Safety Analysis Reports for Packaging in recent years. The Super Tiger shipping container has been liscensed and in operational use for approximately six years. The applicable design and analysis efforts have been reevaluated to the current provisions of 10 CFR Part 71 as discussed in the various chapters of this document. The new storage compartment and inner liner have been designed and analyzed and will be procured by Bettis under the provisions of the Bettis quality assurance program. These components are fabricated of standard stock materials by standard manufacturing processes and have no other critical operational parameters. The acceptance tests will include the supplier certification of materials and processes, Government field inspection, and Bettis receiving and in-house visual inspection as summarized in this section.

8.1 Acceptance Tests

The storage compartment and inner liner suppliers will be required to certify compliance with the defined material and process specifications and Bettis acceptance testing will be limited to the visual inspection and shielding integrity tests as defined below. Cored samples and weight checks will be used to confirm foam density and integrity.

8.1.1 Visual Inspection

The storage compartment and inner liner will be visually inspected for compliance with drawing requirements and basic dimensions upon receipt from the suppliers. The storage comparment will be inspected for weld continuity and proper rear cover and access door installation and function.

The existing Super Tiger shipping container and trailer will be visually reinspected and any discrepancies will be corrected prior to installation of the new components.

The Super Tiger inner cavity will be particularly inspected for such deviations as broken welds, perforations, and pitted or scaled paint which would not be detectable after final installation of the new components.

8.1.2 Structural and Pressure Tests

No structural and pressure testing is required. A Super Tiger prototype was structurally and pressure tested as a prerequisite to the original Certificate of Compliance and the suppliers will certify the construction materials and processes for the new components. No further testing is necessary due to the conservative nature of the design and the absence of critical structural components.

8.1.3 Leak Test

A leak test is not required under the acceptance test program since the existing Super Tiger shipping container is in operational use. The maintenance program leak test, as defined in Paragraph 8.2.2 will be performed prior to initial and subsequent shipments and any required corrective actions will be initiated by Bettis.

8.1.4 Component Tests

No individual components will be tested since, due to the passive nature of the shipments, no individual components are critical. The proper installation of the gaskets on the Super Tiger inner seal plate is mandatory for proper seal and this installation is confirmed during the leak test.

8.1.5 Tests for Shielding Integrity

The composite gamma shielding effect of the two inch shield and the various steel structural members are not critical to the shipping container application since the external radiation levels will be measured prior to each shipment to ensure compliance with highway transport requirements. The radiation levels at the outer container surface, at two meters from the surface, and in the towing vehicle cab will be continually recorded during loading as required by Bettis procedure and the loading will be terminated prior to exceeding allowable transport levels.

The storage compartment design is structurally conservative and shielding integrity testing under hypothetical accident criteria is not required.

8.1.6 Thermal Aceptance Tests

A Super Tiger shipping container prototype was subjected to thermal testing under the hypothetical accident criteria as discussed in Paragraph 2.7.3. No further acceptance tests are required for the new components since the predicted heat generation for the dry unirradiated fuel rod shipments is well within the Super Tiger internal heat dissipation capability.

8.2 Maintenance Program

Super Tiger shipments are dry and all operational features are passive in nature. The maintenance program is limited to the following actions which will be initiated immediately prior to each planned loading for shipment.

8.2.1 Structural and Pressure Tests

No periodic structural and pressure tests are required due to the conservative nature of the structural design and the passive nature of all operational features.

8.2.2 Leak Test

The following leak test will be performed prior to loading the container for each shipment and after the container is loaded to provide an indication of proper closure.

1. Install the inner seal plate with the 36-one half inch bolts torqued to 35-45 foot-pounds.

2. Using a halogen gas source (freon container, gage, and shut-off valve), charge the Super Tiger with a minimum of 15 ounces of freon. Close off valve to prevent freon escape.

3. Using a halogen gas leak detector (adjusted for sensing a leak of one half ounce per year and fitted with an extended probe), check the entire inner seal plate perimeter and bolt hole pattern for leaks. Hold the top of the probe approximately one half inch from the surface and do not exceed a rate of 2.5 feet per minute.

   Deviations discovered during the initial test will be corrected prior to loading the container to minimize personnel radiation exposure. Repair of minor deficiencies may be waived for the loaded container if required to minimize personnel radiation exposure since the fuel rod cladding ensures retention of fissile materials under all defined transport conditions.

8.2.3 Subsystem Maintenance

The Super Tiger trailer will be subjected to standard highway vehicle preventative maintenance at least every six months and standard driver checkout prior to each shipment. The external and accessible internal surfaces of the shipping container and inner containment will be visually inspected for broken welds, pitted or scaled paint, damaged threaded fasteners, and surface perforations prior to loading for each shipment. Any deviations will be corrected prior to loading.

8.2.4 Valves, Rupture Discs, and Gaskets on Containment Vessel

The charging valve, vent plugs, and seal plate gaskets will be checked in conjunction with the leak test, as defined in Paragraph 8.2.2, prior to loading for each shipment. Damaged or non-functional components will be repaired or replaced prior to loading.

8.2.5 Shielding

The gamma shielding will be functionally checked by measuring the external radiation levels as the shipping container is loaded for each shipment. Under no conditions will the shipment be initiated with external radiation levels exceeding allowable limits (200 mrem/hr on contact with the outer container surface, 10 mrem/hr at two meters from the outer container surface, and two mrem/hr in the transport vehicle).

8.2.6 Thermal

No thermal testing or maintenance is required due to the passive nature of the heat dissipation system.

DOE Form EV-618
(11-77)
10 CFR 71

U.S. DEPARTMENT OF ENERGY
CERTIFICATE OF COMPLIANCE
For Radioactive Materials Packages

ENCLOSURE(2)

1a. Certificate Number	1b. Revision No.	1c. Package Identification No.	1d. Page No.	1e. Total No. Pages.
USA/6400 BLF (DOE-NR)	3	USA/6400/BLF (DOE-NR)	1	2

2. PREAMBLE

2a. This certificate is issued to satisfy Sections 173.393a, 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations (49 CFR 170-189).

2b. The packaging and contents described in item 5 below, meets the safety standards set forth in Subpart C of Title 10, Code of Federal Regulations, Part 71, "Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions."

2c. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. This certificate is issued on the basis of a safety analysis report of the package design or application—

(1) Prepared by *(Name and address)*:	(2) Title and Identification of report or application:	(3) Date:
Bettis Atomic Power Laboratory P.O. Box 79 West Mifflin, PA 15122 Attn: W. M. Evans	Safety Analysis Report for Packaging Super Tiger Shipping Container as Adapted for LWBR Type Fuel Rods WAPD-LP(FE)-220, Revision 3 dated February 1983	

4. CONDITIONS

This certificate is conditional upon the fulfilling of the requirements of Subpart D of 10 CFR 71, as applicable, and the conditions specified in item 5 below.

5. Description of Packaging and Authorized Contents, Model Number, Fissile Class, Other Conditions, and References:

A. General Information Concerning Container

The Super Tiger is a protective overpack which provides impact resistance, thermal resistance, and partial containment for its contents. The containment vessel (cavity) is approximately 76" x 76" x 172" constructed of 3/16" thick and 10 gauge mild steel. Closure of the containment vessel is by a 1/4" thick aluminum plate with silicone rubber gasket which is bolted to the containment vessel. A pressure fitting with cap on the closure plate provides a means for leak testing. A die stamped steel identification plate is welded to the outside of the protective overpack.

The containment vessel is centered and supported in an outer 3/16" thick steel jacket by approximately 32" of polyurethane foam insulation at the end and 10" on the sides. A removable section or cap consisting of approximately 34" of polyurethane foam insulation encased in steel with a silicone rubber gasket is bolted to the main outer steel jacket. The overall dimensions of the package are approximately 8' x 8' x 20'. Vent holes are provided on the sides and ends of the container. Set into each corner of the outer container are standard I.S.O. steel castings. The total weight of the fully loaded container will not exceed 45,000 pounds.

6a. Date of Issuance:	6b. Expiration Date:

FOR THE U.S. DEPARTMENT OF ENERGY

7a. Address *(of DOE Issuing Office)*	7b. Signature, Name, and Title *(of DOE Approving Official)*

Total containment is ensured by the Bettis supplied inner rod storage compartment and the cladding of the contained rods. The rod storage compartment consists of four thick-walled round steel tubes welded into a 2 x 2 array with a steel gamma radiation shield welded around the perimeter. The 27½" x 27½" x128" storage compartment will be centered within the Super Tiger cavity by approximately 21" of polyurethane foam on the ends and 24" on the sides. The Super Tiger will accommodate up to four LWBR Rod Storage Containers per shipment.

The Super Tiger is constructed in accordance with Protective Packaging, Inc., Drawings, Reference (1) and the inner rod containment structure is constructed and installed in accordance with Westinghouse Bettis Atomic Lab Drawings, Reference (2). As-built deviations in the DOE owned Super Tiger used by Bettis are defined in Figure 1.6 of Reference (3).

The Safety Analysis Report for Packaging consists of Bettis Report, Reference (3), as supported by Mechanics Research, Inc. Report, Reference (4).

B. Permitted Contents

The Super Tiger can be used to ship fissile material (233 UO_2 + Th O_2) in the form of LWBR-type fuel rods as described in Section 6 of Reference (3) subject to the following restrictions:

(a) Rods shall be in rod storage containers as described in Section 1 of Reference (3);

(b) The fuel content shall not exceed 50 Kg U233 per shipment,

(c) All rod storage containers shall be filled to capacity (at least 70% of cross sectional area) with rods or aluminum shim stock,

(d) Each rod storage container shall contain not more than one sub-container of 5/9 or 12 w/o BMU seed rods,

(e) Each rod storage container shall weigh not more than 2000 pounds, and

(f) The fuel rod heat generation shall not exceed 30 watts.

C. Restrictions

1. Shipments will be made Fissile Class III with a limit of one Super Tiger per transport vehicle.

D. References

(1) Protective Packaging, Inc., Drawing Nos. 32106, Sheet 1, Revision F and 32106, Sheet 2.

(2) Bettis Atomic Power Lab Drawing Nos. 1576E84, 1919F67 and 2960C40.

(3) Bettis Atomic Power Laboratory, Report No. WAPD-LP(FE)-220, "Safety Analysis Report for Packaging, Super Tiger Shipping Container as adapted for LWBR-Type Fuel Rods", Revision 3, February 1983.

(4) Mechanics Research, Inc., Report No. C2378, "Engineering Evaluation of the Super Tiger Overpack Designed for the Shipment of Large Quantities of Hazardous Materials", dated March 4, 1970.

Enclosure (3) to NR memorandum Z#1008

Resolution of NRC Comments on Revision 1 of Super Tiger Shipping Container Safety Analysis Report for Packaging

NRC comments contained in NRC memorandum FCTC:RHO 71-6400 dated June 26, 1981, are repeated below together with their resolution:

1. Water reflection of the storage compartment should be taken into account in accordance with 10 CFR 71.33(a) (2) and 71.36(b) (3). The fuel cladding is assumed to provide the containment of the radioactive material. Currently, no credit is allowed for containment provided by the package.

   Resolution: Calculations indicate that external water reflection of the total Super Tiger container and internal flooding of the fuel rod arrays within the four fuel ports while the square internal shipping compartment itself otherwise remains dry results in the most reactive flooding condition. There would be no reactivity increase if the foam packaging were replaced with water as a result of accident conditions (section 6.4.2.2).

2. Delineate the specific content limits to be applied to each shipment for the various fuel types and correlate these limits with the calculations reported in the safety analysis report.

   Resolution: Each shipment is limited to 50 Kg of fissile material although the package was determined to be nuclearly safe under loading arrangements containing much more fuel (section 6.4.3). The criticality calculations considered all actual and hypothetical packaging combinations including those with both higher fissile material content rods and a greater quantity of rods than actually exist. The most reactive conditions would be partially filled fuel ports flooded with water and these conditions will be prohibited by filling any partially loaded fuel ports with aluminum shim stock. Actual shipments are expected to average less than 40 Kg of fissile material to stay within allowable highway transport radiation limits (sections 1.2.3 and 7.4).

3. Provide revised drawings of the packaging showing the "as built" configuration. Itemize and discuss the "as built" changes from the original packaging drawings.

   Resolution: Figure 1.6 of the SARP is an "as built" drawing of the container and these "as built" deviations are discussed in relation to the specific transport package requirement in applicable paragraphs of the SARP. These deviations consist of defective seal welds, poor metal to foam bonding, non-specification foam density, inconsistent access door seal, and non-specification metal pins installed through the container walls. The U233 fuel rods and the new container components were conservatively designed such that the container can be used for this specific application in compliance with all defined Code of Federal Regulations requirements. The container was refurbished to the original design configuration to the maximum extent practical and the impact of the remaining deficiencies on the transport requirements is discussed in applicable SARP paragraphs. The new polyurethane form inner liner will shore the inner chassis wall against the chassis foam and the rear closure plate to compensate for any lack of wall to foam bonding and potential external pressure loads on the closure plate. This inner liner will also absorb the impact loads on the rod storage compartment under accident conditions such that the compartment would not impact on the chassis wall pins. The rod cladding and rod storage compartment will remain intact under all defined accident conditions such that the fuel materials will be retained under any possible rupture of the Super Tiger containment boundary due to poor welds, improperly sealed access door, or chassis wall pin penetration.