SAFETY ANALYSIS REPORT
FOR THE
ELEKTA TIGER

AUGUST, 1985

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1.0 GENERAL INFORMATION

This section of the ELEKTA TIGER Safety Analysis Report (SAR) presents a general introduction to and a description of the ELEKTA TIGER Package. Terminology used throughout this report is presented in Table 1.0-1.

1.1 Introduction

The ELEKTA TIGER packaging, Model: ELEKTA TIGER, has been developed by Nuclear Packaging, Inc., as a safe means of transporting, via highway or rail, the radiation unit of the Leksell Gamma System (LGS) Model 23016. The LGS is a radiation therapy unit used to eliminate intracranial anomalies which are otherwise untreatable or only treatable using high-risk conventional surgery. The ELEKTA TIGER packaging design is composed of an inner, carbon steel cavity, outer stainless steel walls, and a set of carbon steel ribs between the inner cavity and outer walls. Polyurethane foam fills all voids between the inner cavity and exterior walls. The design includes a lid which bolts into place after the LGS radiation unit is loaded into the packaging. To demonstrate adequacy of design, conventional analytic methods as well as comparisons with test data available from a previously licensed package (SUPER TIGER, Certificate of Compliance No. 6400) are employed herein.

The payload for the ELEKTA TIGER packaging consists of the LGS radiation unit and its support dunnage. The radiation unit contains 201 special form sources of Cobalt-60. As the payload is classified as special form, the primary concern for the ELEKTA TIGER is that shielding be maintained under all applicable load conditions. The packaging is not required to provide a pressure retaining boundary.

Authorization is sought for shipment of the ELEKTA TIGER Package as a Type B(U) package per the definitions delineated in 10 CFR 71.4.

TABLE 1.2-1

Terminology and Notation

1. Leksell Gamma System (LGS) Model 23016: A radiation therapy unit consisting of three main components: a radiation unit, an operating table, and a control unit.

2. Radiation Unit: The LGS radiation unit containing 201 sealed sources of Cobalt-60. This constitutes the ELEKTA TIGER payload.

   Note: each source contains a maximum of 33 curies (nominal source size of 30 curies, plus a 10% error tolerance), and is a certified special form source.

3. Support dunnage: Framework surrounding the LGS radiation unit. Used for lifting and handling the unit. Also serves to distribute impact induced loadings around the LGS radiation unit. A shield door restraint mechanism exists which is considered to be part of the support dunnage.

4. ELEKTA TIGER packaging: The packaging used to transport the radiation unit and its support dunnage.

5. ELEKTA TIGER Package: The complete package consisting of the LGS radiation unit, the support dunnage, and the packaging.

1.2 Package Description

This section presents a basic description of the ELEKTA TIGER packaging and the contents that will be transported. General arrangement drawings and figures are presented in Section 1.3. Gross shipping weight of the ELEKTA TIGER Package is approximately 66,600 pounds. A summary of overall component weights is presented in Table 1.2-1, below:

TABLE 1.2-1
ELEKTA TIGER Component Weights

Component	Weight (lbs)
Packaging Box	19,000
Packaging Lid	5,600
Support Dunnage	5,000
LGS Radiation Unit	37,000
Total	66,600

1.2.1 Packaging

1.2.1.1 Detailed Description of Packaging Design

The ELEKTA TIGER Packaging consists of an inner carbon steel cavity, outer stainless steel walls, and carbon steel ribs which run between the inner cavity and the exterior walls. All voids between the inner cavity and outer walls are filled with polyurethane foam. A bolted lid provides the final closure for the package. The overall design of the packaging is as presented in Section 1.3. The remainder of this subsection fully describes the packaging design features.

1.2.1.1.1 Inner Cavity

The inner cavity of the packaging is in the form of a rectangular box and is fabricated from 0.25 inch thick, ASTM A-36, carbon steel sheet. The inner dimensions of the cavity consist of an 80 inch width, an 88 inch length, and a 76 inch height. The top surface of the cavity is actually the inner surface of the packaging lid.

1.2.1.1.2 Outer Walls

The outer walls of the packaging are fabricated from ASTM A-240, Type 304, stainless steel. The overall outer dimensions of the packaging (with lid installed) consist of a 160 inch length, a 102 inch width, and a 102 inch height. Typically, each wall consists of a series of 3 stacked sheets of 3/16, 1/8, and 1/8 inch thickness. The 3/16 sheet forms the exterior surface of the packaging and the 1/8 inch sheets are tack welded to each other and to the 3/16 sheet. The stacked sheet feature is used to better accomodate the 40 inch drop on a puncture pin event (Section 2.7.2). Stainless steel is used for its high elongation and relatively high strength properties.

1.2.1.1.3 Ribs

The ribs between the inner cavity and the outer walls are 3/16 inch thick ASTM A-36 carbon steel. These ribs serve a number of purposes. They provide a heat transfer path to allow heat to get out of the pagkage, and they provide the boundary between the low density foam used in the sides of the package and the medium density foam used in the ends of the package. The ribs are oriented at a 45 degree angle to the cavity and outer walls so that in flat side impacts, interaction between the inner cavity and the outer walls will be minimized.

1.2.1.1.4 Polyurethane Foam

Polyurethane foam is used to fill all voids between the inner cavity and outer walls of the packaging. Medium density, 16 pcf foam is used in the ends of the packaging and low density, 7 pcf foam is used in the sides. The nominal foam thickness in the package ends is 36 inches, and in the sides it is 11 inches. The medium density foam is employed to limit deformations which could occur under corner and edge drop conditions. The low density foam is used to minimize flat side drop 'g' loads, and to better accommodate the 40 inch drop on a puncture pin event. In other words, medium density foam is desirable with regards to limiting deformations, and low density foam is desirable with regards to limiting 'g' loads. In addition, use of a low density foam in the sides of the packaging allows the stacked sheets making up the exterior walls to deform and develop membrane action, whereas use of a higher density foam would lead to the possibility of punching through the stacked sheets. Use of medium density foam in the package ends is not a problem regarding punch since the foam is nominally 36 inches thick at the end locations. With this 36 inch thickness, significant strain hardening of the foam will not occur in an end punch event.

1.2.1.1.5 Lid

The top surface of the packaging consists of a removable lid. The wall, rib, and foam design details for the lid are essentially the same as described above. The only significant exception to this is that the nominal thickness of the 7 pcf foam used in the lid is 15 inches rather than 11 inches. The lid is secured with 30, 1 1/2 - 6UNC, ASTM A-354, Grade BD, bolts around its periphery. The lid is recessed into the inner cavity to eliminate the possibility of direct shearing of the bolts. The overall size of the lid is 160 inches by 102 inches by 15 inches thick. International Organization for Standardization (I.S.O.) corner fittings are located at the top 4 corners of the lid and are used to lift and handle the lid itself as well as the entire package. The lid does not constitute a pressure boundary, but does include a weather seal to keep dust and moisture from within the packaging.

1.2.1.1.6 Miscellaneous

The design includes a drain for use in cleaning the inner cavity, and tamper indicating features for the lid and drain. The packaging is not intended to provide any shielding for the payload which is self-shielded. With a maximum internal heat load of 104 thermal watts, no coolants are required and the packaging is passively cooled. The only protrusions (outer or inner) from the packaging are the drain plug, and the 14 vent ports used for venting the foam cavities in the event of a hypothetical fire. As there is no pressure retaining boundary for this package, no pressure relief devices are included in the design. This package does not require or include any receptacles, valves, test ports or sampling ports. As the payload is non-fissile in nature, no neutron moderators or absorbers are required or included. The only tiedown devices which are a structural part of the package are the I.S.O. corner fittings. A fixture which rests on top of the lid and interfaces with the I.S.O. corner fittings and/or the cutouts directly above the lid closure bolts will be used for tiedown purposes. During transport, the base of the packaging is restrained laterally by pins which interface with the I.S.O. corner fittings and longitudinally by kickplates.

1.2.2 Operational Features

The ELEKTA TIGER is not considered to be operationally complex. All operational features are readily apparent from an inspection of the General Arrangement Drawings provided in Section 1.3. Operational procedures are delineated in Section 7.0.

1.2.3 Contents of Packaging

The contents for the ELEKTA TIGER consist of the LGS radiation unit and the support dunnage which encompasses it. The radiation unit weighs approximately 37,000 pounds and the support dunnage weighs a maximum of 5,000 pounds for a total maximum payload of 42,000 pounds. The maximum decay heat within the

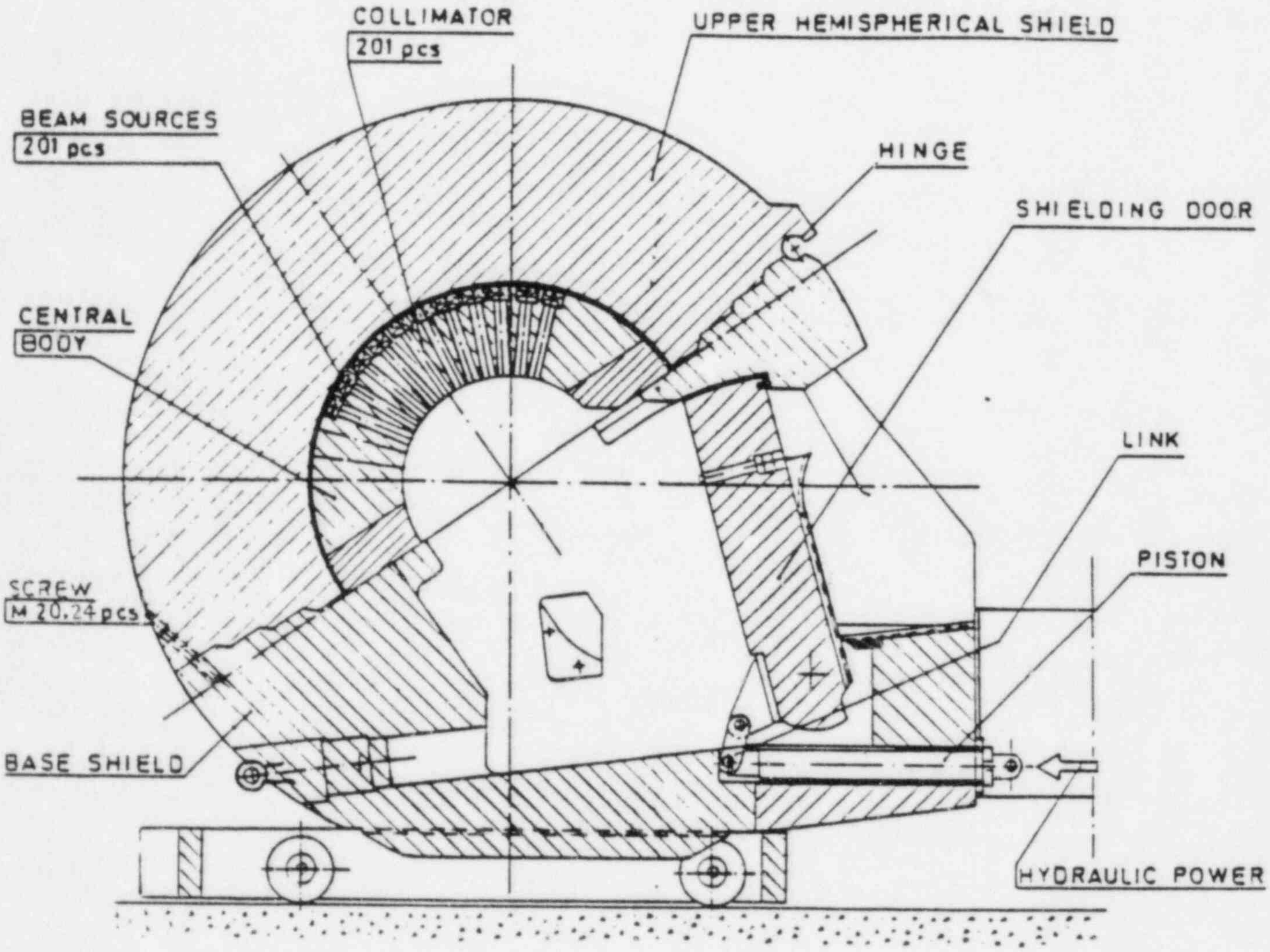
radiation unit is 104 thermal watts. Prior to shipment, radiation levels and contamination levels will be checked for compliance with 10 CFR 71.47 (or 49 CFR 173.441) and 10 CFR 71.87(i)(1) (or 49 CFR 173.443). These hardware are fully described in the remainder of this subsection.

1.2.3.1 LGS Radiation Unit

The radiation unit is shown in Figures 1.2.3-1 through 1.2.3-3, and in Figure 1.3-2 of Section 1.3. Figure 1.2.3-1 presents a cross-section diagram with the door closed, Figure 1.2.3-2 a cross-section with the door open, and Figure 1.2.3-3 a cross-section of the loading-position. The base of the unit is made of cast iron (hereinafter called the 'base section' or 'base'). An internal spherolitic cast iron hemisphere (hereinafter the 'central body'), with its concave inner surface facing the base of the unit, contains the radionuclide sources and beam channels. The cavity below the central body into which the patient is inserted, is shielded below and at the sides by the cast iron base. The central body is 7.68 inches (195 mm) in thickness with an outer radius of 16.53 inches (420 mm) and an inner radius of 8.86 inches (225) mm. The central body contains two half-cylinder cavities (measuring 3.54 inches (90 mm) in radius) beveled in its rim. These cavities are filled with cast iron inserts (illustrated in Figures 1.2.3-1 and 1.2.3-2 as a perpendicular cross-hatching at the front and back of the central body) that are bolted to the central body, which is in turn bolted to the base section with four, 0.79 inch (20 mm) diameter steel bolts.

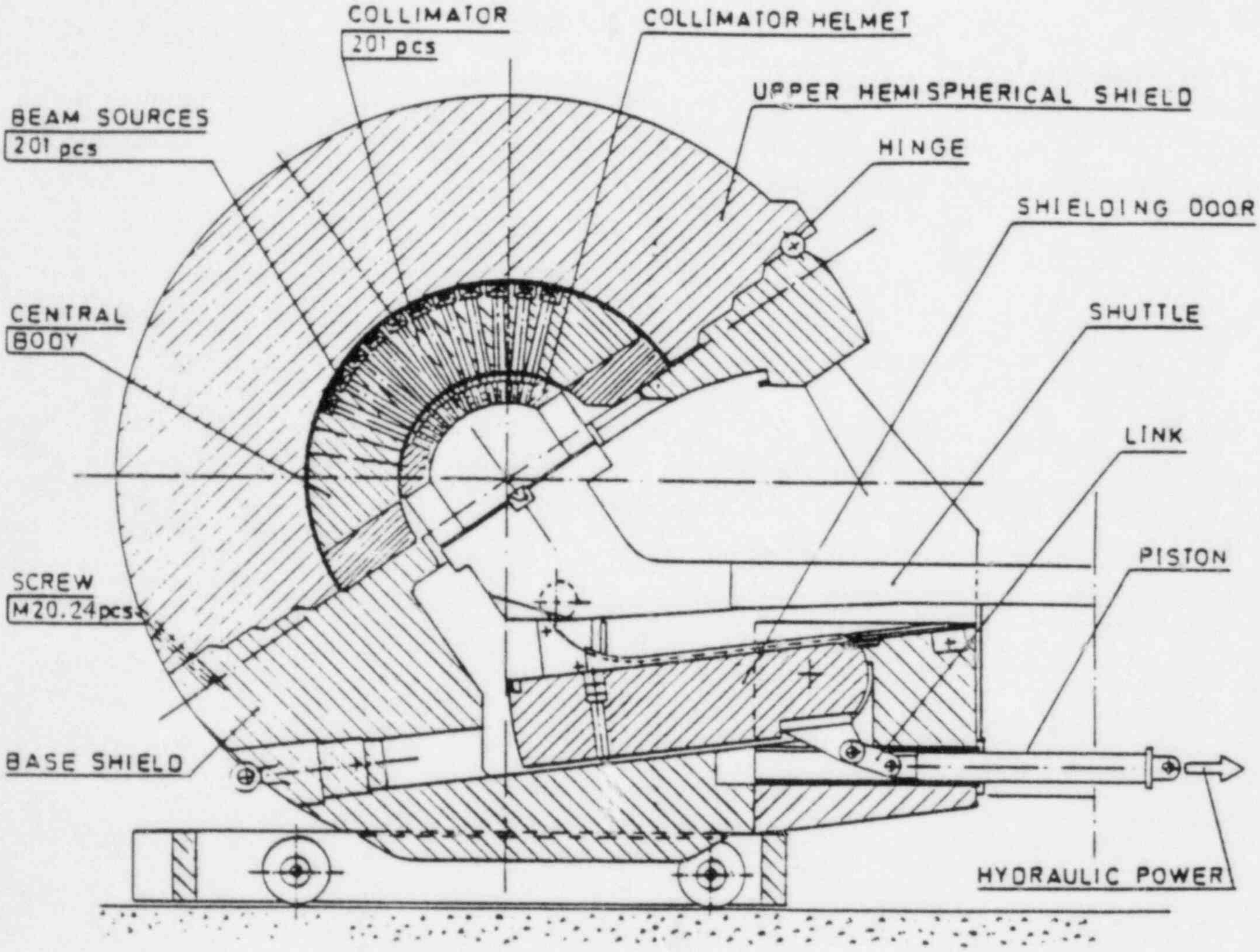
A 'shielding door' made of cast steel pivots and opens inward on a hinge to admit the patient for radiation treatment. The shield door is 7.28 inches (185 mm) thick. The shielding door is operated by hydraulic force in both directions. In its open position, the shielding door rests on a rubber-tipped steel shock absorber, 1.18 inches (30 mm) in diameter, mounted in the door. In the closed position, the overlapping linkage between the hydraulically operated piston and the shielding door serves to lock the door in place by redirecting the force of the door's gravitational weight horizontally against the base. This locking position is static until a hydraulic pulling force is fed to the connecting linkage.

FIGURE 1.2.3-1



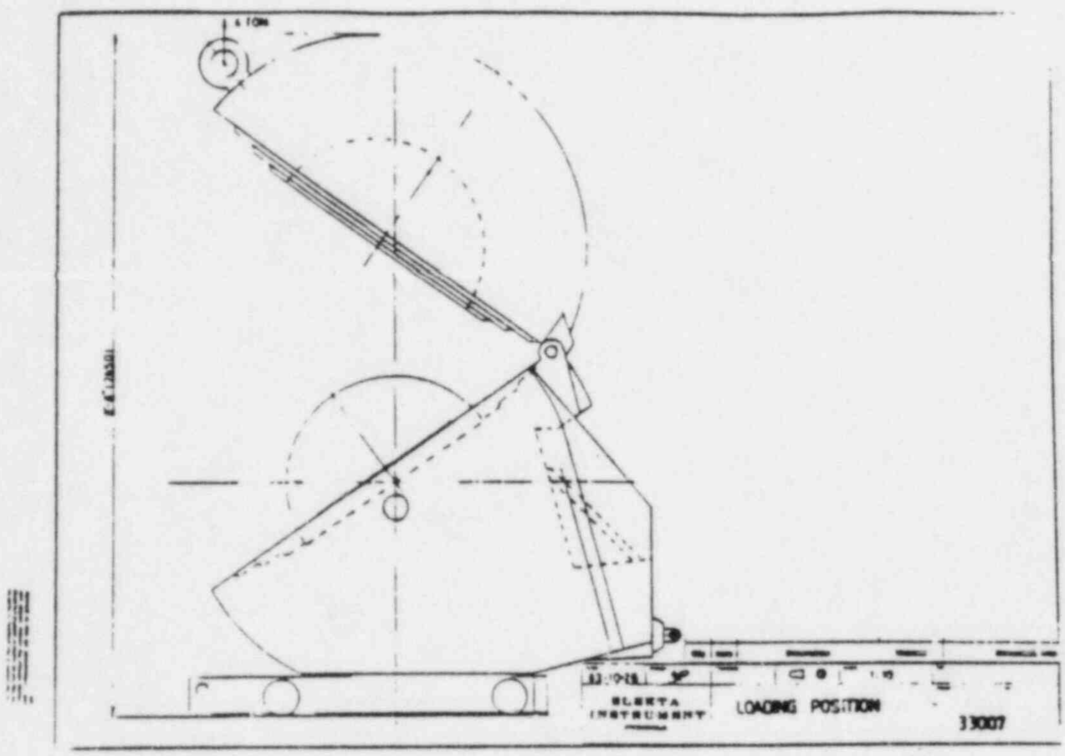
LEKSELL GAMMA UNIT
CROSS SECTION
CLOSED POSITION

FIGURE 1.2.3-2



LEKSELL GAMMA UNIT
CROSS SECTION
OPEN POSITION

FIGURE 1.2.3-3



Fitting over the central body is the upper hemispherical shield with an outer radius of 32.48 inches (825 mm) and 15.75 inches (400 mm) thickness of cast-iron shielding (hereinafter the 'hemispherical shield'). The cast iron base and hemispherical shield are machined for a gapless fit along the staggered, four-step surface where the base and hemispherical shield meet, as shown in Figures 1.2.3-1 and 1.2.3-2.

The central beam of the 201-beam array lies at an angle of 55° to the horizontal plane. The other beams are distributed in an arc of ±48° from the central beam along the axis of the patient and operating table and ±80° along the transverse axis. No primary beam is directed at the shielding door opening. Therefore, only scattered and attenuated radiation exits from the unit when the shielding door is open.

Each beam channel in the central body consists of a compound bushing containing a cavity for the encapsulated Cobalt-60 source, a collimating bushing of 96% tungsten alloy of 2.56 inch (65 mm) thickness, and a collimating bushing of lead 3.64 inches (92.5 mm) thick. These bushings are press-fitted into stainless steel pipes which are in turn press-fitted and secured in the central body by means of machine screws threaded into holes drilled in the central body.

The Leksell Gamma System is equipped with four interchangeable collimator helmets. Each helmet is made of spherolitic cast iron with an outer radius of 8.86 inches (225 mm) and an inner radius of 6.50 inches (165 mm). Each helmet contains a set of 96% tungsten collimators, each 2.36 inches (60 mm) in length. Each collimator is secured by fixing pins into holes drilled into the helmet. Using the four helmets, the operator can create beams exiting each collimator of either 0.158 inches (4 mm), 0.315 inches (8 mm), 0.551 inches (14 mm), or 0.709 inches (18 mm) diameter at the focus. In each case, the intersection of the beams is a three-dimensional focus. The configuration of the irradiated tissue can be further varied on a case-by-case basis, or irradiation of intervening tissue (such as eyes) can be avoided, by plugging individual beam channels. A number of tungsten alloy plugs are included with the unit. The interchangeable helmets are not part of the payload, and are shipped separately from the ELEKTA TIGER package.

The drilling of the beam channels and the design of the sources, bushings, and collimators are such that the radiation from each Cobalt-60 source strikes only tissue within the prescribed three-dimensional focus, with a maximum error tolerance of 0.012 inches (0.3 mm). The source focus distance is 15.787 inches (401 mm).

There is an access port or sump at the rear of the radiation unit which is closed off by means of a stepped plug bolted into place. This port is not routinely used for any purpose but does provide access to the base of the unit to remove any foreign object which might drop into the treatment cavity. Removing the plug does not allow any primary radiation to leak from the unit, but the plug should be removed only under the health physics supervision of a licensee's radiation safety officer, due to scattered radiation that might be present.

The radiation unit weighs 16.8 metric tons, or about 37,000 pounds. It rests on a trolley equipped with roller tracks by means of which it can be rolled into position for installation.

Loading of the Cobalt-60 sources into the radiation unit must be done in a hot cell with a door large enough to accommodate the 5 foot 5 inch diameter of the shield and with the capability for remote manipulation of the unit and the sources. This will be done in a hot cell licensed by an Agreement State or the NRC, as appropriate, to perform the loading operation. The Leksell Gamma System may be loaded at the hot cell of the source supplier or by an independent hot cell operator who would receive the sources directly from the source supplier.

Inside the hot cell, the massive hemispherical shield is lifted open on its hinge to expose the source cavities of the central body (Figure 1.2.3-3). Each of the registered sealed sources is placed in an aluminum bushing assembly for accurate centering into the beam channel. The cap of the aluminum bushing is designed for convenient handling by the remote manipulators of the hot cell. This bushing assembly is not relied on for radiation and source containment. Radiation shielding is provided by the large hemispherical shield above the sources, by the central body in which the source bushing

assemblies fit, by the collimators below the bushing assemblies, and by the base and shielding door of the unit. The inside diameter of the tungsten collimator bushing immediately adjacent to and directly below each source bushing assembly, is only 0.173 inches (4.4 mm), as compared to the sealed source's outside diameter of 0.315 inches (8 mm).

Once all the sources are inserted, the hemispherical shield is lowered into place. The tight fit between the hemispherical shield and the central body holds the sources in their channels. The hemispherical shield is bolted to the base of the unit with twenty-four (24), 0.787 inches (20 mm) diameter steel bolts. The lifting ring and the external parts of the hemispherical shield's hinge are removed after loading, and the remaining holes in the hemispherical shield are filled with threaded steel plugs.

1.2.3.2 Support Dunnage

The support dunnage is a framework of beams and plates which fully encompass the LGS radiation unit. The support dunnage is used to lift and handle the LGS radiation unit as well as to provide additional protection for the unit during Regulatory drop events. The dunnage is sized so that it can be loaded into a cavity of the following dimensions (i.e., the size of the ELEKTA TIGER cavity):

width = 80 inches (2032 mm)
length = 88 inches (2235 mm)
height = 76 inches (1930 mm)

Significant features of the support dunnage are the inclusion of a shield door restraint mechanism (Figure 1.3-1), and the following design requirements.

1. A minimum bearing area of 250 in^2 shall be provided at the dunnage/LGS unit interface on each of the six sides of the LGS unit. The bearing area shall be approximately centered on each of the sides and be such that a three foot diameter circle can be fully inscribed within its outer periphery.

2. A minimum bearing area of 1200 in^2 shall be provided at the dunnage/packaging interface on each of the six sides of the cavity. The bearing area shall be well distributed over each interface (i.e., the bearing area shall not be concentrated at the center of a side).

3. The maximum weight for the support dunnage is limited to 5,000 pounds.

4. There shall be no sharp protrusions from the dunnage.

5. When installed within the packaging, all dunnage/packaging interfaces will be shored/shimmed for a snug fit.

1.3 Appendix

This Appendix provides the General Arrangement Drawings for the ELEKTA TIGER packaging (Drawing JR-20-100D, Sheets 1 - 3). A drawing of the special form sources is also provided (GE drawing 183C8174, Rev. 1). Also included are figures showing the details of the shield door restraint mechanism (Figure 1.3-1) and the basic design of the LGS radiation unit (Figure 1.3-2). Additional LGS radiation unit design details are available from Figures 1.2.3-1 through 1.2.3-3.

Drawing JR-20-100D, Sheet 1 of 3

8 | 7 | 6 | 5

NOTES: UNLESS OTHERWISE SPECIFIED

1 INTERPRET DRAWING PER MIL-STD-100.

2 ALL WELDING, PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME CODE, SECTION IX. WELD PROCEDURES AND WELDER QUALIFICATIONS SHALL BE AVAILABLE FOR AUDIT OR REVIEW.

3 ALL WELDS SHALL BE VISUALLY EXAMINED IN ACCORDANCE WITH AWS D1.1, SECTION 8.15.1, AND NUPAC PROCEDURE VT-01.

4 WELDS SHALL BE LIQUID PENETRANT INSPECTED ON FINAL PASS IN ACCORDANCE WITH ASME CODE, SECTION III, DIVISION 1, SUBSECTION NB, ARTICLE NB-5000 AND SECTION V, ARTICLE 6.

5 LIFTING, HANDLING AND TIE DOWN LUGS SHALL BE LOAD TESTED IN ACCORDANCE WITH NUPAC PROCEDURE LOT-25.

6 FINISH: PAINT ALL CARBON STEEL SURFACES WITH ONE (1) PRIMER COAT (3-5 MILS DFT) MOBIL CHEM EPOXY, NO. 89 AND ONE (1) FINISH COAT (3-5 MILS DFT) MOBIL CHEM EPOXY NO. 89. COLOR: WHITE. APPLY PAINT IN ACCORDANCE WITH NUPAC PROCEDURE PP-01. OPTIONAL UPON NUPAC APPROVAL: TNEMEC NO. 66-2000.

7 7 POUND PER CUBIC FOOT FOAM PER NUPAC PROCEDURE NPLF-16.

8 16 POUND PER CUBIC FOOT FOAM PER NUPAC PROCEDURE NPLF-17.

9 TYPE 304 SST PER ASTM - A240.

10 CARBON STEEL PER ASTM - A36.

11 CARBON STEEL PER ASTM - A500, Grade B

12 TYPE 304 SST PER ASTM - A269.

13 CLOSED CELL NEOPRENE

14 TACK WELD SUFFICIENTLY SO AS TO HOLD PLATES IN PLACE DURING FOAMING OPERATION ONLY. NO STRUCTURAL BOND.

D

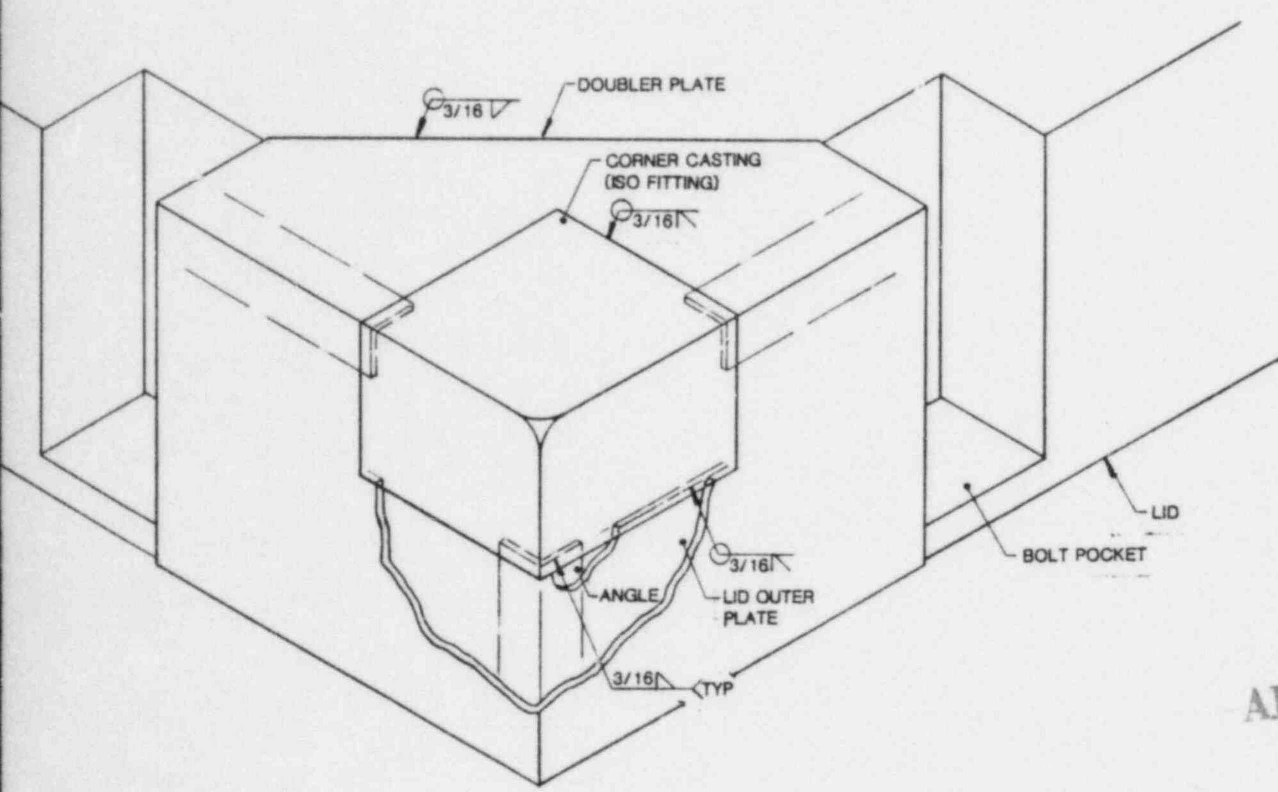
C

B

A

8 | 7 | 6 | 5

LTR	REVISIONS DESCRIPTION	DATE	APPROVED



TYPICAL CORNER CASTING (ISO FITTING) MOUNTING

TI
APERTURE
CARD

Also Available On
Aperture Card

8509300051-01

JR-20-100D SH 1 OF 3

ITEM	PART NO.	DESCRIPTION
ASSEMBLY & QUANTITY		LIST OF MATERIAL

NUCLEAR PACKAGING
A Pacific Nuclear Company
FEDERAL WAY, WA.

NUPAC
ELEKTA TIGER

REL	[signature]	9-30-85
APPD	Robert A. [signature]	8-15-85
APPD		
APPD		
APPD		
QA	[signature]	8/30/85
CHECK	[signature]	8-85
DRAWN	PHIL PEARSON	8-85

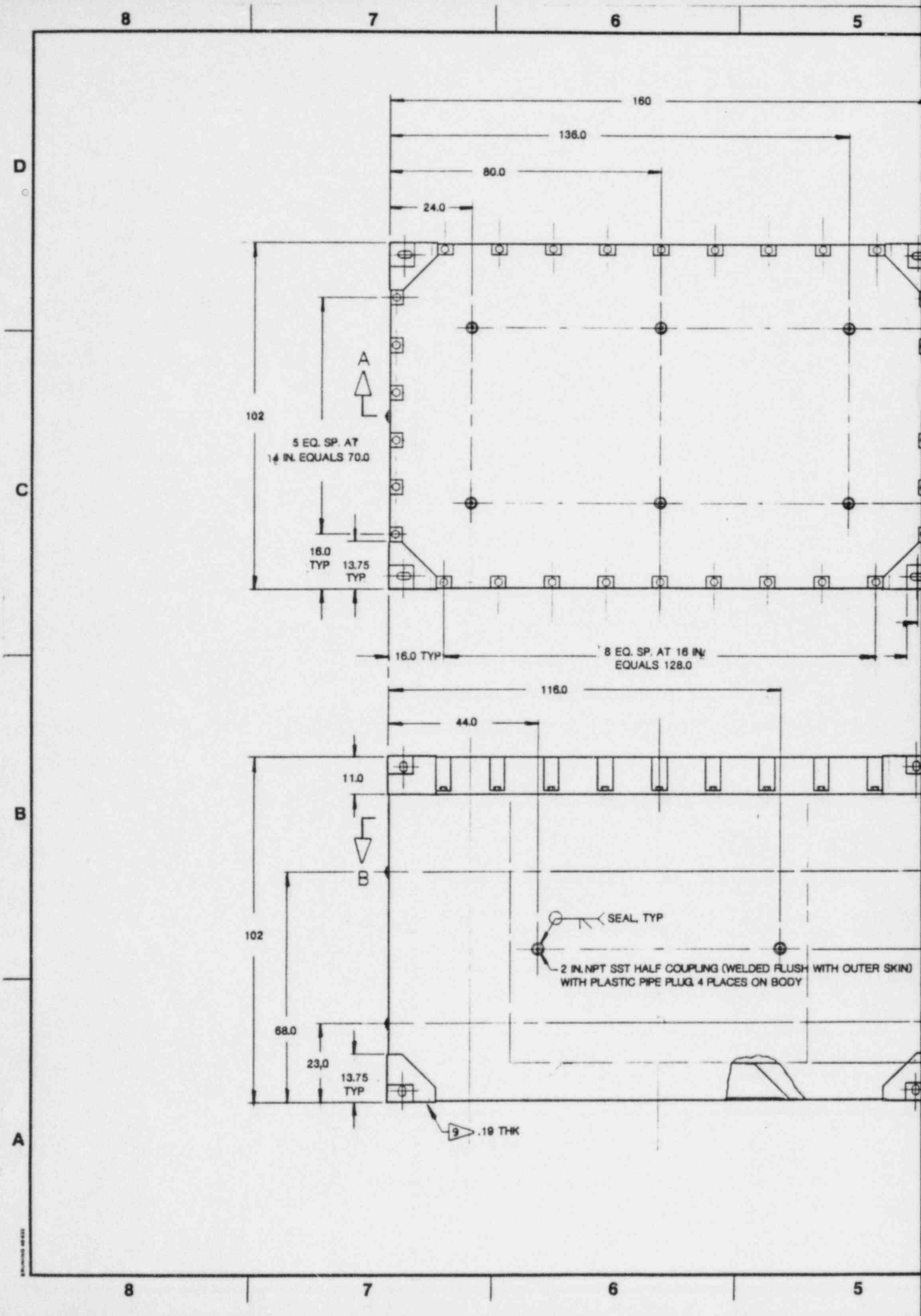
UNLESS OTHERWISE SPECIFIED
DIMENSIONS ARE IN INCHES.
TOLERANCES:
FRACTIONS ±
ANGLES ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMALS ±

IT | QTY | NEXT ASSY

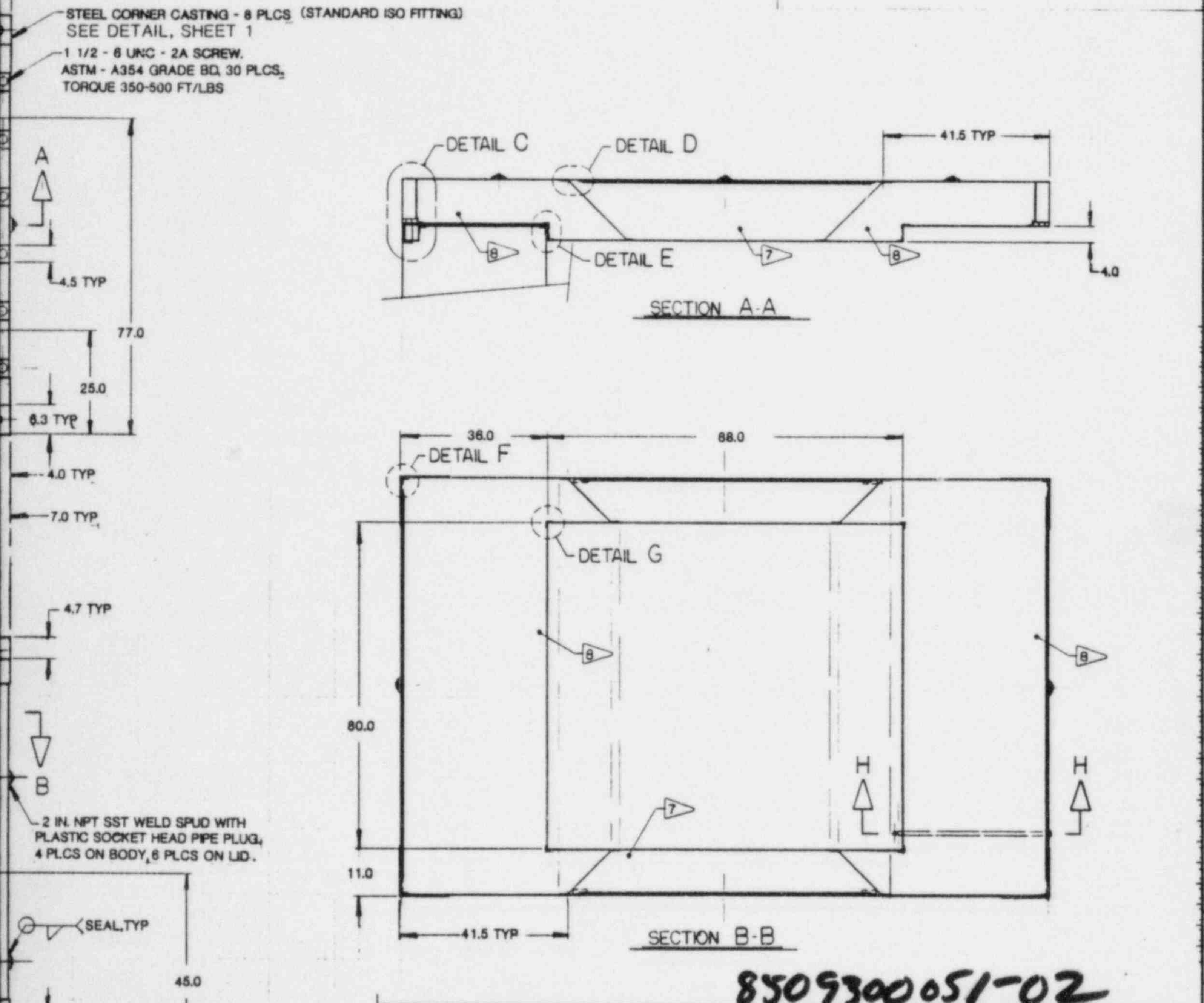
PROPRIETARY DATA: This drawing and the design it covers are the property of NUCLEAR PACKAGING, INCORPORATED. It is transmitted to you in confidence and trust and is to be returned upon request. Its contents may not be disclosed in whole or in part to others or used for other than the purposes for which transmitted without prior written permission of NUCLEAR PACKAGING, INCORPORATED.

SCALE: — | WT. 24,600
REV NONE | SHEET 1 OF 3
DWG SIZE D | DWG NO. JR-20-100D

Drawing JR-20-100D, Sheet 2 of 3



8
7
6
5
D
C
B
A
160
136.0
80.0
24.0
102
A
5 EQ. SP. AT
14 IN. EQUALS 70.0
16.0
TYP
13.75
TYP
16.0 TYP
8 EQ. SP. AT 16 IN.
EQUALS 128.0
116.0
44.0
11.0
B
102
SEAL, TYP
2 IN. NPT SST HALF COUPLING (WELDED FLUSH WITH OUTER SKIN)
WITH PLASTIC PIPE PLUG. 4 PLACES ON BODY
68.0
23.0
13.75
TYP
9
.19 THK



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LTR	REVISIONS DESCRIPTION	DATE	APPROVED

IT	QTY	NEXT ASSY	ITEM	PART NO.	DESCRIPTION
				ASSEMBLY & QUANTITY	LIST OF MATERIAL

NUCLEAR PACKAGING
A Pacific Nuclear Company
FEDERAL WAY, WA.

NUPAC
ELEKTA TIGER

REL 8-30-85
APPD 8-15-85
APPD
APPD
APPD
QA 8/14/85
CHECK 8-85
DRAWN PHIL PEARSON 8-85

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES.
TOLERANCES:
FRACTIONS ±
ANGLES ±
3 PLACE DECIMALS ±
2 PLACE DECIMALS ±
1 PLACE DECIMALS ±

SCALE: 1/16 | WT. —
REV NONE | SHEET 2 OF 3
DWG SIZE D | DWG NO. JR-20-100D

JR-20-100D SH 2 OF 3

Drawing JR-20-100D, Sheet 3 of 3

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GE Drawing 183C8174, Rev.1

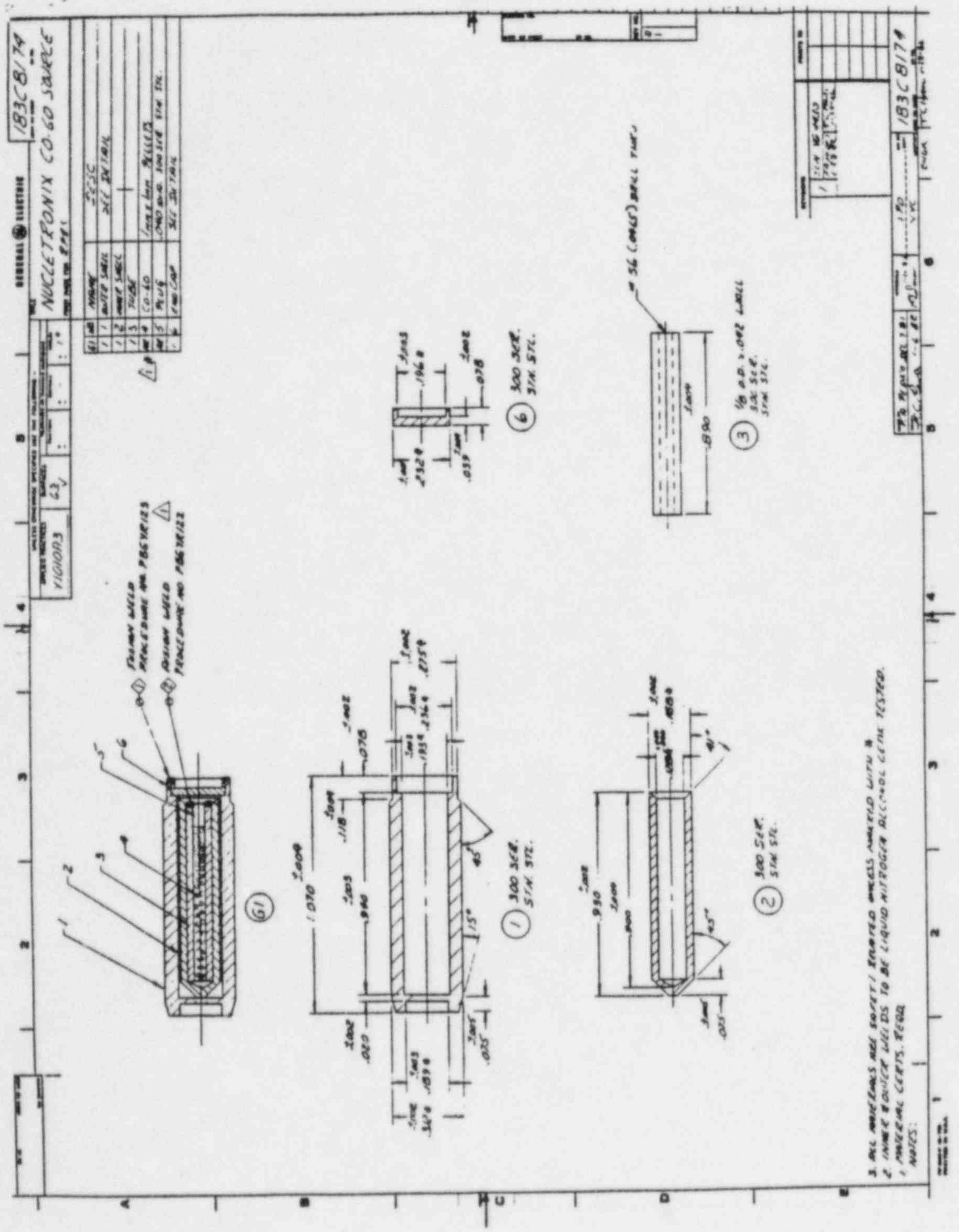
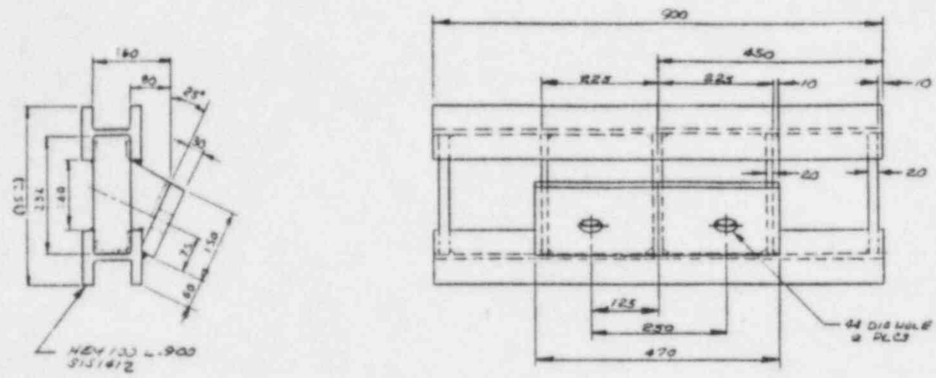
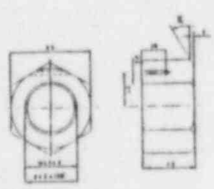


FIGURE 1.3-1

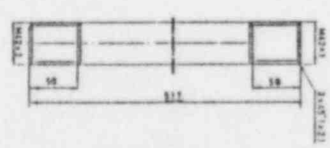
Shield Door Restraint Mechanism



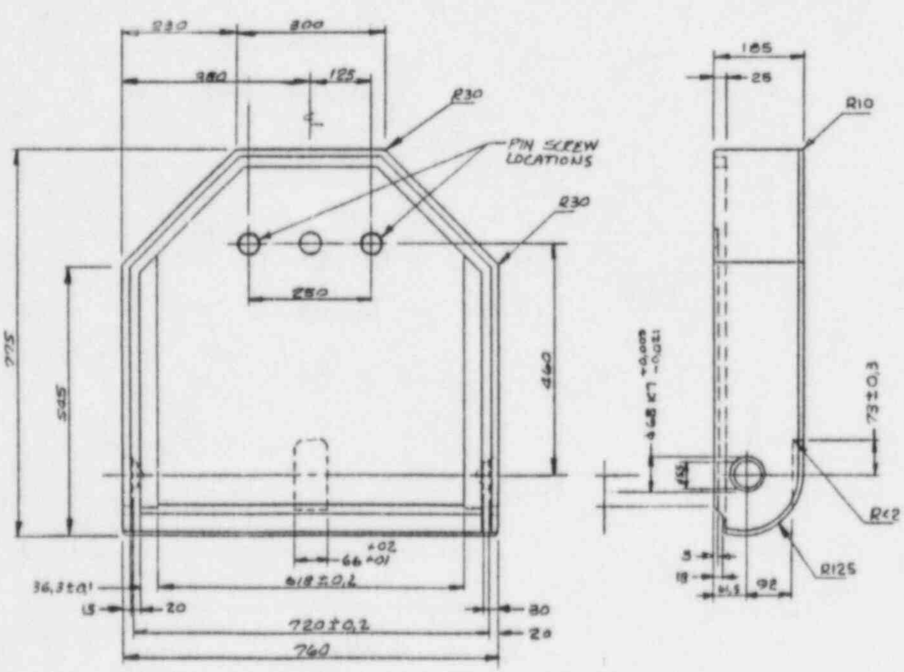
DETAIL
DOOR SAFETY BEAM



DETAIL
NUT



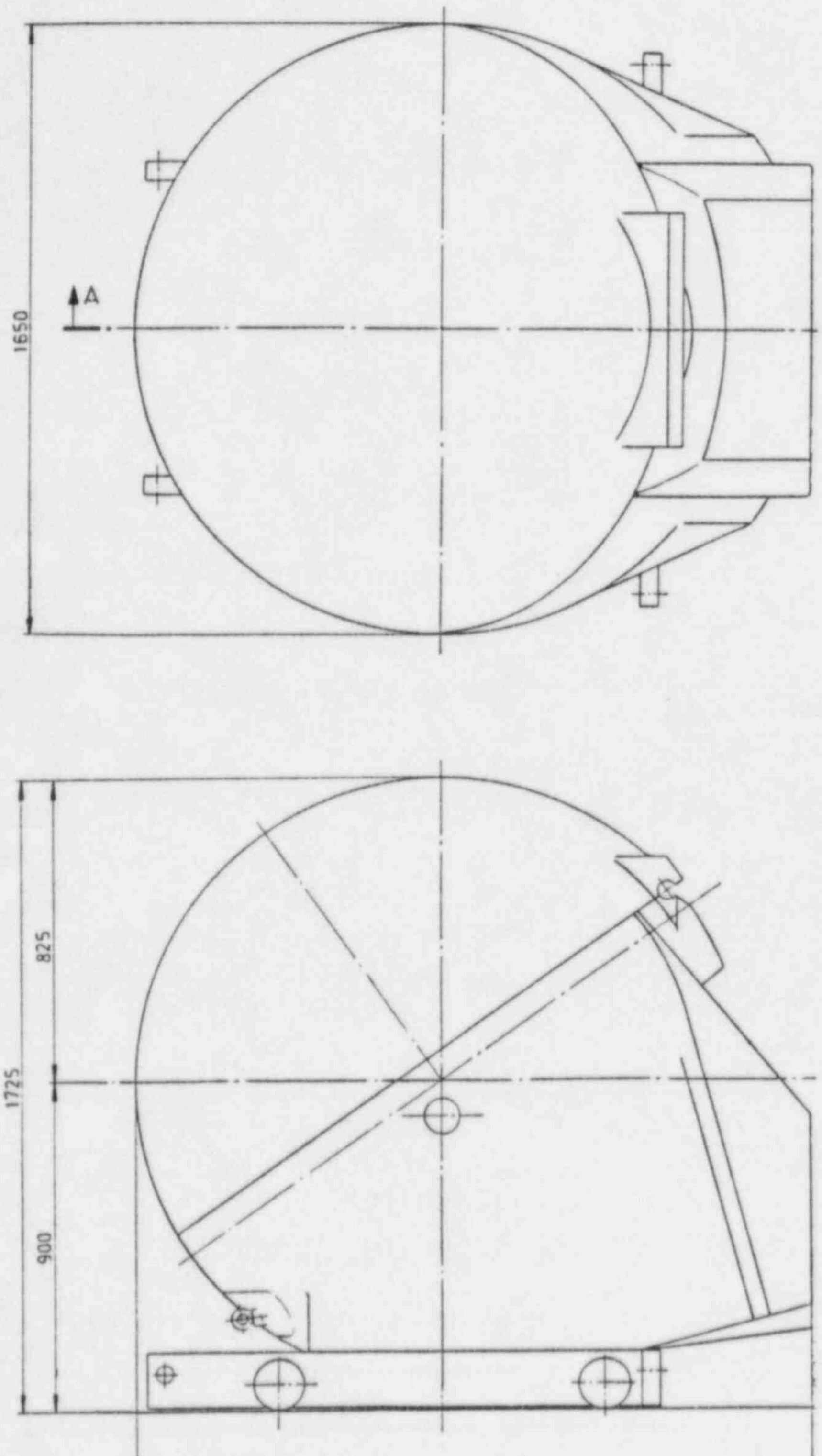
DETAIL
PIN SCREW



DOOR DETAIL

FIGURE 1.3-2

Basic Design of the LGS Radiation Unit



Top View

Side View

2.0 STRUCTURAL EVALUATION

This section presents structural evaluations demonstrating that the ELEKTA TIGER Package meets all applicable structural criteria. The energy absorbing packaging and the payload (support dunnage and LGS radiation unit) are evaluated and shown to provide adequate shielding for the special form Cobalt-60 sources under all normal and hypothetical accident conditions. Evaluations are performed in accordance with 10 CFR 71 requirements.

2.1 Structural Design

2.1.1 Discussion

The ELEKTA TIGER Package consists of three basic components: (1) the external packaging, (2) the support dunnage, and (3) the LGS radiation unit. The external packaging is a polyurethane foam filled steel box which will absorb the energy associated with all defined drop events. Foams with densities of 7 and 16 pounds per cubic foot (pcf) are selectively placed to minimize both package 'g' loads and deformations resulting from the one foot normal condition and 30 foot accident drop events. Energy associated with the 40 inch drop on a puncture pin is absorbed by a series of three stacked stainless steel plates (in combination with the foam which backs them). Regarding heat transfer, as the foam fully encloses the payload, a heat transfer path is required to get the heat (104 thermal watts) out from within the packaging. This path is provided by steel ribs which run between the inner and outer packaging walls.

2.1.2 Design Criteria

Table 2.1.2-1 identifies the allowable stress limits used for evaluating the ELEKTA TIGER Package. It is noted that these allowables are somewhat relaxed from allowables specified in Regulatory Guide 7.6, Design Criteria for Structural Analysis of Shipping Cask Containment Vessels. This is because the ELEKTA TIGER Package is not considered a containment vessel. The criteria

TABLE 2.1.2-1

Allowable Stress Limits

Stress Category	Non-Fastener Allowable Stresses	
	Normal Conditions	Accident Conditions
Primary membrane stress intensity	S_y	$0.7S_u$
Primary membrane + bending stress intensity	S_y	S_u
Range of primary + secondary stress intensity	$2.0S_y$	Not Applicable
Bearing stress	S_y	S_u
Pure shear stress	$0.6S_y$	$0.42S_u$

Stress Category	Fastener Allowable Stresses	
	Normal Conditions	Accident Conditions
Membrane stress*	S_y	S_y
Membrane + bending stress*	S_y	S_u

* Not considering stress concentrations

specified is consistent with the desired goal of showing that shielding is maintained for the special form sources under all loading conditions.

2.2 Weights and Centers of Gravity

The total weight of the ELEKTA TIGER Package, including the payload, is 66,600 pounds. All structures are nearly symmetrical and the center of gravity for the entire package can reasonably be taken as corresponding to the geometric center of the packaging. Individual component weights are as follows:

Component	Weight (lbs)
Packaging Lid	5,600
Packaging Box	19,000
Support dunnage	5,000
LGS radiation unit	37,000
Total Package	66,600

2.3 Mechanical Properties of Materials

The ELEKTA TIGER packaging is fabricated from ASTM A-240, Type 304, stainless steel, ASTM A-36 carbon steel, ASTM A-500, Grade B, carbon steel, polyurethane foam (7 pcf and 16 pcf density), and ASTM A-354, Grade BD, fasteners. The general arrangement drawings presented in Section 1.3 define the specific material used for each portion of the packaging.

The primary materials of construction for the LGS radiation unit are equivalent to ASTM A-48, Number 45B, cast iron (for all shielding except the shield door), and ASTM A-27, 70-36 cast steel (for the shield door). The shield door pivot pins have minimum strengths as specified in the following table. The shield door restraint mechanism uses the equivalent of ASTM A-284 carbon steel

for the main structure, and pin screws with specified minimum strengths as presented in the following table. Materials for the remainder of the support dunnage are not specifically defined herein. The following table presents the applicable material properties for the above specified materials.

Material Identification	Yield Strength, S_y (psi)	Ultimate Strength, S_u (psi)
ASTM A-240, Type 304, Stainless	30,000	75,000
ASTM A-36 Carbon Steel	36,000	58,000
ASTM A-500, Grade B, Carbon Steel	46,000	58,000
ASTM A-48, Number 45B, Cast Iron	*	45,000
ASTM A-27, Grade 70-36, Cast Steel	36,000	70,000
ASTM A-354, Grade BD	130,000	150,000
ASTM A-284 Carbon Steel	30,000	60,000
Pin Screws (Shield Door restraint)	72,514	101,520
Shield Door Pivot Pins	85,000	125,000

* Yield Strength is very near ultimate strength per Page 6-48 of Reference 2.10.3.

All welds are of compatible materials and exhibit the same (or better) properties as the base materials.

The applicable stress-strain curves (at room temperature, approximately 70 - 75° F) for the 7 and 16 lb/ft^3 polyurethane foam used in the packaging are presented in Figures 2.3-1 and 2.3-2. The nominal, room temperature stress-strain curves are bounded by ± 15% on stress to cover potential deviations in foam density from the nominal value, and to cover variations in stress-strain data for a given foam density. At room temperature, the stress-strain characteristics of the actual foams used in the ELEKTA TIGER packaging will fall within the respective ±15% bounding curves. The drop analyses herein consider bounding, nominal +60% and -25% curves. These bounding curves were selected to cover the effects of temperature on foam stress-strain characteristics and do include the density deviation effects previously discussed. The bounding +60% and -25% values are based upon available manufacturer's test data corresponding to -20° F and +115° F (i.e., the bounding foam temperatures for the ELEKTA TIGER packaging under accident drop conditions), respectively.

2.4 General Standards for All Packages

This section demonstrates that the general standards for all packages are met.

2.4.1 Minimum Package Size

The overall package size is enveloped by a 102 inch width, a 102 inch height, and a 160 inch length. These dimensions can also be taken as defining the minimum package size.

2.4.2 Tamper-Indicating Feature

A lockwire, or equivalent, will be utilized between a point on the ELEKTA TIGER lid and a point on the lower portion of the packaging during a loaded shipment. This is illustrated in the General Arrangement Drawings presented in Section 1.3. Failure of said device will indicate purposeful tampering in accordance with 10 CFR 71.43(b). A similar feature is also provided on the drain plug.

FIGURE 2.3-1

This page is proprietary.

FIGURE 2.3-2

This page is proprietary.

2.4.3 Positive Closure

Following loading of the payload within the ELEKTA TIGER cavity, the lid is installed using 30 pretorqued fasteners. This alone guarantees that inadvertent opening of the ELEKTA TIGER Package cannot occur. Inadvertent opening is further protected against by the presence of the tiedown fixture which will be placed over the lid during transport.

2.4.4 Chemical and Galvanic Reactions

The materials from which this package and payload are fabricated (i.e., stainless steel, carbon steel, polyurethane foam, cast steel, cast iron, and a variety of steel fasteners) will not cause significant chemical, galvanic, or other reactions in air or water environments. Exposed carbon steel surfaces are painted for rust prevention purposes.

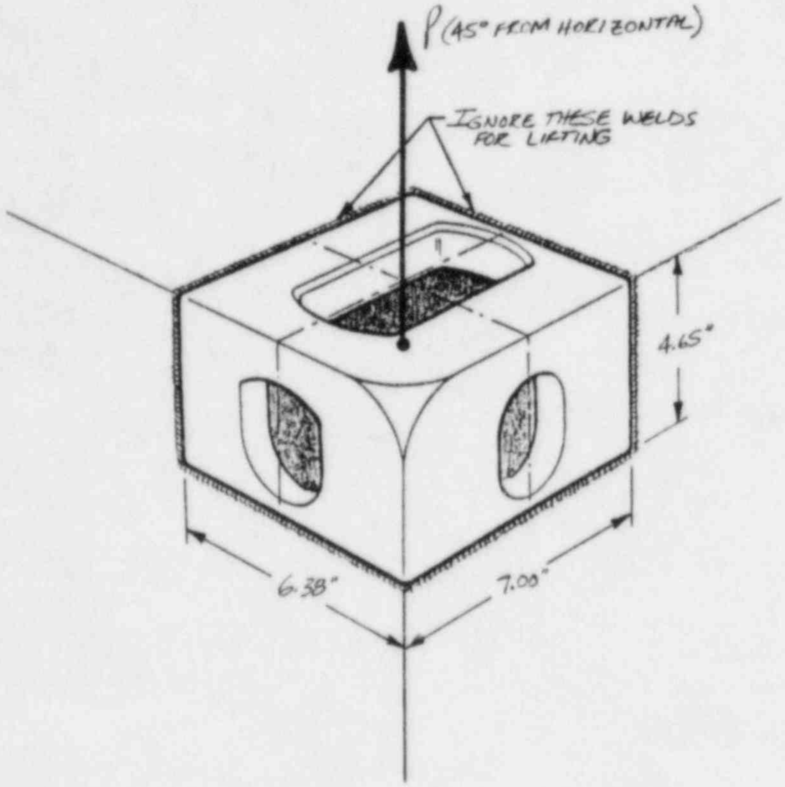
2.5 Lifting and Tiedown Standards for All Packages

2.5.1 Lifting Devices

The I.S.O. corner fitting on each of the four corners of the ELEKTA TIGER Package serve as the lifting devices. Evaluation of these lifting points will consider a lift on two diagonally opposed fittings at an angle of 45° from horizontal. The margins of safety are calculated using a load factor of three on the dead weight and an allowable equal to the applicable material yield strength per the requirements of 10 CFR 71.45(a). Therefore, the total load in each corner is:

$$P = 3W/2(\sin 45^{o}) = 3(66,600)/2(0.707) = 141,300 \text{ lbs}$$

Each corner casting is secured to the ELEKTA TIGER via 3/16 inch bevel welds to the 3/16 inch thick package outer shell and 3/16 inch thick doubler plate, as illustrated below:



The shear capacity of the I.S.O. corner casting attachment welds is:

$$P_w = \sigma_{sy} A_w$$

Where:

$$\sigma_{sy} = (30,000)(0.6) = 18,000 \text{ psi}$$

$$A_w = L_w t_w$$

$$L_w = 2[6.375 + 7.0 + 2(4.65)] = 45.35 \text{ in}$$

$t_w = 0.1875$ in (full penetration bevel welds)

Then,

$$P_w = (18,000)(45.35)(0.1875) = 153,000 \text{ lbs}$$

Therefore, the attachment weld shear capacity Margin of Safety is:

$$M.S. = (P_w/P) - 1 = (153,000/141,300) - 1 = \underline{+\ 0.08}$$

Conservatively assume two bolts at each corner must carry the load. The 1 1/2 - 6 UNC bolt capacity, based upon ASTM A-354, Grade BD, specifications is:

$$P_b = 2\sigma_y A_b$$

Where:

σ_y = 130,000 psi per Section 2.3

A_w = 1.405 in^2 per Reference 2.10.2

Then,

$$P_b = 2(130,000)(1.405) = 365,300 \text{ lbs}$$

Therefore, the bolt load capacity Margin of Safety is:

$$M.S. = (P_b/P) - 1 = (365,300/141,300) - 1 = \underline{+\ 1.59}$$

Shearout of a bolt from a carbon steel insert and shearout of an insert from the square mechanical tubing are addressed as follows:

The shear area for a 1 1/2 - 6 UNC-2B internal thread is given as 3.566 in^2 per inch of engagement (Reference 2.10.7). Assume two bolts carry the load at each of the two corners. With a 3.0 inch engagement per Drawing JR-20-100D, Sheet 3 (Section 1.3), shear stress in the threads is:

$$\tau = 141,300/2(3.0)(3.566) = 6,604 \text{ psi}$$

With an allowable shear stress of $0.6S_y$ per Table 2.1.2-1, the Margin of Safety is:

$$M.S. = (0.6S_y/\tau) - 1 = [0.6(36,000)/6,604] - 1 = \underline{+\ 2.27}$$

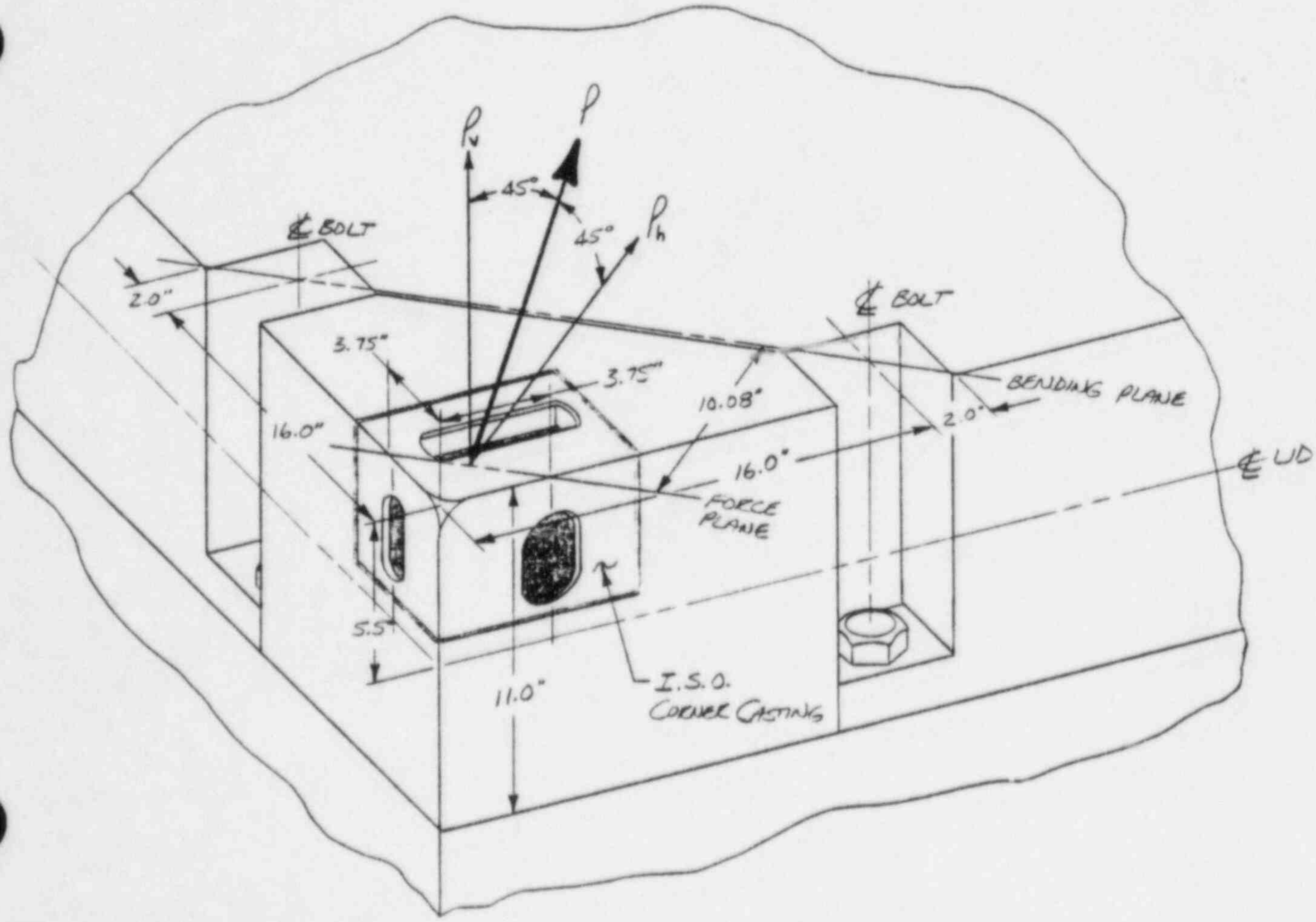
Attachment of the insert to the square mechanical tubing is accomplished by two 3/8 inch full penetration bevel welds and one 3/8 inch fillet weld. Therefore, the stress in the welds is:

$$\sigma = 141,300/2\pi(2.5)[1 + 1 + (\sin 45^{o})](0.375) = 8,861 \text{ psi}$$

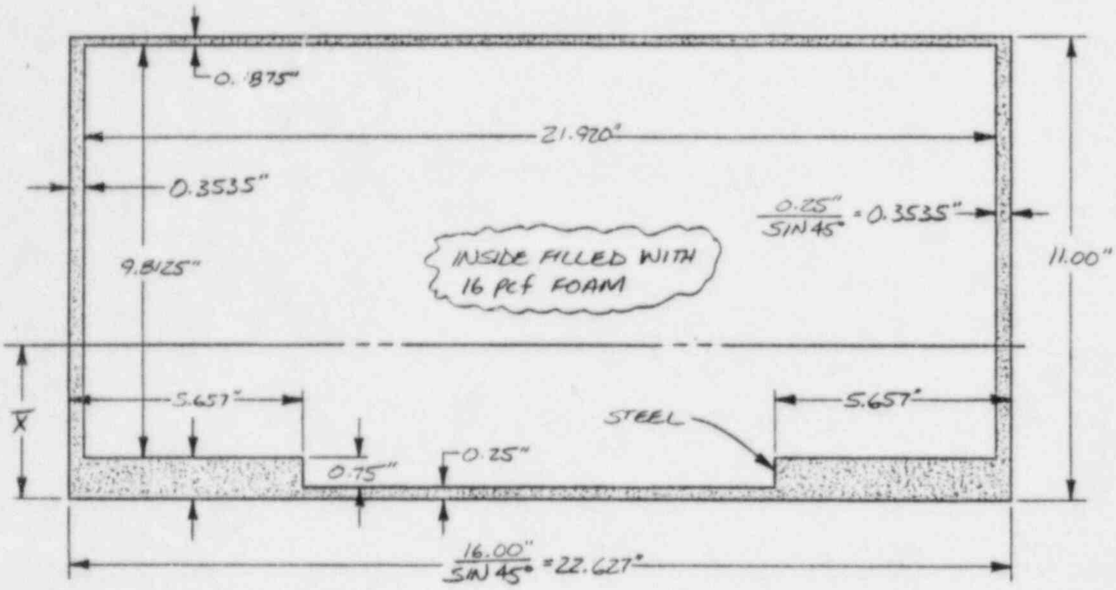
Treating this stress as a shear stress, the allowable stress becomes $0.6S_y$. Therefore, the resulting Margin of Safety is:

$$M.S. = (0.6S_y/\sigma) - 1 = [0.6(36,000)/8,861] - 1 = \underline{+ 1.44}$$

The lifting load is carried to the two adjacent bolts via the composite steel and foam lid section. For purposes of this analysis, assume the lifting load acts through the I.S.O. corner fitting, and the lid corner cantilevers about the diagonal defined by the plane bisecting the two corner bolts, as illustrated below:



A sectional cut through the diagonal results in the following geometry:



The load, P, is broken into a vertical component, P_v, and a horizontal component, P_h, as follows:

$$P_v = 141,300(\sin 45^o) = 99,900 \text{ lbs}$$

$$P_h = 141,300(\cos 45^o) = 99,900 \text{ lbs}$$

With reference to the above illustration, the effective moment of inertia of the bending section may be determined. The distance to the neutral axis, $\bar{x}$, is calculated as follows (neglecting the 16 pcf foam):

b (in)	h (in)	A (in^2)	x (in)	Ax (in^3)
22.627	11.000	+248.90	5.500	+1,368.95
21.920	-9.813	-215.09	5.906	-1,270.32
11.314	-0.750	-8.49	0.625	-5.31
		$\sum A$ = 25.32		$\sum Ax$ = +93.32

Then,

$$\bar{x} = \sum Ax/\sum A = 93.32/25.32 = 3.686 \text{ in}$$

The moment of inertia of the section is determined utilizing the parallel axis theorem as follows:

$$I = bh^3/12 + A(x - \bar{x})^2$$

b (in)	h (in)	A (in^2)	$x - \bar{x}$ (in)	I (in^4)
22.627	11.000	+248.90	1.814	+3,328.74
21.920	-9.813	-215.09	2.220	-2,785.88
11.314	-0.750	-8.49	3.061	-79.95
				$\sum I$ = 462.91

The stress is at the extreme fiber due to bending is:

$$\sigma = Mc/I$$

Where:

$$M = P_v(10.08) + P_h(11.00 - 3.686)$$
$$= 99{,}900(10.08) + 99{,}900(7.314) = 1{,}737{,}660 \text{ in-lbs}$$

$$c = 11.000 - 3.686 = 7.314 \text{ in}$$

$$I = 462.91 \text{ in}^4$$

Then,

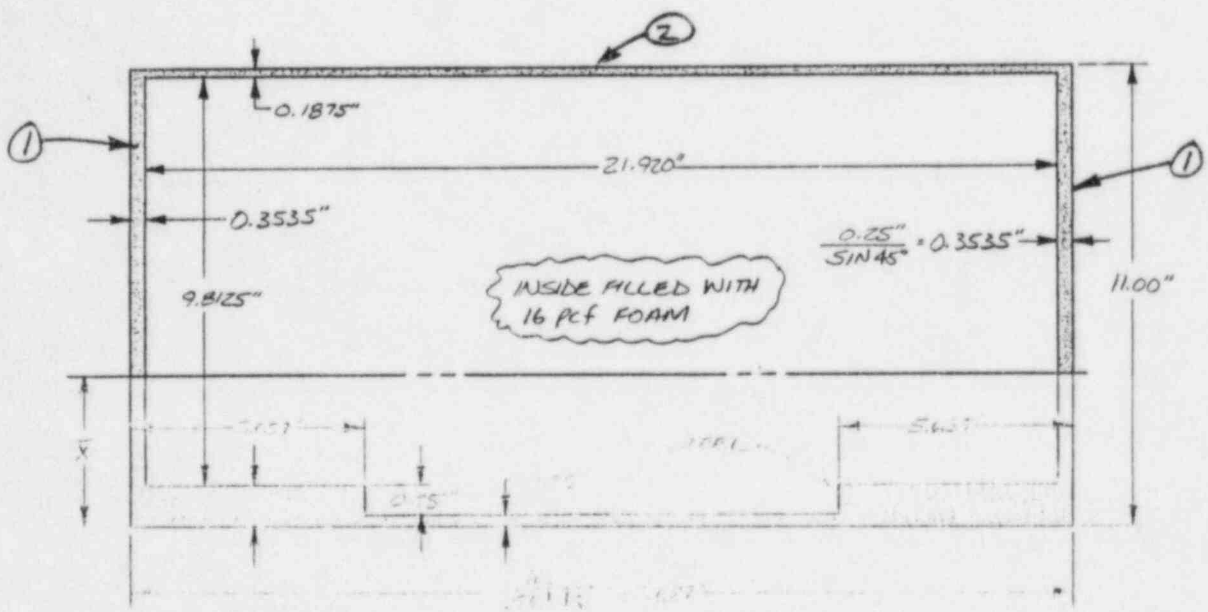
$$\sigma = 1{,}737{,}660(7.314)/462.91 = 27{,}455 \text{ psi}$$

From Table 2.1.2-1, the allowable membrane stress is given as S_y. The minimum yield strength for the section is for the stainless, S_y = 30,000 psi. Therefore, the Margin of Safety is:

$$M.S. = (S_y/\sigma) - 1 = (30,000/27,455) - 1 = \underline{+0.09}$$

The maximum shear stress occurs at the neutral axis, as illustrated below. Utilizing the shearing stress formula, the shear stress is:

$$\tau = VQ/It$$



Where:

$V = P_v$ = 99,900 lbs

I = 462.91 in^4

$t = 2[0.25/(\sin 45^{o})]$ = 0.707 in

and, the area integral, Q, is $\sum A\bar{x}$

Number	A (in^2)	$\bar{x}$ (in)	Q (in^3)
1	5.04	3.563	17.96
2	4.11	7.220	29.67
			Q = 47.63

Then, solving for the shear stress:

$$\tau = 99{,}900(47.63)/(462.91)(0.707) = 14{,}539 \text{ psi}$$

From Table 2.1.2-1, the allowable shear stress is given as $0.6S_y$. The minimum yield strength for the section is for the stainless, S_y = 30,000 psi. Therefore, the Margin of Safety is:

$$M.S. = (0.6S_y/\tau) - 1 = (18{,}000/14{,}539) - 1 = \underline{+0.24}$$

Paragraph (a) of 10 CFR 71.45 states that failure of any lifting device under excessive load would not impair the ability of this package to meet other requirements of this subpart. From the above calculations, it is apparent that the attachment welds could fail due to excessive loading, thereby tearing the I.S.O. corner fittings from the lid. This failure, however, would not significantly alter the results obtained for either the normal or hypothetical accident drops or the fire transient. This is due to 1) the relatively small area affected if a fitting were to tear out, and 2) the conservatisms which exits in the corner drop evaluations (i.e., no rotation of the package and no energy absorbed by the steel members).

Therefore, it is safely concluded that the ELEKTA TIGER Package meets the requirements set forth in 10 CFR 71.45 for lifting of a package.

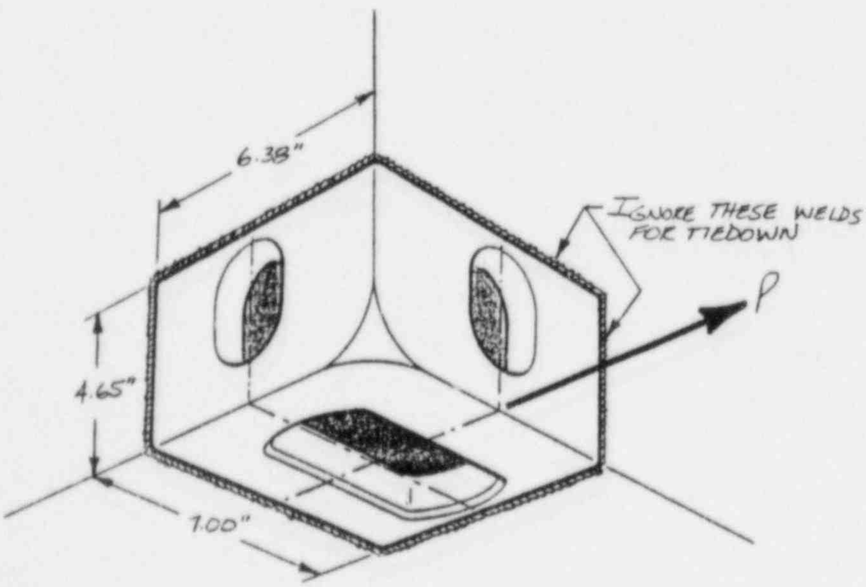
2.5.2 Tiedown Devices

Tiedown of the package will be accomplished as follows. The four I.S.O. corner fittings at the base of the packaging will fit over four mating pins. These pins will resist the 5 'g' lateral load specified in 10 CFR 71.45(b). Kickplates at each end of the packaging will be used to resist the specified 10 'g' longitudinal loading and a fixture over the top of the lid will resist the specified 2 'g' vertical loading. The top fixture will interface via pins with the I.S.O. corner fittings and/or with the cutout regions above the lid bolts. With this tiedown scheme, the only tiedowns which are a structural part of the package are the I.S.O. corner fittings. Adequacy of these fittings is addressed as follows:

The 5 'g' lateral tiedown requirement induces a lateral load in an I.S.O. corner castings of (assuming only two of the four castings share the load):

$$P = (66,600)(5\ g's)/2 = 166,500\ lbs$$

As discussed in the preceeding lifting analysis, and as illustrated below, two full penetration 3/16 inch bevel welds are utilized along two locations of the length (7.00 in), width (6.375 in), and height (4.65 in) of the I.S.O. corner castings.



The capacity of the attachment welds is determined as follows (recognizing that the 7.00 and 4.65 inch long welds are loaded in tension and the 6.375 inch long welds are loaded in shear):

$$P_w = \sigma_y A_{tw} + \sigma_{sy} A_{sw}$$

Where:

$$\sigma_y = 30{,}000 \text{ psi}$$

$$\sigma_{sy} = (0.6)(30{,}000) = 18{,}000 \text{ psi}$$

$$A_{tw} = L_{tw} t_w$$

$$A_{sw} = L_{sw} t_w$$

$$L_{tw} = 2(7.00 + 4.65) = 23.3 \text{ in}$$

$$L_{sw} = 2(2)(6.375) = 25.5 \text{ in}$$

$$t_w = 0.1875 \text{ in} \quad \text{(full penetration bevel welds)}$$

Then,

$$P_w = (30{,}000)(23.3)(0.1875) + (18{,}000)(25.5)(0.1875)$$
$$= 217{,}125 \text{ lbs}$$

Therefore, the attachment weld Margin of Safety is:

$$M.S. = (P_w/P) - 1 = (217{,}125/166{,}500) - 1 = \underline{+\ 0.30}$$

There are no lift points that could potentially be used as additional tiedown points, thus the requirements of 10 CFR 71.45(b)(2) are satisfied.

In addition, as discussed in the lifting analysis, tearout of an I.S.O. corner casting would not impair the ability of the ELEKTA TIGER Package to meet other requirements of 10 CFR 71. Therefore, the requirement of 10 CFR 71.45(b)(3) is met.

2.6 Normal Conditions of Transport

The ELEKTA TIGER Package, when subjected to normal conditions of transport as specified in 10 CFR 71.71, meets the performance requirements specified in Subpart E of 10 CFR 71. This is demonstrated in the following subsections where each normal condition is addressed and the package is shown to meet the applicable design criteria previously discussed in Section 2.1.2.

2.6.1 Heat

The thermal evaluation for the normal heat condition is presented in Section 3.4. The normal heat condition consists of exposing the package to direct sunlight and 100^{o} F still air per the requirements of 10 CFR 71.71(c)(1), with insolation per Regulatory Guide 7.8. A maximum internal heat load of 104 watts is used for the evaluation.

2.6.1.1 Summary of Pressures and Temperatures

The conditions of normal heat result in the following maximum temperatures, from Section 3.1, for the various package components.

Location	Temperature (^{o}F)
Side outer wall	173.8
End outer wall	149.7
Inner cavity wall	151.1
Weather seal area	151.1
LGS radiation unit	149.0

Taking 175° F as a conservative estimate of the maximum temperature within the package, the maximum pressure rise for the package is determined as follows:

$$P_1/T_1 = P_2/T_2$$

Where:

P_1 = 14.7 psia = initial pressure

T_1 = 70° F = 530° R = initial temperature

T_2 = 175° F = 635° R = final temperature

Then,

P_2 = 14.7(635/530) = 17.6 psia = 2.9 psig

This pressure is considered to be of negligible consequence for the package. Pressures of this magnitude are addresed in Sections 2.6.3 and 2.6.4. In addition, the packaging is not intended to provide a pressure retaining boundary, thus any gradual increase in temperature would not actually lead to an increase in pressure.

2.6.1.2 Differential Thermal Expansion

Differential thermal expansions are of little consequence for the ELEKTA TIGER Package. From an inspection of the preceeding table, the maximum temperature gradient across the foam will be on the order of 25° F, and since growth (or shrinkage) of the packaging outer walls relative to the walls of the inner cavity is accomodated by flexibility of the 3/16 inch thick ribs which run between them, significant stresses cannot develop. In addition, any stresses which do develop can be classified as secondary, displacement limited stresses for which relaxed allowable stress limits apply.

2.6.1.3 Stress Calculations

As stated in Section 2.6.1.1, a negligible pressure (and, therefore, negligible primary stresses) will be associated with the condition of normal heat.

2.6.1.4 Comparison With Allowable Stresses

Stresses associated with the normal heat condition are rather trivial. Therefore, the design criteria for normal conditions, specified in Sections C.2 through C.5 of Nuclear Regulatory Guide 7.6 are easily met.

2.6.2 Cold

For the cold condition, a -40° F steady state ambient temperature is assumed as is no internal heat generation. This is overly conservative since the special form, Cobalt-60 sources are well defined and will always provide a source of internal heat. In any event, the above assumptions will result in a -40° F temperature throughout the package. The only stresses in the package at this steady state condition are those due to dead weight and differential expansion. As these stress magnitudes are small, brittle fracture is not a problem for the cold condition. Brittle fracture concerns are further discussed in Section 2.7.1 (30 foot drop at -20° F).

2.6.3 Reduced External Pressure

The effect of a reduced external pressure of 3.5 psia (11.2 psig), per 10 CFR 71.71(c)(3), is considered to be negligible for the ELEKTA TIGER Package. This is because the packaging does not provide a pressure boundary and the special form sources, by definition, are leaktight under a one atmosphere (14.7 psig) differential pressure per 10 CFR 71.75(d).

2.6.4 Increased External Pressure

Similar to Section 2.6.3, above, the effect of an increased external pressure of 20.0 psia (5.3 psig external pressure), per 10 CFR 71.71(c)(4), is considered to be negligible for the ELEKTA TIGER Package. This is because the packaging does not provide a pressure boundary and the special form sources are leaktight under a one atmosphere (14.7 psig) differential pressure per 10 CFR 71.75(d).

2.6.5 Vibration

The effects of vibrations normally incident to transport are considered to be negligible. The sandwiched steel/foam structure used for this packaging is considered to be highly resistant to the effects of vibration and will act as an isolator for the payload. In addition, the cast iron shielding used for the LGS unit itself is highly resistant to vibration (discussed on Page 6-48 of Reference 2.10.3).

2.6.6 Water Spray

As the outer surface of the package is made of stainless steel, and the lid design incorporates a weather seal, the effect of the water spray test per 10 CFR 71.71(c)(6) is considered to be negligible.

2.6.7 Free Drop

The ELEKTA TIGER Package weighs 66,600 pounds. Subpart F of 10 CFR 71 requires that a package in excess of 33,000 pounds weight be dropped one (1) foot onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected. This normal drop condition has been considered and results are presented in the remainder of this Section.

The loads and deflections associated with the normal drop condition are available from Section 2.11.2. From that section, the maximum 'g' load on the package, regardless of drop orientation, is 99.0 g's. The following table summarizes the maximum 'g' load for all drop orientations. All maximums are associated with the cold foam condition (i.e., maximum foam crush strength).

Package Orientation	Calculated 'g' Loading
Flat drop on end	55.8 g's
Flat drop on side	99.0 g's
Edge drop on end	13.4 g's
Edge drop on side	13.9 g's
Corner drop	7.1 g's

Regarding deformations, all drop orientations result in less deformation than would be required for the inner cavity of the package to 'bottom out'. Package deformations are summarized in the following table (as available from Section 2.11.2). All tabulated deformations are for the case of minimum foam crush stresses (maximum foam temperatures) which results in worst case deformations.

Package Orientation	Package Deformation (in)	Allowable Deformation (in)
Flat drop on end	0.65	36.00
Flat drop on side	0.35	11.00
Edge drop on end	3.19	33.23
Edge drop on side	3.06	15.56
Corner drop	11.83	33.49

Drop orientations other than those in the preceeding tables are possible, but will not lead to worst case 'g' loads or deformations. Worst case 'g' loads will occur for flat drop orientations, and worst case deformations will occur for the edge and corner drop orientations considered herein (i.e., orientations where a minimum crush area develops for a given deformation). As the drop programs used for analysis (Section 2.11.1) do not allow any drop energy to go into rotational energy of the package, all energy is forced to go into deforming the packaging. This inherently leads to conservative estimates for 'g' loads and deformations for each of the bounding foam curves considered.

From the preceeding tables, it is apparent that the deformations associated with the one foot drop will in no way compromise the integrity of the ELEKTA TIGER Package (i.e., the crush depth is significantly less than the distance from the point of contact on the exterior of the packaging to the closest point on the inner cavity of the packaging). In addition, the maximum normal condition 'g' load acting on the package for the worst case package orientation (flat drop on side) is 99.0 g's. Per Section 2.7.1, the maximum hypothetical accident 30 foot drop condition 'g' load is 228.5 g's. Thus, the normal condition drop results in only 0.43 times the 'g' load as the accident condition. From Section 2.1.2, the minimum ratio of normal condition allowable to accident condition allowable is S_y/S_u. For the materials making up the ELEKTA TIGER payload, the minimum value for this ratio occurs for the carbon steel in the shield door restraint mechanism and equals 30/60 or 0.50. As this ratio of allowables exceeds the ratio of applied loads, the accident condition drop will govern the design of the ELEKTA TIGER Package.

It is noted that the packaging exterior walls and the walls of the special form source capsules are made of stainless steel which exhibits a ratio of yield to ultimate of 0.40, a value less than the 0.43 ratio of applied loads. However, this is acceptable since deformation of the packaging outer wall is allowed under the normal condition drop event, and an unprotected special form source capsule will survive a 30 foot drop onto an unyielding surface per 10 CFR 71.75 and 10 CFR 71.77.

2.6.8 Corner Drop

This test does not apply for the ELEKTA TIGER Package since the package weight is in excess of 100 kg (220 lb).

2.6.9 Compression

This test does not apply for the ELEKTA TIGER Package since the package weight is in excess of 5,000 kg (11,000 lb).

2.6.10 Penetration

As there are no sensitive external protrusions from the package, and the fully loaded package is designed to withstand a 40 inch drop on a puncture pin, the 40 inch drop of a 13 pound mass will be of negligible consequence for the package.

2.7 Hypothetical Accident Conditions

The ELEKTA TIGER Package, when subjected to hypothetical accident conditions as specified in 10 CFR 71.73, meets the performance requirements specified in Subpart E of 10 CFR 71. This is demonstrated in the following subsections where each accident condition is addressed and shown to meet the applicable design criteria previously discussed in Section 2.1.2.

2.7.1 Free Drop

Subpart F of 10 CFR 71 requires that a 30 foot free drop be considered for the ELEKTA TIGER Package. The drop is to be onto a flat, essentially unyielding, horizontal surface in a position for which maximum damage is expected. Per 10 CFR 71.73(b), the initial ambient temperature for the drop is to be the worst case constant temperature between -20^{o} F and 100^{o} F. Internal heat generation from the special form sources is also considered when it is conservative to do so (i.e., included for 100^{o} F ambient to maximize deformations, but excluded for -20^{o} F to maximize 'g' loads). Consistent with 10 CFR 71 requirements, insolation is not considered as an initial condition for the accident drop evaluations. As this packaging does not provide a pressure boundary, pressure is neglected in the following evaluations.

The loads and deflections considered for the drop evaluations are available from Section 2.11.2. From that Section, the maximum 'g' loading on the package regardless of drop orientation is 228.5 g's. The following table summarizes the maximum 'g' loading for all drop orientations. As indicated, maximum foam crush strengths (i.e., cold foam) typically lead to maximum 'g' loadings. However, for the edge drop on the side of the package, minimum foam strength leads to maximum 'g' load due to strain hardening of the foam.

Package Orientation	Foam Crush Strength	Calculated 'g' Loading
Flat drop on end	maximum	200.7
Flat drop on side	maximum	228.5
Edge drop on end	maximum	68.8
Edge drop on side	minimum	95.9
Corner drop	maximum	49.5

Regarding deformations, all drop orientations result in less deformation than would be required for the inner cavity of the package to 'bottom out'. Package deformations are summarized in the following table (as available from Section 2.11.2). All tabulated deformations are for the case of minimum foam crush stresses (maximum foam temperatures) which results in worst case deformations.

Package Orientation	Package Deformation (in)	Allowable Deformation (in)
Flat drop on end	4.80	36.00
Flat drop on side	3.75	11.00
Edge drop on end	15.86	33.23
Edge drop on side	13.91	15.56
Corner drop	30.05	33.49

Drop orientations other than those in the preceeding tables are possible, but will not lead to worst case 'g' loads or deformations. Worst case 'g' loads will occur for flat drop orientations, and worst case deformations will occur for the edge and corner drop orientations considered herein (i.e., orientations where a minimum crush area develops for a given deformation). As the drop programs used for analysis (Section 2.11.1) do not allow any drop energy

to go into rotational energy of the package, all energy is forced to go into deforming the packaging. This inherently leads to conservative estimates for 'g' loads and deformations. Of particular importance, the corner drop calculated deformation of 30.05 inches is expected to be quite conservative as rotational effects will be significant for this orientation.

2.7.1.1 Flat Side Drop

This orientation leads to the maximum loading on the ELEKTA TIGER Package of 228.5 g's. As there will be little, if any, tendency for the lid to separate from the packaging in this flat side orientation, and as the packaging deformations are within acceptable limits per Section 2.7.1, the packaging itself adequately performs its function. For these reasons, the remainder of this Section need only address the consequences of the 228.5 'g' loading on the LGS radiation unit and the surrounding support dunnage.

A flat side impact will directly load the support dunnage to LGS radiation unit interface with a load of:

$$P = (228.5 \text{ g's})(37,000) = 8.455(10)^6 \text{ lbs}$$

With a minimum bearing area of 250 square inches, per Section 1.2.3.2, the bearing stress is:

$$\sigma_b = 8.455(10)^6/250 = 33,820 \text{ psi}$$

With the bearing allowable equal to S_u, or 45,000 psi for the more limiting cast iron LGS unit, the Margin of Safety becomes:

$$M.S. = (S_u/\sigma_b) - 1 = (45,000/33,820) - 1 = \underline{+0.33}$$

Other than these localized bearing stresses, the stresses which develop in the LGS radiation unit itself will be rather modest as the result of the 228.5 'g' loading. Stresses in the unit will be determined for the following, typical (or representative) geometries under the 228.5 'g' distributed loadings.

Case 1:

A 30.0 inch by 30.0 inch by 7.0 inch thick, simply supported rectangular plate which is representative of the shield door or portions of the lower shield.

Utilizing Table 26, Case 1 of Reference 2.10.1, the maximum stress becomes:

$$\sigma = \beta(q)(b)^2/(t)^2$$

Where,

$a = b = 30.0$ inches, thus $\beta = 0.2874$ (for $a/b = 1.0$)

$t = 7.0$ inches

$q = 228.5$ g's$(0.284 \text{ lb/in}^3/\text{g})(7.0) = 454.3$ psi

Then,

$$\sigma = (0.2874)(454.3)(30.0)^2/(7.0)^2 = 2,400 \text{ psi}$$

Case 2:

Hemisphere with a 32.48 inch outer radius and a 16.73 inch inner radius which is representative of the upper shield.

Utilizing Table 29, Case 3c of Reference 2.10.1, the maximum stress becomes:

$$\sigma = \delta(R_2)/2$$

Where,

$R_2 = (32.48 + 16.73)/2 = 24.61$ inches

$\delta = (228.5 \text{ g's})(0.284) = 64.89 \text{ lb/in}^3$

Then,

$$\sigma = (64.89)(24.61)/2 = 800 \text{ psi}$$

It is noted that the above calculated stress is only a rough approximation in that the formula used is intended for thin wall spheres. For this reason, the following calculation for a thick walled sphere under external pressure will also be carried out. Using Table 32, Case 2b of Reference 2.10.1, the maximum stress occurs at the inner surface and is:

$$\sigma = 3(q)(a)^3/2(a^3 - b^3)$$

Where,

$a = 32.48$ inches

$b = 16.73$ inches

$$q = 228.5(\text{weight of the hollow sphere})/(\text{surface area of sphere})$$
$$= 228.5(0.284)\{(4/3)\pi[(32.48)^3 - (16.73)^3]\}/4\pi(32.48)^2 = 607 \text{ psi}$$

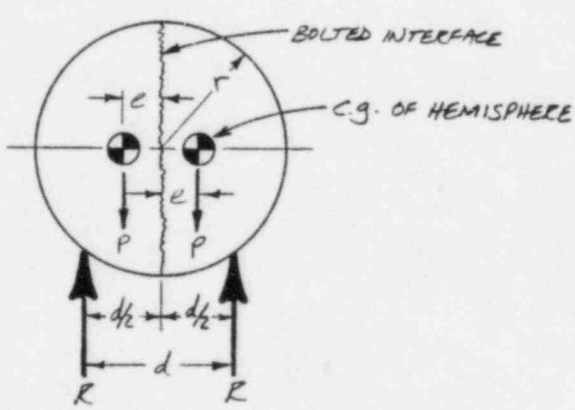
Then,

$$\sigma = 3(607)(32.48)^3/2[(32.48)^3 - (16.73)^3] = 1{,}055 \text{ psi}$$

From the preceeding calculations, it is apparent that stresses in the LGS radiation unit (other than localized, compressive, bearing stresses at the surface of the unit) will be relatively small. As the bearing stress limit specified in Section 2.1.2 has been shown to be met, and other stress limits specified in Section 2.1.2 are easily met, the only item remaining to be addressed is brittle fracture. Per Page 3 of Reference 2.10.5 (Pellini), tensile stresses in excess of approximately 20% of yield are typically required for brittle fracture to be of concern. Below this stress level, fracture propagtion is not considered to be possible 'because the minimum, small amount of elastic strain energy release required for continued propagation of brittle fractures is not attained.' Since bearing stresses are compressive in nature, and since bending stresses are less than 2,500 psi per the preceeding calculations, brittle fracture will not be a problem for the LGS radiation unit shielding (non-containment). In addition, the contianment boundary for the special form source capsules is stainless steel for which brittle fracture is not of concern.

The shield door restraint system would be loaded in this drop orientation, but to a much lesser extent than for an end drop orientation where the applied load would be nearly parallel to the axes of the restraining pin screws. For this reason, the shield door restraint system is analyzed in Section 2.7.1.2 (flat end drop).

The multi-stepped interface between the upper and lower shields of the LGS radiation unit will easily resist any shear loads which develop there. Additionally, the support dunnage, by virtue of its well distributed bearing area on six sides of the LGS radiation unit, will not allow significant loads to develop in the 24 bolts which connect the upper and lower shields. With the requirement in Section 1.2.3.2 that a three foot diameter circle can be inscribed within the outer periphery of the bearing area, the tendency for the upper and lower shields to separate is virtually eliminated. This may be shown by the following sketch where a reaction, R, is seen to be outboard of the applied load, P.



Where:

r = outer radius of cast iron shielding
= 32.5 in

e = centroid of a hemisphere = 3r/8
= 12.19 in

d = minimum periphery of the bearing area
= 36.0 in (3.0 foot diamter circle)

2.7.1.2 Flat End Drop

This orientation leads to a 200.7 'g' loading on the ELEKTA TIGER Package. As there will be little, if any, tendency for the lid to separate from the packaging in this flat end orientation, and as the packaging deformations are within acceptable limits per Section 2.7.1, the packaging itself adequately performs its function. For these reasons, the remainder of this Section need only address the consequences of the 200.7 'g' loading on the LGS radiation unit and the surrounding support dunnage.

The flat side drop event discussed in Section 2.7.1.1 is typically the worst case for the LGS radiation unit and the support dunnage. Bearing stresses at the support dunnage to LGS radiation unit interfaces are governed by flat side drops as are the general states of stress in the LGS radiation unit. The only item requiring additional analysis is therefore the shield door restraint system. This analysis is carried out as follows:

Per Figure 1.3-1 of Section 1.3, the distance between the shield door pivot pins and the location of the restraint pin screws is 460 mm (18.11 inches). The shield door weighs 736 kg (1,623 lb), and its center of gravity is approximately 231.8 mm (9.126 inches) from the pivot pin location towards the pin screws. Therefore, the load on each pin screw is:

$$P = (200.7\ g's)(1{,}623)(9.126/18.11)/2$$
$$= 82{,}073\ \text{lb}$$

For an M42 x 3.0 metric thread, the tensile stress area is 1.859 in^2, using Formula 3.1 on Page 31 of Reference 2.10.2. Thus, the resulting stress in a pin screw is:

$$\sigma = P/A = 82{,}073/1.859 = 44{,}150\ \text{psi}$$

The minimum tensile yield strength for the pin screw is specified as 500 N/mm^2 (72,514 psi) resulting in the following Margin of Safety:

$$M.S. = (\sigma_y/\sigma) - 1 = (72{,}514/44{,}150) - 1 = \underline{+\ 0.64}$$

Similarly, the shield door pivot pins will each see a direct shear load of:

$$P = 200.7(1,623)[(18.11 - 9.126)/18.11]/2$$
$$= 80,796 \text{ lbs}$$

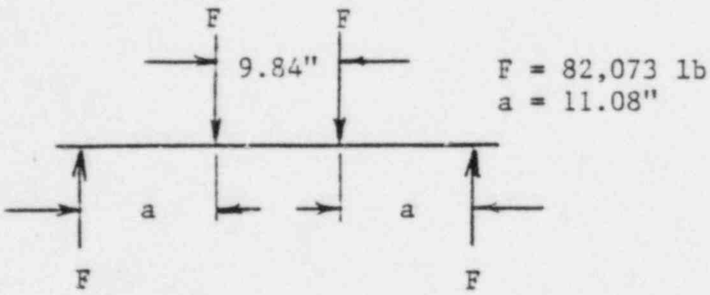
With a minimum diameter of 39 mm (1.535 inches), the shear stress is:

$$\tau = P/A = 80,796/\pi(1.535/2)^2$$
$$= 43,635 \text{ psi}$$

The minimum ultimate strength, S_u, of the pins is 125,000 psi per Section 2.3. From Table 2.1.2-1, the allowable shear stress is $0.42S_u$. Therefore, the pivot pin shear Margin of Safety is:

$$M.S. = (0.42S_u/\tau) - 1 = [0.42(125,000)/43,635] - 1 = \underline{+\ 0.20}$$

The 'H' beams used for restraint are checked by considering them as two parallel beams, simply supported, loaded as follows:



Therefore, the stress in the beams becomes:

$$\sigma = Mc/I$$

Where,

$$M = Fa = 82,073(11.08) = 909,370 \text{ in-lb}$$

$$I/c = 2(11.625) = 23.25 \text{ in}^3 \text{ for 2, HEM-100 beams}$$

Then,

$$\sigma = 909{,}370/23.25 = 39{,}110 \text{ psi}$$

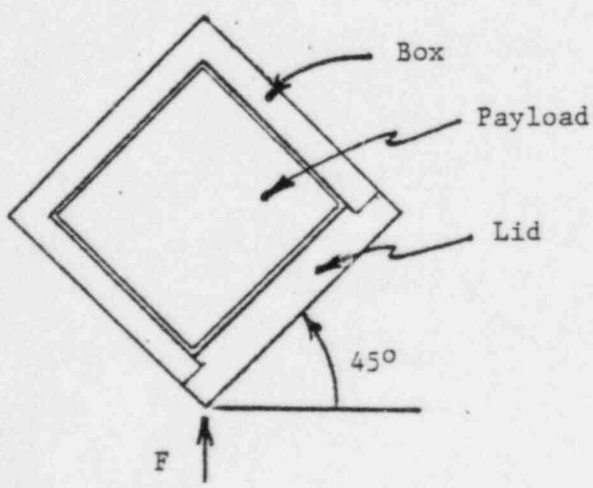
The allowable limit for this bending stress is S_u, or 60,000 psi for the ASTM A-284 material used for these beams. The corresponding Margin of Safety is:

$$M.S. = (S_u/\sigma) - 1 = (60{,}000/39{,}110) - 1 = \underline{+0.53}$$

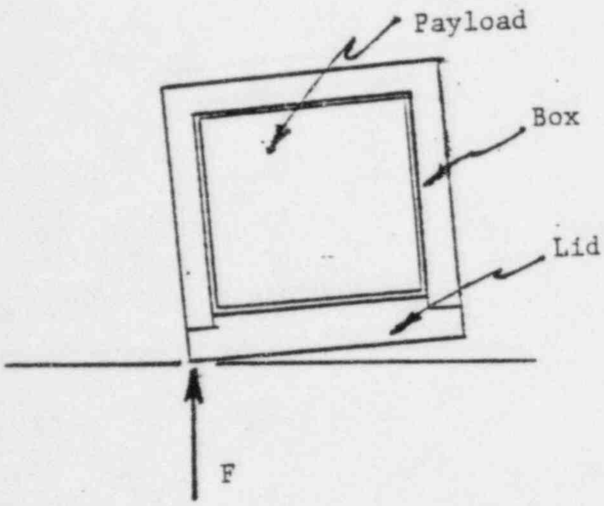
2.7.1.3 Edge and Corner Drops

Per Section 2.7.1, packaging deformations associated with edge and corner drops are within acceptable limits. Also per Section 2.7.1, 'g' loads associated with these drop orientations are significantly less severe than the 'g' loads for flat side and flat end impacts. For this reason, the LGS radiation unit and the support dunnage will adequately survive the edge and corner drop events. The only issue to be addressed for the edge and corner drop orientations is, therefore, attachment of the packaging lid. This is done in the remainder of this Section.

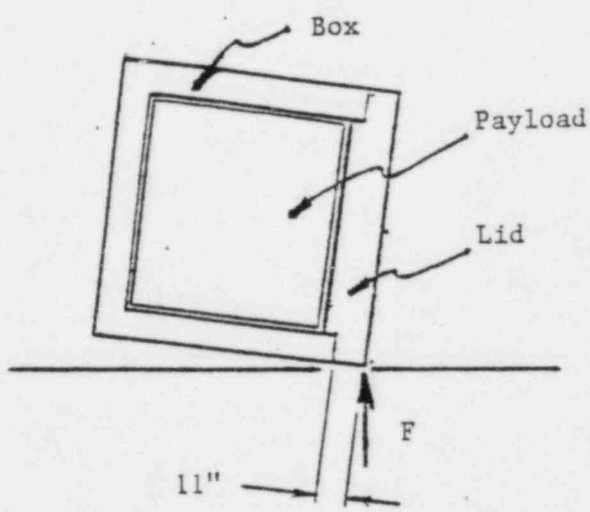
The orientation for the worst case loading of the lid attachment bolts is as shown in the following sketch:



This edge drop orientation is a worst case since 'g' loads are relatively high (95.9 'g') and very little rotation of the package would occur (i.e., center of gravity over struck corner). For other orientations, the package will tend to rotate as the payload imposes a load on the lid thereby limiting the potential for driving the lid from the package. More specifically, the following two orientations were also considered and judged to be less critical than the above edge drop orientation:



Case 1

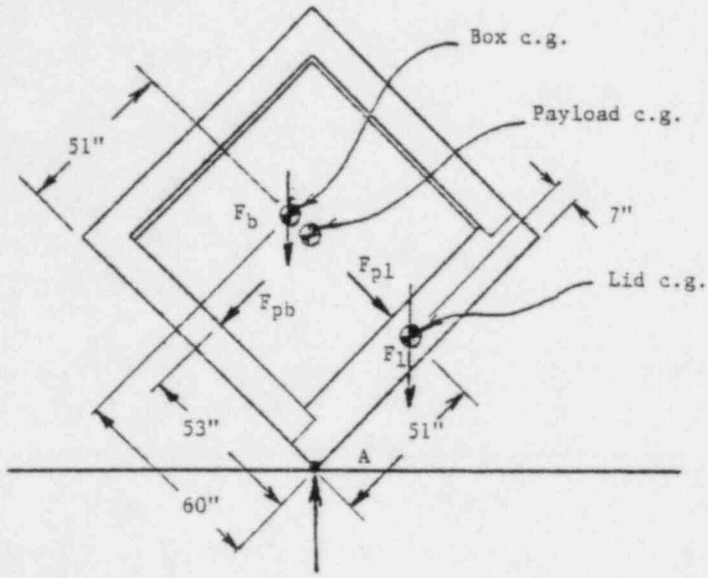


Case 2

In Case 1, not only will the package tend to rotate prior to significant loads developing on the lid, but there is only the inertial resistance of the box tending to separate the lid to box interface.

In Case 2, the package will again tend to rotate prior to significant loads developing on the lid. In addition, the magnitude of the moment acting on the lid which would tend to separate the lid from the package is severely limited by the short moment arm (11 inch lid thickness) from the bolted interface to the initial point of contact with the ground. Finally, this moment arm will rapidly decrease as the package deforms, further limiting the magnitude of the moment which can develop on the lid.

Returning to the more critical edge drop orientation, the following free body diagram applies:



Where,

F = maximum impact force = 95.9(66,600) = 6.387(10)^6 lbs

F_l = inertial force on lid = 95.9(5,600) = 537,040 lbs

F_b = inertial force on box = 95.9(19,000) = 1.822(10)^6 lbs

F_{pl} = inertial force on lid from payload
= 95.9(0.707)(42,000) = 2.848(10)^6 lbs

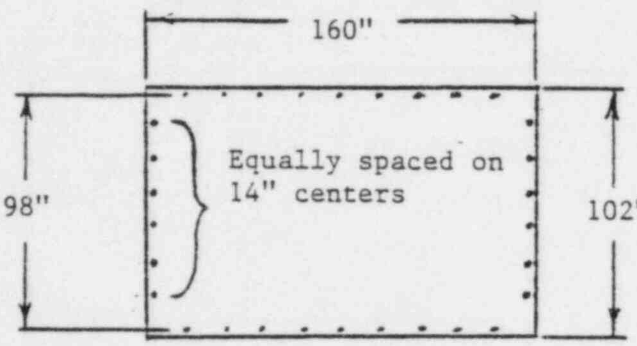
F_{pb} = inertial force on box from payload
= 95.9(0.707)(42,000) = 2.848(10)^6 lbs

Considering moments about point 'A', F_l and F_{pl} will contribute to a clockwise moment about 'A', whereas F_b and F_{pb} will contribute to a counterclockwise moment about 'A'. The magnitude of these moments are as follows:

$$\text{Clockwise moment} = F_l(\sin 45^\circ)(51.0 - 7.0) + F_{pl}(51.0) = 1.619(10)^8 \text{ in-lbs}$$

$$\text{Counterclockwise moment} = F_b(\sin 45^\circ)(60.0 - 51.0) + F_{pb}(53.0) = 1.625(10)^8 \text{ in-lbs}$$

These moments are nearly identical, indicating that very little rotation of the package would be expected for this orientation. The lid attachment bolts will be analyzed for the loading imposed by a moment of $1.63(10)^8$ in-lbs. Thirty (30), 1 1/2 - 6 UNC bolts will be used to secure the lid to the package as shown below:



The maximum bolt load, P, associated with this configuration is as follows:

$$M = 98.0(9P) + 2P\{[(84)^2 + (70)^2 + (56)^2 + (42)^2 + (28)^2 + (14)^2]/98.0\} = 1.63(10)^8$$

Solving for the maximum bolt load, P:

P = 130,820 lbs

The tensile area for these bolts is 1.405 in^2 per Reference 2.10.2. Therefore, the resultant maximum bolt stress is:

$$\sigma = P/A = 130,820/1.405 = 93,110 \text{ psi}$$

With an allowable tensile stress of S_y, or 130,000 psi for these ASTM A-354, Grade BD, bolts, the resultant Margin of Safety is:

$$M.S. = (S_y/\sigma) - 1 = (130,020/93,110) - 1 = \underline{+\ 0.40}$$

The load from these bolts must be resisted by the welds attaching the square mechanical tubing (or 1.0 inch thick plate used in the lid) to the 3/16 inch thick stainless shell and by the shell itself. This is addressed in the following analysis:

For the shell itself, the total load along the 160 inch length of the package results from 9 bolts. Thus, the load to be reacted is $9(130,820) = 1.177(10)^6$ pounds. This results in a stress in the package outer shell of:

$$\sigma = 1.177(10)^6/(3/16)(160) = 39,250 \text{ psi}$$

With an allowable tensile stress of $0.7S_u$, or 52,500 psi for ASTM A-240, Type 304, stainless steel, the resultant Margin of Safety becomes:

$$M.S. = (0.7S_u/\sigma) - 1 = (52,500/39,250) - 1 = \underline{+\ 0.34}$$

For the welds attaching the ASTM A-500, Grade B, square mechanical tubing to the stainless outer shell, the equivalent of 80 inches of 0.25 inch plug welds, plus two 160 inch lengths of flare-bevel welds exist. In the following calculation, the upper flare-bevel weld will be treated as half effective since the stainless shell does not extend the full height of the square mechanical tubing.

The effective weld area (using 5/16 of the 0.75 inch bend radius of the square tubing as the effective throat for the flare-bevel welds per Table 1.14.6.1.3 of Reference 2.10.6) is:

$$A = 80(0.25) + 160(1.5)(5/16)(0.75) = 76.25 \text{ in}^2$$

Therefore, the stress in these welds is determined to be:

$$\sigma = P/A = 1.177(10)^6/76.25 = 15,440 \text{ psi}$$

Treating this stress as a shear stress, the allowable stress limit becomes $0.42S_u$, or 24,360 psi using the limiting ASTM A-500, Grade B, base metal properties. The resulting Margin of Safety is:

$$M.S. = (0.42S_u/\sigma) - 1 = (24,360/15,440) - 1 = \underline{+0.58}$$

For the welds attaching the 1.0 inch thick stainless plate used in the lid to the stainless outer shell, the equivalent of two 3/16 inch fillet welds will extend the full 160 length of the package. Additionally, there will be a 3/16 inch fillet around each of the 9 bolt pockets. Therefore, the total weld length is:

$$L = 2(160) + 9[2(4.0) + 4.5] = 432.5 \text{ inches}$$

Then, the stress in the welds is:

$$\sigma = 1.177(10)^6/(432.5)(3/16)(\sin 45^o) = 20,530 \text{ psi}$$

Treating this stress as a shear stress, the allowable stress limit becomes $0.42S_u$, or 31,500 psi for the ASTM A-240, Type 304, stainless steel. Therefore, the resulting Margin of Safety is:

$$M.S. = (0.42S_u/\sigma) - 1 = (31,500/20,530) - 1 = \underline{+0.53}$$

Next, consider pullout of the 2.5 inch diameter ASTM A-36 carbon steel inserts which weld to the square mechanical tubing. Attachment of the insert is via two 0.375 inch full penetration welds and one 0.375 inch fillet weld. The stress in the welds is:

$$\sigma = P/A = 130,820/[\pi(2.5)(2.707)(0.375)] = 16,410 \text{ psi}$$

Treating this stress as a shear stress, the allowable stress limit becomes $0.42S_u$, or 24,360 psi using the limiting ASTM A-36 carbon steel base metal properties. Therefore, the resulting Margin of Safety is:

$$M.S. = (0.42S_u/\sigma) - 1 = (24,360/16,410) - 1 = \underline{+0.48}$$

Finally, consider shear of the bolts from the insert. The shear area for the 1 1/2 - 6 UNC-2B internal thread is given as 3.566 in^2 per inch of engagement (Reference 2.10.7). Therefore, for a three inch thread engagement, the resultant stress is:

$$\tau = P/A = 130,820/(3.0)(3.566) = 12,230 \text{ psi}$$

With an allowable shear stress in the ASTM A-36 carbon steel inserts of 24,360 psi as determined above, the Margin of Safety is:

$$M.S. = (0.42S_u/\tau) - 1 = (24,360/12,230) - 1 = \underline{+\ 0.99}$$

2.7.1.4 Summary of Results

As evidenced by the preceeding evaluations, the packaging will adequately protect the LGS radiation unit in the event of a 30 foot, hypothetical accident drop event. The energy associated with the drop is almost entirely absorbed by the packaging, as desired. The lid of the packaging will remain attached, thus providing protection for following pin puncture, immersion, or fire transient events. Significant 'g' loads can develop on the package for certain drop orientations, but with the exception of bearing stresses at the support dunnage/LGS radiation unit interface, stresses throughout the unit are relatively small. In any event, stresses which could develop will not compromise the shielding for the special form sources. A summary of damage resulting from the full accident test sequence is presented in Section 2.7.6.

2.7.2 Puncture

Subpart F of 10 CFR 71 requires that a 40 inch free drop of the ELEKTA TIGER Package onto the upper end of a solid, vertical, cylindrical, mild steel bar mounted on an essentially unyielding, horizontal surface be considered. The bar must be 6.0 inches in diameter and its edge rounded to a radius of not more than 0.25 inches. The package is to be oriented in a position for which

maximum damage is expected and the length of the pin is to be such that maximum damage will occur.

The approach used to qualify the package for this puncture event involves a comparison with a similar package for which tests were performed. The similar package is the SUPER TIGER (NRC Certificate of Compliance No. 6400). The SUPER TIGER is of similar construction, overall size and weight. In particular, the walls of the SUPER TIGER are constructed of a series of 3 stacked plates with thicknesses identical to the plates used for the ELEKTA TIGER. The weight of the fully loaded (and tested) SUPER TIGER was 45,000 pounds, or 21,600 pounds less than the fully loaded ELEKTA TIGER Package. The higher weight for the ELEKTA TIGER results in more drop energy and the potential for more damage. This potential is accounted for in the design by using ASTM A-240, Type 304, stainless steel outer walls on the ELEKTA TIGER whereas ASTM A-36 carbon steel was used on the SUPER TIGER. As stainless steel can absorb significantly more energy than carbon steel, the ELEKTA TIGER design can be shown to be acceptable as follows:

Parameter	SUPER TIGER	ELEKTA TIGER
Package weight (lbs)	45,000	66,600
Drop height (in)	40	40
Drop energy (in-lbs)	1,800,000	2,664,000

The ratio of drop energies is 2.664/1.800 = 1.48. Using ASTM specified minimum material properties, the relative energy absorbing capabilities of ASTM A-36 carbon steel and ASTM A-240, Type 304, Stainless steel are determined in the following table. In this table, energy absorption capability is set equal to the area under the applicable stress-strain curve and is closely approximated by multiplying the average of the materials yield and ultimate strengths by the materials ultimate elongation.

Steel Identification	Yield Strength (psi)	Ultimate Strength (psi)	Ultimate Elongation (in/in)	Energy Absorption (in-lbs/in^3)
ASTM A-36	36,000	58,000	0.23	10,810
ASTM A-240, Type 304	30,000	75,000	0.40	21,000

As stainless can absorb 21,000/10,810 = 1.943 times more energy than carbon steel, and the ratio of drop energies is only 1.48, the ELEKTA TIGER design is considered good by comparison with the SUPER TIGER design. Per Page 36 of Reference 2.10.4, the pin puncture test of the SUPER TIGER resulted in a localized side wall indentation of approximately 2.50 inches. Deformations for the ELEKTA TIGER may be somewhat larger than this value due to the larger drop energy and the slightly lower yield point for stainless than for carbon steel, but even if deformations were doubled, the 11.0 inch minimum side thickness of the ELEKTA TIGER packaging would remain adequate.

As a final note, the response of the package payload to the puncture event will be significantly less severe than the response to the 30 foot drop event, which was previously discussed in Section 2.7.1.

2.7.3 Thermal

The hypothetical fire transient is analyzed in Section 3.5, and resultant maximum temperatures are summarized in the following table. The maximum temperature obtained for the walls of the inner cavity or the LGS radiation unit itself is 133° F. The packaging, therefore, adequately protects the payload and the fire transient is of little consequence for the ELEKTA TIGER Package. Of note, thermal stresses which would develop in the packaging can be classified as secondary, displacement limited stresses and are of little consequence in the fire transient since secondary stress limits do not exist for accident conditions (see Table 2.1.2-1).

Location	Temperature (^{o}F)
Side outer wall	1,474
End outer wall	1,133
Inner cavity wall	133
Weather seal area	133
LGS radiation unit	118

It is noted that the model used for the thermal analysis (Section 3.4) is rather coarse in that each node represents a large region of steel and/or foam. Each nodal temperature, therefore, represents an average temperature for the material associated with the node of interest. This explains why the temperature reported for the end outer wall (1,133^{o}F) is significantly less than that reported for the side outer wall (1,474^{o} F). However, this coarse modeling in no way compromises the conclusion reached that the fire transient is of little consequence for the package.

2.7.4 Immersion - Fissile Material

As there is no fissile material associated with the ELEKTA TIGER Package, the requirement of 10 CFR 71.73(c)(4) does not apply.

2.7.5 Immersion - All Packages

Per 10 CFR 71.73(c)(5), the effect of a 21 psig external pressure upon the special form source capsules must be addresed. The geometry of the source capsules is shown on General Electric Drawing 183C8174, presented in Section 1.3. Stresses due to the 21 psig external pressure are determined as follows:

Bending of the 0.020 inch thick, 0.189 inch diameter, outer capsule end plate is determined using Table 24, Case 10b of Reference 2.10.1:

$$M = qa^2/8$$

Where:

M = radial bending moment

$q = 21\ \text{lb/in}^2$

$a = 0.189/2 = 0.0945$ in

Then,

$$M = 21(0.0945)^2/8 = 0.02344\ \text{in-lbs/in}$$

The bending stress is:

$$\sigma = 6M/t^2$$

Where:

$t = 0.020$ in

Then,

$$\sigma = 6(0.02344)/(0.020)^2 = 352\ \text{psi}$$

Hoop stress at the welded end of the outer capsule (the location of minimum wall thickness) is:

$$\sigma = q[(a^2 + b^2)/(b^2 - a^2)]$$

Where:

$a = 0.236$ in

$b = 0.275$ in

Then,

$$\sigma = 21\{[(0.236)^2 + (0.275)^2]/[(0.275)^2 - (0.236)^2]\} = 138 \text{ psi}$$

The above calculations demonstrate stresses of such small magnitudes to ensure large Margins of Safety for any 300 series stainless steel as specified on the General Electric drawing.

2.7.6 Summary of Damage

The analyses presented in Sections 2.7.1 through 2.7.5 demonstrate that the ELEKTA TIGER packaging adequately protects the payload under all normal condition and hypothetical accident loadings. The only significant damage to the package is restricted to the packaging as desired. It is therefore concluded that the accident test sequence will not compromise the integrity of the special form sources or the shielding which surrounds them.

2.8 Special Form

The 201, Cobalt-60 sources contained within the LGS radiation unit are special form sources. These special form sources are virtually identical to existing Nucletronix, Cobalt-60 sources for which an IAEA certificate already exists (Figure 2.8-1). Application has been made for the IAEA certificate for the AB ELEKTA, Cobalt-60 sources. As indicated, the special form sources are doubly encapsulated in stainless steel and meet the requirements set forth in 1) Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition, International Atomic Energy Agency, Vienna, Austria, and in 2) Title 49, Code of Federal Regulations, Parts 170 - 178. Although the attached special form certification states that up to 60 curies of Cobalt-60 are acceptable for each Nucletronix, Cobalt-60 source, this application is limited to a maximum of 33 curies per each of 201, AB ELEKTA, Cobalt-60 sources. The Nucletronix special form sources are as shown in General Electric Drawing 183C8174, presented in Section 1.3. Table 2.8-1 presents a dimensional comparison of the Nucletronix and AB ELEKTA, Cobalt-60 sources.

FIGURE 2.8-1

Special Form Source Documentation

U.S. Department of Transportation

Research and Special Programs Administration

400 Seventh Street, S.W.
Washington, D.C. 20590

IAEA CERTIFICATE OF COMPETENT AUTHORITY

Special Form Radioactive Material Encapsulation

Certificate Number USA/0245/S

This certifies that the encapsulated source, as described, when loaded with the authorized radioactive contents, has been demonstrated to meet the regulatory requirements for special form radioactive material as prescribed in IAEA 1/ and USA 2/ regulations for the transport of radioactive materials.

I. Source Description - The source described by this certificate is identified as the Nucletronix Co-60 source which is a welded, double encapsulation construction of stainless steel and measures 0.312 inches in diameter by 1.07 inches in length. Construction is in accordance with General Electric drawing number 183C8174A, Rev. 1.

II. Radioactive Contents - The authorized radioactive contents of this source consist of not more than 60 curies of cobalt-60 as metal pellets.

III. This certificate, unless renewed, expires February 28, 1987.

This certificate is issued in accordance with paragraph 803 of the IAEA Regulations 1/, and in response to the February 5, 1982 petition by General Electric Co., Pleasanton, CA and in consideration of the associated information therein.

Certified by:

R. R. RAWL
Chief, Radioactive Materials Branch
Office of Hazardous Materials Regulation
Materials Transportation Bureau

February 16, 1981
DATE

1/ " Safety Series No. 6, Regulations for the Safe Transport of Radioactive Materials, 1973 Revised Edition", published by the International Atomic Energy Agency (IAEA), Vienna, Austria.

2/ Title 49, Code of Federal Regulations, Part 170-178, USA.

TABLE 2.8-1

Dimensional Comparison of the Cobalt-60 Sources

(All Dimensions in Inches)

Parameter	Nucletronix	AB ELEKTA
Outer Containment:		
Length	1.07	1.07
Outside/Inside Diameter	0.312/0.193	0.3146/0.1975
Window Diameter/Thickness	0.189/0.020	0.189/0.020
Cap Thickness	0.039	0.039
Wall Thickness	0.0595	0.0585
Inner Containment:		
Length	0.93	0.93
Outside/Inside Diameter	0.188/0.128	0.1965/0.126
Wall Thickness	0.030	0.035
Cobalt Pellet Tube:		
Length	0.89	0.89
Outside/Inside Diameter	0.125/0.0465	0.125/0.0465
Wall Thickness	0.039	0.039

2.9 Fuel Rods

This Section does not apply for the ELEKTA TIGER Package.

2.10 References

2.10.1 Roark and Young, Formulas for Stress and Strain, McGraw-Hill, Fifth Edition.

2.10.2 Bickford, John H., An Introduction To The Design And Behavior of Bolted Joints, Marcell Dekker, Inc., 1981, Appendix H.

2.10.3 Marks' Standard Handbook for Mechanical Engineers, Eighth Edition, McGraw-Hill Book Company, 1978.

2.10.4 Engineering Evaluation of the SUPER TIGER Overpack Designed for the Shipment of Large Quantities of Hazardous Materials, Prepared by Mechanics Research, Inc., May 4, 1970.

2.10.5 NRL Report 5920, Fracture Analysis Diagram Procedures for the Fracture-Safe Engineering Design of Steel Structures, W. S. Pellini and P. P. Puzak, March 15, 1963.

2.10.6 AISC Manual of Steel Construction, Eighth Edition.

2.10.7 Table Speeds Calculation of Strength of Threads, Product Engineering, November 27, 1961, Pages 41-49.

2.10.8 Shigley, Joseph E., Mechanical Engineering Design, Second Edition, McGraw-Hill, 1972.

2.11 Appendices

2.11.1 Description of NuPac Proprietary Drop Programs

2.11.2 Drop Evaluation Results From FACE, EDGE, and CORNER

2.11.1 Description of NuPac Proprietary Drop Programs

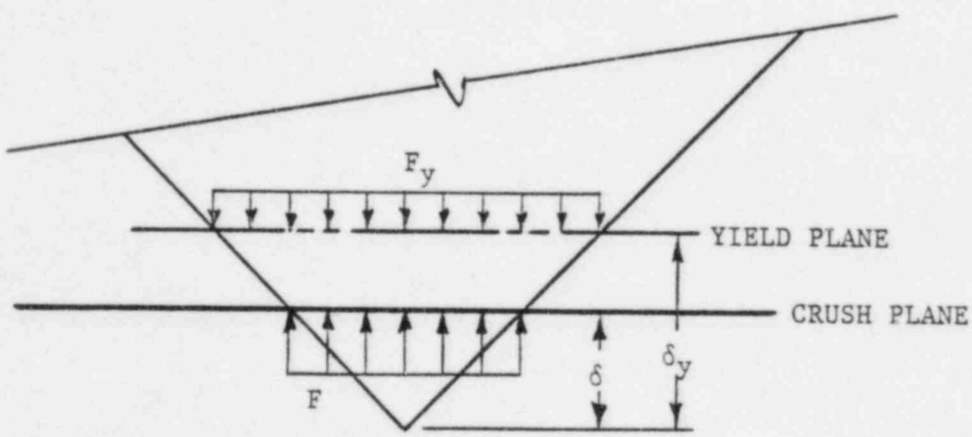
This section briefly documents the methodology employed by the computer programs used to demonstrate compliance of the package with applicable provisions of 10 CFR 71 for normal and hypothetical accident conditions. The following three subsections deal with impact in each of the three major orientations: face, edge, and corner, respectively. In addition, a final subsection describes the quality assurance program utilized to maintain all NuPac computer codes. These subsections describe techniques and computer programs developed by Nuclear Packaging, Inc., of Federal Way, Washington, as follows:

- 2.11.1.1: Describes the derivation of the face drop load-deflection relations.
- 2.11.1 2: Describes the derivation of the edge drop load-deflection relations.
- 2.11.1.3: Describes the derivation of the corner drop load-deflection relations.
- 2.11.1.4: Describes the quality assurace program utilized to maintain NuPac computer codes.

The ELEKTA TIGER package is surrounded on all sides by polyurethane foam of two densities. For purposes of analysis, the polyurethane foam is assumed to absorb, in pure plastic deformation, the entire kinetic energy of the drop event. None of the drop kinetic energy is transferred to kinetic or strain energy of the target (the flat, essentially unyielding surface assumption of 10 CFR 71.71(c)(7) and 10 CFR 71.73(c)(a)), or of the non-foam portions of the package. All impact orientations conservatively neglect rotational effects, which would reduce the impact deformations and accelerations.

For the three drop orientations, the prediction of polyurethane foam crush behavior can be approached by utilizing a 'localized strain' approach. The localized strain approach assumes that a zone directly above the crush plane experiences inelastic strains, and the remaining foam remains under yield.

With reference to the following illustration, the yield depth, δ_y, is determined by iteration and a solution at each crush depth, δ, is achieved when the force at the crush plane, F, is equal to the force at the yield plane, F_y ($F = F_y$). This approach is considered to give more realistic estimates for package response than using a uniform strain assumption. In the localized strain approach, foam strain calculations are based upon the yield depth whereas in the uniform strain approach, strain calculations are based upon the full thickness of the foam. Of note, if the area of the crush plane does not increase with increasing deformation (i.e., the face drop orientation), the localized and uniform strain assumptions will give identical results.



From the above illustration, the variables are:

δ = crush depth

F = crush force

δ_y = yield depth

F_y = yield force

The kinetic energy of the drop is:

$$KE = W(h + \delta)$$

Where:

W = package weight

h = drop height

The strain energy of the deforming foam is:

$$SE = \int_0^{\delta} F \, dx$$

Where:

F = crush force at the target/package interface at a deformation equal to 'δ'

The package is at rest when the deformation, δ, is found such that the strain energy of foam crush, SE, is equivalent to the kinetic energy of the drop, KE.

Each of the three impact orientations, face, edge, and corner, is treated by an individual computer program reflecting the differing geometry characteristics of each event. All three computer programs employ the common energy balance techniques discussed above to assess maximum package deformations, and utilize a common description of the stress-strain characteristics of the crushable energy absorbing foam.

The foam typically exhibits a stress-strain plateau of nearly constant crush stress up to a total strain of 40 - 50%. Above this strain value, pronounced strain hardening effects commence which reflect the collapse, or consolidation of the entrapped air bubbles within the foam. Accordingly, a tabular definition of foam stress-strain relations is employed in each of the three computer programs. This tabular definition is taken directly from measured properties and accurately relects the strain hardening behavior of the foam up to strains of approximately 80%.

As a default option, the computer programs set the plateau stress for a given foam equal to the stress corresponding to a 10% strain. This plateau stress

is used to establish the yield depth, where the area for the yield plane is equal to the crush force divided by the plateau stress, and the yield depth is determined by geometry once the yield plane area is known.

Both the face and edge impact computer programs are designed to consider the combined effects of up to three different foams acting in parallel. Analysis of the ELEKTA TIGER packaging deals with two different foams in these impact orientations: approximately 7 and 16 pcf (pound per cubic foot) foam. For simplicity, the corner impact computer program considers only a single foam stress-strain curve.

2.11.1.1 Face Drop (FACE)

The computer program FACE performs the energy balance calculation described above for a range of deformation values, δ_{cr}. For each value of deformation, the energy balance is monitored and reported. Solution for total package deformation is found by an interpolation of the energy balance equation (i.e., where the potential energy of the drop is equal to the strain energy of foam crush). Since the crush area is constant, the 'yield depth' automatically defaults to the face thickness and the foam experiences a uniform strain throughout the thickness. FACE assumes a constant foam strain across the entire crush area, neglecting any effects of unbacked areas.

The force imposed upon the package is simply:

$$F = \sum_{n=1}^{3} A_n \sigma_{\varepsilon n}$$

Where, for foam number 'n':

A_n = the impact area

$\sigma_{\varepsilon n} = \xi[\varepsilon_n]$, the foam crush stress at a strain of 'ε_n'

$\xi[\varepsilon_n]$ = the tabular definition of foam stress-strain properties

$\varepsilon_n = \delta/t_f$

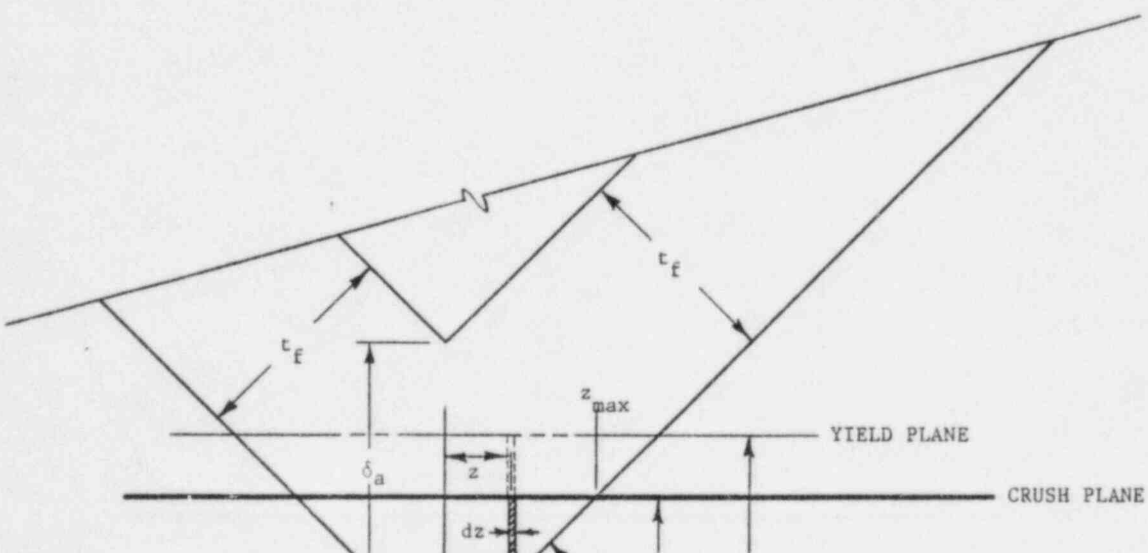
t_f = face thickness

2.11.1.2 Edge Drop (EDGE)

The computer program EDGE differs from the face drop solution only in the fact that both deformation and strain vary from point-to-point and total force at a given crush depth must be found by geometric integration over these points. EDGE assumes a constant foam strain along the entire crush length, neglecting any effects of unbacked areas. In addition, the computer program EDGE assumes the face thickness is equal on both sides and uses an impact angle 45° from the face to produce maximum deformation.

At an angle of 45°, where the yield depth, δ_y, is less than the maximum allowable crush depth, δ_a, the force imposed upon the package is simply:

$$F = \sum_{n=1}^{3} \left[2L_n \int_0^{z_{max}} \sigma_{\xi zn} \, dz \right]$$



Where, for foam number 'n':

$\delta_a = t_f/(\sin 45^\circ)$

L_n = the impact length

$z_{max} = \delta$ (for an angle of 45°)

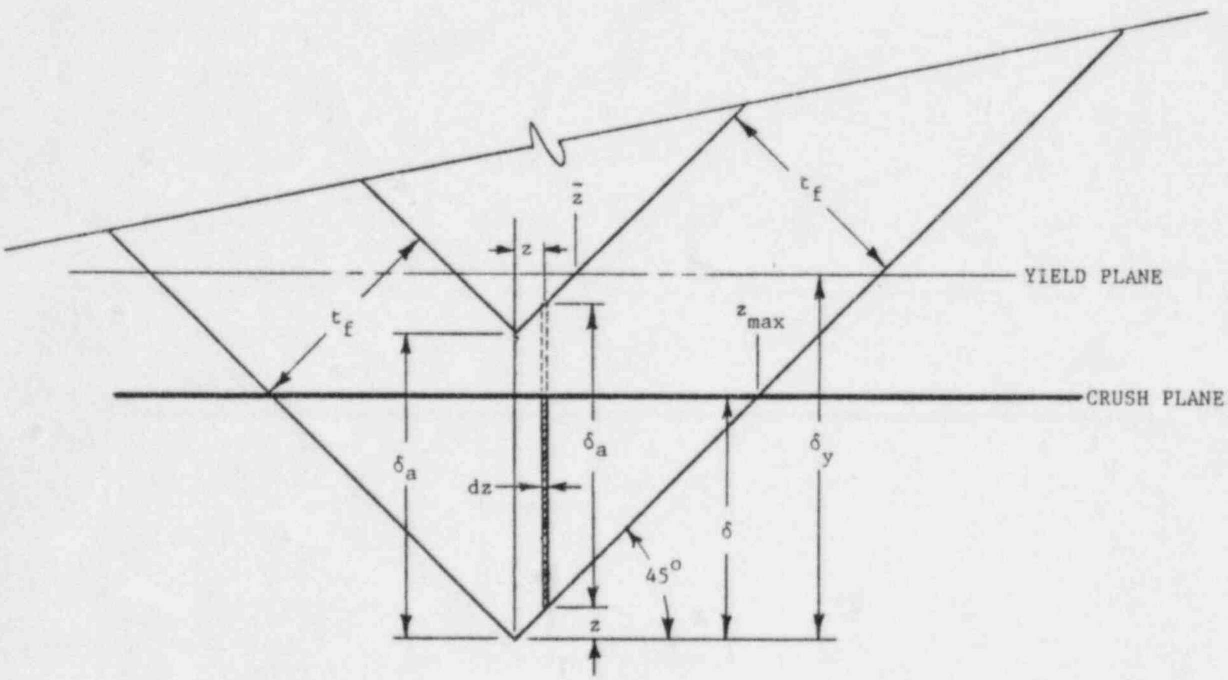
$\sigma_{\varepsilon nz} = \xi[\varepsilon_{nz}]$, the foam crush stress at a strain of 'ε_{nz}'

$\xi[\varepsilon_{nz}]$ = the tabular definition of foam stress-strain properties

ε_{nz} = the foam strain at location 'z' = $(\delta - z)/(\delta_y - z)$

At an angle of 45°, where the yield depth, δ_y, exceeds the maximum allowable crush depth, δ_a, the force imposed upon the package is then:

$$F = \sum_{n=1}^{3} \left[2L_n \int_0^{\bar{z}} \bar{\sigma}_{\varepsilon zn}\, dz + 2L_n \int_{\bar{z}}^{z_{max}} \sigma_{\varepsilon zn}\, dz \right]$$



Where, for foam number 'n':

$$\bar{\sigma}_{\varepsilon nz} = \xi[\bar{\varepsilon}_{nz}]\text{, the foam crush stress at a strain of '}\varepsilon_{nz}\text{'}$$

$$\xi[\bar{\varepsilon}_{nz}] = \text{the tabular definition of foam stress-strain properties}$$

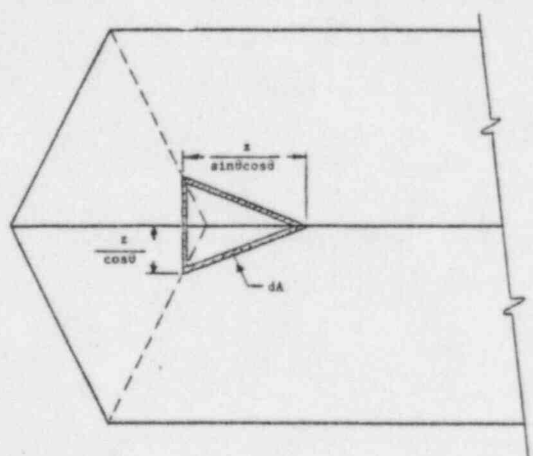
$$\bar{\varepsilon}_{nz} = (\delta - z)/\delta_a$$

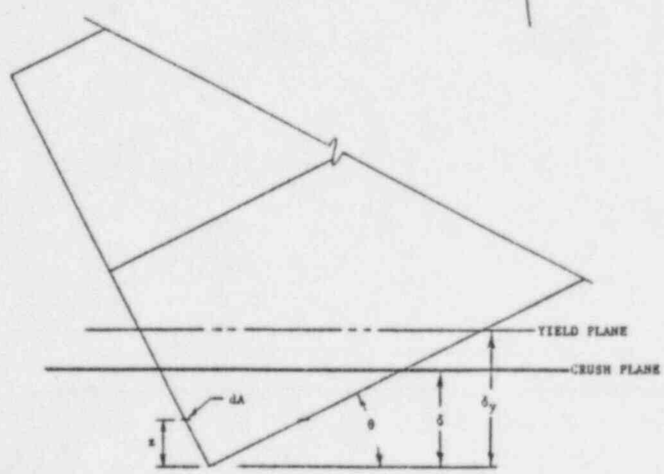
$$\bar{z} = \delta_y - \delta_a$$

All other variables are as previously defined.

2.11.2.3 Corner Drop (CORNER)

The computer program CORNER is similar to the computer program EDGE. In CORNER, the package orientation is defined by starting from an edge orientation (i.e., package on edge with faces 45° from horizontal) and rotating through an angle, θ, as shown in the illustration below.





A primary difference between EDGE and CORNER is in the integration element. Whereas EDGE utilizes a rectangular element to determine the force in the impact plane, CORNER utilizes a triangular element, as previously illustrated.

The force imposed upon the package is:

$$F = \int_{0}^{z_{max}} \sigma_{\varepsilon z} \, dA$$

Where:

$$A = z^2/(\sin \Theta)(\cos^2 \Theta)$$

$$dA = 2z/(\sin \Theta)(\cos^2 \Theta) \, dz$$

Θ = angle of package edge with respect to the horizon

$\sigma_{\varepsilon z} = \xi[\varepsilon_z]$, the foam crush stress at a strain of 'ε_z'

$\xi[\varepsilon_z]$ = the tabular definition of foam stress-strain properties

ε_z = the foam strain at location 'z' = $(\delta - z)/(\delta_y - z)$

$z_{max} = \delta$

Then, the force imposed upon the package may be rewritten as:

$$F = \int_{0}^{z_{max}} [2z/(\sin \Theta)(\cos^2 \Theta)]\sigma_{\varepsilon z} \, dz$$

2.11.1.4 NuPac Computer Code Quality Assurance

NuPac computer analysis programs are maintained in accordance with a formal quality assurance program approved by the Nuclear Regulatory Commission under certificate number 0192 that complies with ANSI N45.2. These provisions are applied to both NuPac authored software and vendor supplied software. Vendors of computer services, such as Boeing Computer Services, have demonstrated that their quality standards are in accordance with the provisions of ANSI N45.2. Documentation of such compliance is maintained in NuPac Quality Assurance files.

The requirements of ANSI N45.2 are interpreted to impose the following stipulations upon computing software:

ANSI N45.2 Section	Requirement
4.3	The supplier shall require the identification and performance of verification/qualification evaluations which demonstrate that computer codes are capable of producing information of sufficient accuracy to satisfy design requirements. All calculations and computer input data shall receive documented, independent, in-house verification.
7.0	The supplier shall establish responsibilities and procedures relating to computer code configuration identification and configuration control. NOTE: Configuration identification is the establishment and use of a unique identifier for a code version. Configuration control includes the documentation and preservation of a code version to assure its retrievability and includes similar preservation of input for computer runs to assure that output results can subsequently be reconstructed.

A valid computer solution requires that each of the following tests be satisfied:

- o Does the analytic method accurately represent the modeled physical processes?
- o Does the computer code fully and accurately implement the analytic method?
- o Does the input problem data accurately reflect the physical properties of the situation being analyzed?
- o Can the resultant output data be uniquely identified as resulting from a particular input data set?

NuPac procedures assure that each of the above questions is answered in an affirmative fashion. These procedures include the following configuration control elements.

1. Each safety analysis report or design analysis summary provides a complete description of appropriate analysis methods implemented in NuPac developed software.
2. Version identification for each run of the computer code is maintained by the automatic appearance of current code revisions numbers and dates in both output headers and day file listings.
3. All superseded versions of codes are maintained on file.
4. All input data are automatically echoed on output for verification and checking purposes.
5. All output data, including plots, are labeled with a machine generated name, time and date corresponding to the run which generated the reported engineering results.

2.11.2 Drop Evaluation Results from FACE, EDGE, and CORNER

The overall response of the ELEKTA TIGER Package to normal condition, one foot drops, and hypothetical accident, thirty foot drops is determined using the NuPac proprietary computer codes FACE, EDGE, and CORNER. These computer codes are further described in Section 2.11.1. For all drop evaluations, analyses are performed utilizing +60% and -25% foam crush strength bounds which take into account deviations in foam crush strength due to temperature and density. Significant results from the normal condition and hypothetical accident condition drop events are summarized in the following tables:

Table 2.11.2.1-1	Normal Condition End Face Drop, +60% Foam Strength
Table 2.11.2.1-2	Normal Condition End Face Drop, -25% Foam Strength
Table 2.11.2.1-3	Normal Condition Side Face Drop, +60% Foam Strength
Table 2.11.2.1-4	Normal Condition Side Face Drop, -25% Foam Strength
Table 2.11.2.2-1	Normal Condition End Edge Drop, +60% Foam Strength
Table 2.11.2.2-2	Normal Condition End Edge Drop, -25% Foam Strength
Table 2.11.2.2-3	Normal Condition Side Edge Drop, +60% Foam Strength
Table 2.11.2.2-4	Normal Condition Side Edge Drop, -25% Foam Strength
Table 2.11.2.3-1	Normal Condition Corner Drop, +60% Foam Strength
Table 2.11.2.3-2	Normal Condition Corner Drop, -25% Foam Strength
Table 2.11.2.4-1	Accident Condition End Face Drop, +60% Foam Strength
Table 2.11.2.4-2	Accident Condition End Face Drop, -25% Foam Strength
Table 2.11.2.4-3	Accident Condition Side Face Drop, +60% Foam Strength
Table 2.11.2.4-4	Accident Condition Side Face Drop, -25% Foam Strength
Table 2.11.2.5-1	Accident Condition End Edge Drop, +60% Foam Strength
Table 2.11.2.5-2	Accident Condition End Edge Drop, -25% Foam Strength
Table 2.11.2.5-3	Accident Condition Side Edge Drop, +60% Foam Strength
Table 2.11.2.5-4	Accident Condition Side Edge Drop, -25% Foam Strength
Table 2.11.2.6-1	Accident Condition Corner Drop, +60% Foam Strength
Table 2.11.2.6-2	Accident Condition Corner Drop, -25% Foam Strength

The edge drop analyses performed assume an impact orientation 45° from a face. This assumption minimizes impact area which develops for a given deformation, thereby inducing the maximum packaging deformations. Likewise, the corner drop impact angle of 35.27° corresponds to a minimum impact area plane (in the shape of an equilateral triangle) for a given deformation. By ignoring rotational effects, the maximum possible deformation is achieved. The above orientations are expressly chosen to give maximum deformations to assess package clearances, whereas the face impact orientations produce the maximum acceleration. The following table provides a summary of package deformations and accelerations for the above listed drop analyses:

Condition	Deformation (in)	Acceleration (g's)
Normal End Face Drop, +60% Foam	0.43	55.8
Normal End Face Drop, -25% Foam	0.65	37.3
Normal Side Face Drop, +60% Foam	0.23	99.0
Normal Side Face Drop, -25% Foam	0.35	63.9
Normal End Edge Drop, +60% Foam	2.10	13.4
Normal End Edge Drop, -25% Foam	3.19	9.6
Normal Side Edge Drop, +60% Foam	2.02	13.9
Normal Side Edge Drop, -25% Foam	3.06	9.8
Normal Corner Drop, +60% Foam	8.78	7.1
Normal Corner Drop, -25% Foam	11.83	6.0
Accident End Face Drop, +60% Foam	2.81	200.7
Accident End Face Drop, -25% Foam	4.80	98.3
Accident Side Face Drop, +60% Foam	1.93	228.5
Accident Side Face Drop, -25% Foam	3.75	113.0
Accident End Edge Drop, +60% Foam	10.78	68.8
Accident End Edge Drop, -25% Foam	15.86	47.4
Accident Side Edge Drop, +60% Foam	10.40	73.6
Accident Side Edge Drop, -25% Foam	13.91	95.9
Accident Corner Drop, +60% Foam	23.20	49.5
Accident Corner Drop, -25% Foam	30.05	38.9

TABLE 2.11.2.1-1

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TABLE 2.11.2.1-2

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TABLE 2.11.2.2-1

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TABLE 2.11.2.3-1

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TABLE 2.11.2.4-1

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TABLE 2.11.2.4-4

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TABLE 2.11.2.5-1

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TABLE 2.11.2.5-4

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TABLE 2.11.2.6-1

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TABLE 2.11.2.6-2

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3.0 THERMAL EVALUATION

This section identifies and describes the principle thermal engineering design aspects of the ELEKTA TIGER package important to safety and compliance with the performance requirements of 10 CFR 71.

3.1 Discussion

The ELEKTA TIGER package is designed as a totally passive thermal system capable of safely transporting a payload of 104 thermal watts. The principle physical characteristics of this thermal system consist of a stainless steel outer shell, carbon steel inner shell, and polyurethane foam, completely enclosing the payload.

Three heat transfer analyses were run utilizing the computer thermal network analyzer program THAN: steady state analyses at an ambient temperature of 100° F, with solar heating to model normal conditions of transport, without solar heating as initial conditions for the transient analysis, and a transient analysis at an ambient temperature of $1,475^{\circ}$ F for thirty (30) minutes to model the hypothetical accident condition. The following maximum temperatures in Table 3.1-1 were determined by these analyses, the details of which are presented in Sections 3.4 and 3.5.

In the transient analysis, the temperature of the LGS Radiation Unit does not reach a maximum during the sixteen hours following the fire. The maximum temperature in the package sixteen hours following the fire is 119.9° F at the center of the inside end wall, Node 15. Since the source, Node 12, is increasing at a rate of only 0.025° F per hour and all other nodes are very near or below the source temperature, the source temperature will peak only slightly higher than currently recorded.

A summary of the ELEKTA TIGER Package maximum temperatures is provided in Table 3.1-1, below.

TABLE 3.1-1

Summary of Maximum Temperatures (^{o}F)

Location	Node	Steady State (with solar)	Steady State (without solar)	Fire Accident Transient
Side Outer Wall	2	173.8		
	17		101.7	
	14			1,473.6
End Outer Wall	6	149.7		
	6		100.2	
	18			1,133.3
Inner Wall	10	151.1		
	20		115.5	
	9			133.0
Seal Area	10	151.1		
	9		114.7	133.0
Source (LGS Rad Unit)	12	149.0	116.4	117.7

3.2 Summary of Thermal Properties of Materials

The ELEKTA TIGER packaging is fabricated entirely of stainless and carbon steel, and polyurethane foams of approximately 7 and 16 pounds per cubic foot (pcf). The following table documents the thermal properties used in the model and the references from which they were obtained:

Material	Density (lb/ft^3)	Conductivity (BTU/hr-ft-°F)	Specific Heat (BTU/lb-°F)	Emmisivity
Stainless Steel	488[1]	9.4[1]	0.11[1]	0.5[2]
Carbon Steel	490[1]	26.0[1]	0.11[1]	0.8[2]
Cast Iron	---	---	0.11[1]	0.66[2]
7 pcf Foam	7	0.0183[3]	0.30[3]	---
16 pcf Foam	16	0.0275[3]	0.30[3]	---
Air	---	See Below[4]	---	---

1. Reference 3.6.1
2. Reference 3.6.2
3. Reference 3.6.3
4. Reference 3.6.4

Since the thermal conductivity of air varies significantly with temperature, the thermal model computed the conductivity across air gaps as a function of temperature (presented in the following table). All other package components were modeled using a fixed conductivity since the variation is slight over the temperature range of interest.

Air Temperature (°F)	Conductivity (BTU/hr-ft-°F)
0	0.0133
32	0.0140
100	0.0154
200	0.0174
300	0.0193
400	0.0212
500	0.0231
600	0.0250
700	0.0268
800	0.0286
900	0.0303
1,000	0.0319
1,500	0.0400
2,000	0.0471

3.3 Technical Specifications of Components

The neoprene dust seal constitutes the only temperature sensitive material utilized within the ELEKTA TIGER packaging. The allowable temperature range of the neoprene is -65° F to 300° F per the manufacturer's recommendations given in Reference 3.6.5. The recommended temperature range for the polyurethane foam is -30° F to 250° F, again per the manufacturer's recommendations. Temperature excursions to -40° F have been demonstrated to not permanantly degrade the foam properties. In addition, temperatures in excess of 250° F, such as those encountered in the fire transient condition, have been demonstrated to produce a char layer that resists further decomposition, thereby continuing to effectively insulate the payload from the high temperatures. Foam strength sensitivity to temperatures is addressed in Section 2.3. The melt temperature of stainless and carbon steels is approximately 2,600° F and 2,750° F, respectively.

3.4 Thermal Evaluation for Normal Conditions of Transport

This section presents the thermal analysis of the ELEKTA TIGER for normal conditions of transport per 10 CFR 71.71, the requirements of which are 100° F ambient temperature with solar loading per the following table:

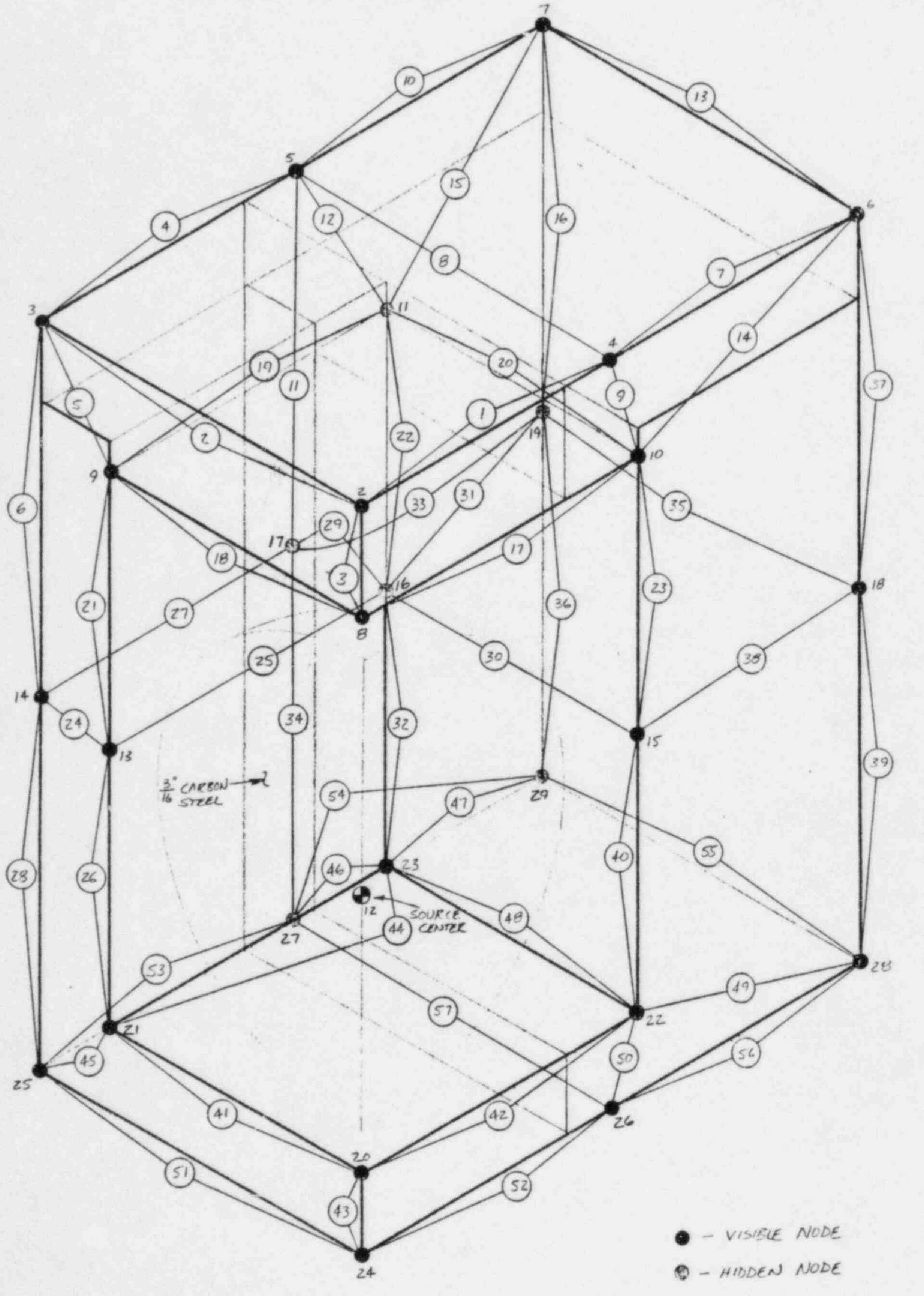
Form and Location of Surface	Total Insolation for a 12-Hour Period (BTU/ft^2)
Flat surfaces transported horizontally	
- Base	None
- Other surfaces	2,950
Flat surfaces not transported horizontally	737
Curved surfaces	1,475

3.4.1 Analytic Model

A schematic of one-quarter of the ELEKTA TIGER package, divided through the center of geometry, is presented in Figure 3.4-1. The model considered the different properties of the materials presented in Section 3.2. Each of the 111 elements, consisting of 57 steel and foam conduction elements, 11 air conduction elements, 16 convection elements, and 27 radiation elements, used in this analysis are presented in a manner compatible with input to the THAN computer program.

For simplicity, the model presented in Figure 3.4-1 illustrates only the steel and foam conduction elements. Although not shown, radiation and convection elements link the ambient, identified as Node 1, with the outer surfaces of the model, identified by Nodes 2, 3, 4, 5, 6, 7, 14, 17, 18, 19, 24, 25, 26, 27, 28, and 29. The top, or lid side, is identified by Nodes 2 through 7 on the outside, and Nodes 8 through 11 on the inside. The base is identified by Nodes 24 through 29. The LGS radiation unit, or source, is identified as Node 12.

FIGURE 3.4-1
Thermal Analysis Model



The 'source' includes the entire 42,000 pound payload (radiation unit and support dunnage), for simplicity modeled thermally as a sphere with a 32.0 inch radius. The sphere is assumed to float freely within the confines of the inner wall, neglecting the effects of conduction through the dunnage to the package inner wall, with heat transfer to the inner wall via air conduction and internal radiation. The effects of this assumption are small, causing slightly higher source temperatures during normal conditions and, due to the relatively large thermal mass of the source, slightly lower source temperatures during the accident condition fire transient. Detailed calculations of element constants and nodal capacitances are presented in Section 3.7.

3.4.2 Maximum Temperatures

The following table delineates the normal condition, steady state, nodal temperature distribution. Ambient air temperature is taken as 100° F, with the solar heat load distribution as described above. The maximum nodal temperature of 173.8° F occurs at the top center of the package, Node 2.

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	173.8309746	3	149.1743291	4	172.2907460
5	149.1379401	6	149.6569912	7	141.5005964	8	149.8092789
9	148.9468703	10	151.1196384	11	148.8029398	12	148.9839713
13	147.6593213	14	125.9811040	15	147.9371361	16	145.4419715
17	127.8197192	18	125.7863834	19	125.6914905	20	146.9508742
21	146.8314366	22	143.7244319	23	143.6649214	24	101.2630089
25	116.1060797	26	105.5547600	27	118.0722888	28	115.3895144
29	119.1532335						

3.4.3 Minimum Temperatures

The minumum temperature for the ELEKTA TIGER package will occur with the absence of decay heat and an ambient air temperature of -40° F, per 10 CFR 71.71(c)(2). The -40° F temperature limit is within the allowable range of all package components. As a potential initial condition for all normal or accident condition events, a -20° F minimum uniform temperature must be considered per 10 CFR 71.71(b) and 10 CFR 71.73(b), respectively.

3.4.4 Maximum Internal Pressures

The severity of thermal testing of the special form source capsules per the requirements of 10 CFR 71.77(d), compared to the temperatures encountered in either the normal or accident condition events, will induce higher source capsule internal pressures.

The effects of internal pressures within the ELEKTA TIGER packaging due to a maximum normal condition temperature of approximately 175° F is considered in Section 2.6.1.1.

3.4.5 Maximum Thermal Stresses

Maximum thermal stresses, during normal conditions of transport, would arise from the temperature distribution described in Section 3.4.2. Normal condition thermal stresses are discussed in Section 2.6.1.

3.4.6 Evaluation of the Package Performance for Normal Conditions of Transport

The component temperatures associated with the normal thermal conditions presented in Sections 3.4.2 and 3.4.3 are all within the allowable limits for the respective materials of fabrication per Section 3.3. As input to the structural analyses in Section 2.0, the minimum temperature for any package component is taken as -40° F (-20° F when combined with other load cases) and the maximum temperature as 180° F for the package and payload.

3.5 Hypothetical Accident Thermal Evaluation

This section presents the thermal analyses of the ELEKTA TIGER package for the hypothetical fire accident condition, delineated in 10 CFR 71.73(c)(3). The initial temperature distribution in the package prior to the fire is taken as

that corresponding to the 100° F steady state condition without the solar loads per the requirements set forth in 10 CFR 71.73(b). To determine the effect of the fire, the package is exposed to a 1,475° F fire for one-half hour at which time the thermal boundary is returned to the 100° F ambient air condition. The transient analysis is then continued for a time sufficient to determine maximum values for all temperatures within the package. A time limit of sixteen hours after the end of the fire was utilized thereby allowing the determination of the package upper bound temperatures.

3.5.1 Thermal Model

The thermal model utilized for the accident condition fire transient analysis was exactly identical to the thermal model used for the normal condition steady state analysis. This is because the structural and drop analyses performed upon the package in Section 2.0 produced no deformations that would allow a direct heat path to the interior cavity, thereby ensuring results very close to that of an undamaged package.

3.5.2 Package Conditions and Environment

As discussed above in Section 3.5.1, the fire accident thermal model was identical to the normal condition thermal model. Analyses performed upon the package in Section 2.0 assure the presence of some quantity of foam at the onset of the fire. Even considering the elimination of all the foam within the ELEKTA TIGER packaging and replacing it with air would only affect the temperatures of the package in a secondary manner. This is because the conductivity of air is at worst (at 1,475° F) only about twice the conductivity of the polyurethane foams. By comparison, the majority of heat is carried into the package via conduction through the carbon and stainless steel (approximately 75% by calculation) at the diagonal plates and lid-to-box interface plates, respectively.

In addition, actual fire tests carried out on a very similar package, the SUPER TIGER (NRC Certificate of Compliance No. 6400), demonstrated internal temperatures below 150° F (Page 62 of Reference 3.6.6). Analysis of the ELEKTA TIGER during the accident fire produces internal temperatures of similar magnitude (133° F), thereby verifying modeling assumptions.

3.5.3 Package Temperatures

The following table delineates the initial accident condition, steady state, nodal temperature distribution. Ambient air temperature is taken as 100° F, without the solar heat load distribution as described in Section 3.4. The maximum nodal temperature of 116.4° F occurs at the center of the package, Node 12.

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	100.2301715	3	100.5655946	4	101.3069115
5	101.3564706	6	100.2436021	7	100.1489099	8	115.4626699
9	114.6769691	10	113.7838762	11	113.1781918	12	116.4304273
13	115.1821995	14	100.3037596	15	115.2771217	16	113.4730731
17	101.6957245	18	100.1048212	19	100.0756875	20	115.5280604
21	115.1764268	22	114.1705969	23	113.4695931	24	100.2415910
25	100.3669877	26	101.3604924	27	101.3627290	28	100.0765486
29	100.0593547						

The following table presents nodal temperatures at the end of the 1,475° F fire (30 minutes after the start of the fire accident event):

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	1475.0000000	2	1471.0763645	3	1471.1568413	4	1452.9690454
5	1463.9190268	6	1173.4219037	7	1385.4244226	8	119.1080706
9	124.8448159	10	123.3612909	11	127.2213895	12	116.4449737
13	122.6660463	14	1473.1480755	15	115.7131076	16	126.2828747
17	1468.738[illegible]629	18	1094.6487713	19	1299.3053952	20	120.1893257
21	123.594[illegible]355	22	121.3668609	23	126.7963953	24	1473.3658911
25	1473.3090401	26	1464.1812567	27	1468.4597720	28	1362.1812578
29	1410.8301632						

At a time sixteen hours after the end of the 1,475° F fire (16 1/2 hours after the start of the fire accident event), nodal temperatures are:

CLASS 2 - TEMPERATURE, T

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	100.4711108	3	100.8235628	4	102.5067663
5	102.2602963	6	109.8597956	7	102.9456780	8	118.1568511
9	117.3794383	10	119.8415985	11	118.9625318	12	117.9092613
13	117.5825889	14	100.4677023	15	119.8958332	16	118.7819548
17	102.5544877	18	114.2012243	19	105.5568160	20	117.7263575
21	117.3530532	22	119.3036814	23	118.3851496	24	100.3731354
25	100.5051932	26	102.1103540	27	102.0525039	28	103.4150475
29	102.1040016						

Additionally, Figures 3.5-1 and 3.5-2 graphically illustrate the fire transient results at key nodes on and within the ELEKTA TIGER package.

3.5.4 Maximum Internal Pressures

Since the internal temperatures produced by the fire accident are less than the internal temperatures produced by normal conditions, the normal condition internal pressure is the maximum case. This pressure is negligible per Section 2.6.1.1.

3.5.5 Maximum Thermal Stresses

Fire accident thermal stresses are discussed in Section 2.7.3.

3.5.6 Evaluation of Package Performance for the Hypothetical Accident Thermal Condition

None of the temperatures noted from the transient analyses exceeded the temperature limitations of the respective materials as defined in Section 3.3. Additionally, since the only major concern is to maintain the shielding integrity of the package, it may be concluded that the package meets all the thermal requirements set forth in 10 CFR 71.73(c)(3).

FIGURE 3.5-1

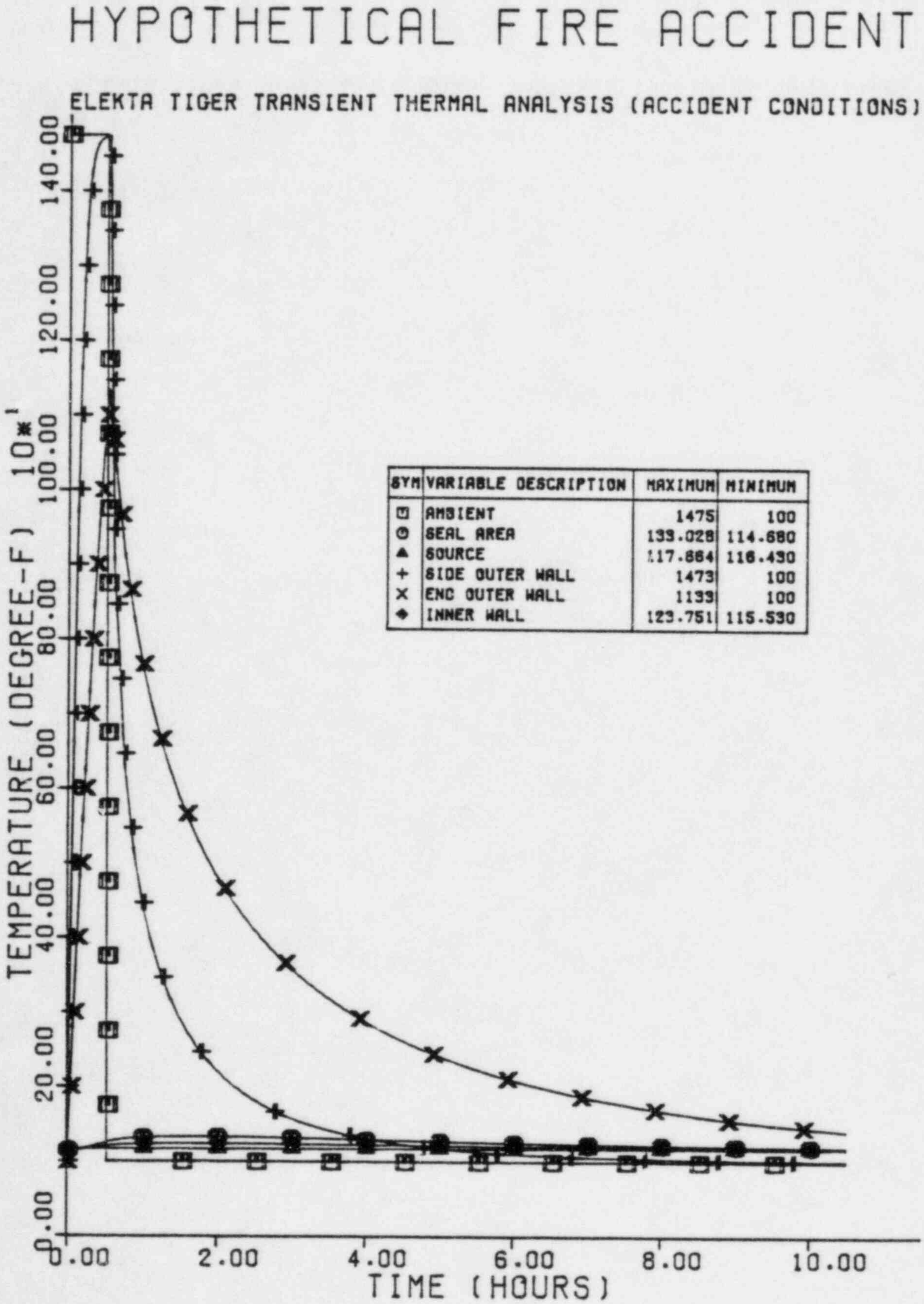
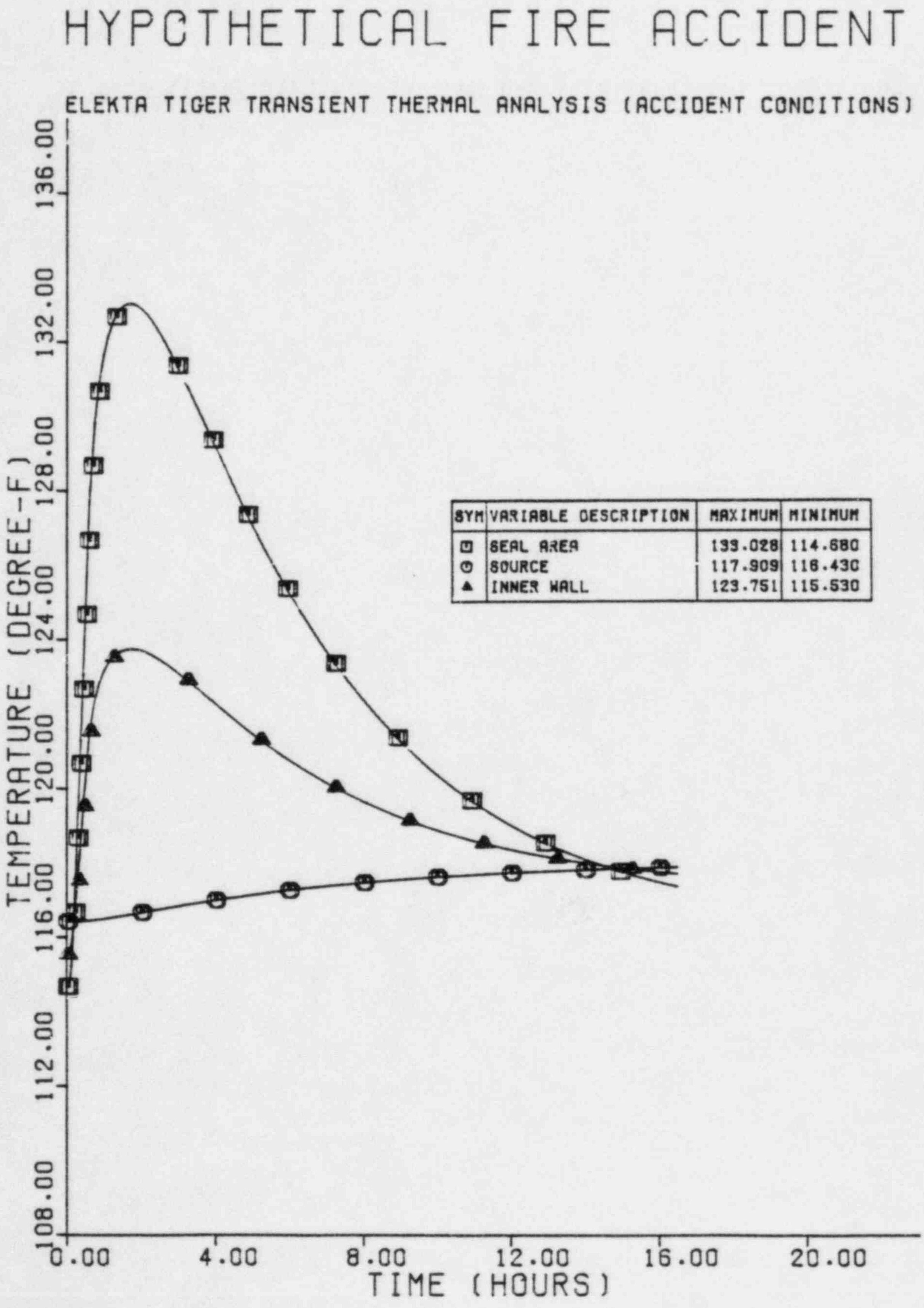

HYPOTHETICAL FIRE ACCIDENT
ELEKTA TIGER TRANSIENT THERMAL ANALYSIS (ACCIDENT CONDITIONS)
TEMPERATURE (DEGREE-F) 10*1
TIME (HOURS)
0.00
20.00
40.00
60.00
80.00
100.00
120.00
140.00
0.00
2.00
4.00
6.00
8.00
10.00
SYM VARIABLE DESCRIPTION MAXIMUM MINIMUM
AMBIENT 1475 100
SEAL AREA 133.028 114.680
SOURCE 117.864 116.430
SIDE OUTER WALL 1473 100
ENC OUTER WALL 1133 100
INNER WALL 123.751 115.530

FIGURE 3.5-2


HYPOTHETICAL FIRE ACCIDENT
ELEKTA TIGER TRANSIENT THERMAL ANALYSIS (ACCIDENT CONDITIONS)
TEMPERATURE (DEGREE-F)
108.00
112.00
116.00
120.00
124.00
128.00
132.00
136.00
TIME (HOURS)
0.00
4.00
8.00
12.00
16.00
20.00
SYM VARIABLE DESCRIPTION MAXIMUM MINIMUM
SEAL AREA 133.028 114.680
SOURCE 117.909 116.430
INNER WALL 123.751 115.530

3.6 References

3.6.1 Frank Kreith, Principles of Heat Transfer, 3rd Edition, IEP, Table A-1.

3.6.2 Kreith, Table 5-2.

3.6.3 Product brochure for 'LAST-A-FOAM', General Plastics Manufacturing Company, Tacoma, Washington.

3.6.4 Kreith, Table A-3.

3.6.5 Parker O-Ring Handbook, ORD 5700, 1982, pp. A3-A5.

3.6.6 Engineering Evaluation of the SUPER TIGER Overpack Designed for the Shipment of Large Quantities of Hazardous Materials, prepared by Mechanics Research, Inc., May 4, 1970.

3.7 Appendix

3.7.1 Details of Thermal Model

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

FINAL THERMAL ANALYSIS

PERFORM THE ELEKTA TIGER THERMAL ANALYSIS BASED UPON A QUARTER-SECTION MODEL.

CONDUCTION ELEMENTS: (NEGLECT 2 - 1/8" S-STEEL SHEETS)

CARBON STEEL[1] ⟹ $k = 26.0$ BTU/HR-FT-°F (R_{CS})

STAINLESS STEEL[1] ⟹ $k = 9.4$ BTU/HR-FT-°F (R_{SS})

7 PCF FOAM[2] ⟶ $k = 0.22$ BTU/HR-FT-°F/IN (R_{7F})

16 PCF FOAM[2] ⟶ $k = 0.33$ BTU/HR-FT-°F/IN (R_{16F})

$$R = \frac{L}{kA}$$ FOR AXIAL HEAT FLOW, HR-°F/BTU

ELEMENT ①: (NODES 2,4)

$$R_{SS} = \frac{40(12)}{(9.4)(25.5)(0.1875)} = 10.6800$$

$$R_{7F} = \frac{(33)(12)^2}{(0.22)(25.5)(7.5)} = 112.94$$

$$R_{16F} = \frac{7(12)^2}{(0.33)(25.5)(7.5)} = 15.97$$

$$R_1 = \frac{1}{\frac{1}{10.6800} + \frac{1}{112.94 + 15.97}} \quad ; \quad \underline{R_1 = 9.8629}$$

ELEMENT ②: (NODES 2,3)

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(26.67)(7.5)} = 166.89$$

$$R_2 = \frac{1}{\frac{1}{13.0196} + \frac{1}{166.89}} ; \quad \underline{\underline{R_2 = 12.0774}}$$

ELEMENT ③: (NODES 2, 8)

$$R_{7F} = \frac{15(12)^2}{(0.22)(26.67)(25.5)} = 14.4367 ; \quad \underline{\underline{R_3 = 14.4367}}$$

ELEMENT ④: (NODES 3, 5)

$$R_{SS} = \frac{40(12)}{(9.4)(25.5+34+5.5)(0.1875)} = 4.1899$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(25.5+34-11)(7.5)} = 59.38$$

$$R_{16F} = \frac{7(12)^2}{(0.33)(25.5+34-11)(5.5)} = 11.45$$

$$R_4 = \frac{1}{\frac{1}{4.1899} + \frac{1}{59.38+11.45}} ; \quad \underline{\underline{R_4 = 3.9559}}$$

ELEMENT ⑤: (NODES 3, 9)

$$R_{CS} = \frac{4(12)}{(26)(28)(0.50)} = 0.1319$$

$$R_{SS} = \frac{(11+11)(12)}{(9.4)(28)(0.375)} = 2.6748$$

$$R_{7F} = \frac{11(12)^2}{(0.22)(28)(34)} = 7.5630$$

$$R_5 = \frac{1}{\frac{1}{0.1319+2.6748} + \frac{1}{7.5630}} \quad ; \quad \underline{\underline{R_5 = 2.0470}}$$

<u>ELEMENT ⑥</u>: (NODES 3,14)

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(26.67)(5.5)} = 227.58$$

$$R_6 = \frac{1}{\frac{1}{13.0196} + \frac{1}{227.58}} \quad ; \quad \underline{\underline{R_6 = 12.3151}}$$

<u>ELEMENT ⑦</u>: (NODES 4,6)

$$R_{SS} = \frac{40(12)}{(9.4)(25.5)(0.1875)} = 10.6800$$

$$R_{16F} = \frac{40(12)^2}{(0.33)(25.5)(7.5)} = 91.27$$

$$R_7 = \frac{1}{\frac{1}{10.6800} + \frac{1}{91.27}} \quad ; \quad \underline{\underline{R_7 = 9.5611}}$$

<u>ELEMENT ⑧</u>: (NODES 4,5)

$$R_{CS} = \frac{51(12)}{(26)(7.5/\sin 45^\circ)(0.1875)} = 11.8359$$

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(6.33)(7.5)} = 703.14$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(20.33)(7.5)} = 145.95$$

$$R_8 = \frac{1}{\frac{1}{11.8359} + \frac{1}{13.0196} + \frac{1}{703.14} + \frac{1}{145.95}} \; ; \; \underline{R_8 = 5.8973}$$

<u>ELEMENT ⑨</u>: (NODES 4,10)

$$R_{CS} = \frac{(15/\sin 45^\circ)(12)}{(26)(25.5)(0.1875)} = 2.0477$$

$$R_{7F} = \frac{15(12)^2}{(0.22)(25.5)(6.33)} = 60.83$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(25.5)(20.33)} = 9.2592$$

$$R_9 = \frac{1}{\frac{1}{2.0477} + \frac{1}{60.83} + \frac{1}{9.2592}} \; ; \; \underline{R_9 = 1.6319}$$

<u>ELEMENT ⑩</u>: (NODES 5,7)

SEE PAGE 20 FOR R_{10} CALC'S; $\underline{R_{10} = 7.5684}$

<u>ELEMENT ⑪</u>: (NODES 5,17)

$$R_{CS} = \frac{51(12)}{(26)(5.5/\sin 45^\circ)(0.1875)} = 16.1398$$

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(6.33)(5.5)} = 958.83$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(20.33)(5.5)} = 199.03$$

$$R_{11} = \frac{1}{\frac{1}{16.1398} + \frac{1}{13.0196} + \frac{1}{958.83} + \frac{1}{199.03}} ; \quad \underline{\underline{R_{11} = 6.9045}}$$

ELEMENT (12): (NODES 5,11)

$$R_{CS} = \frac{(13/\sin 45°)(12)}{(26)(34+25.5-13)(0.1875)} = 0.9732$$

$$R_{SS} = \frac{(4+11+11)(12)}{(9.4)(26.67)(0.375)} = 3.3188$$

$$R_{7F} = \frac{13(12)^2}{(0.22)(34+25.5-13)(6.33)} = 28.9086$$

$$R_{16F} = \frac{13(12)^2}{(0.33)(34+25.5-13)(20.33)} = 6.0007$$

$$R_{12} = \frac{1}{\frac{1}{0.9732} + \frac{1}{3.3188} + \frac{1}{28.9086} + \frac{1}{6.0007}} ; \quad \underline{\underline{R_{12} = 0.6536}}$$

ELEMENT (13): (NODES 6,7)

$$R_{SS} \; \frac{51(12)}{(9.4)(26.67+25.5)(0.1875)} = 6.6558$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(26.67)(25.5)} = 32.723$$

$$R_{13} = \frac{1}{\frac{1}{6.6558} + \frac{1}{32.723}} ; \quad \underline{\underline{R_{13} = 5.5308}}$$

ELEMENT ⑭: (NODES 6,10)

$$R_{CS} = \frac{4(12)}{(26)(25.5)(0.50)} = 0.1448$$

$$R_{SS} = \frac{(36+11)(12)}{(9.4)(25.5)(0.375)} = 6.2745$$

$$R_{16F} = \frac{36(12)^2}{(0.33)(25.5)(30)} = 20.5344$$

$$R_{14} = \frac{1}{\frac{1}{0.1448+6.2745} + \frac{1}{20.5344}} \; ; \quad R_{14} = 4.8905$$

ELEMENT ⑮: (NODES 7,11)

$$R_{SS} = \frac{(36+11)(12)}{(9.4)(25.5)(0.375)} = 6.2745$$

$$R_{16F} = \frac{36(12)^2}{(0.33)(25.5)(22)} = 28.002$$

$$R_{15} = \frac{1}{\frac{1}{6.2745} + \frac{1}{28.002}} \; ; \quad R_{15} = 5.1259$$

ELEMENT ⑯: (NODES 7,19)

$$R_{SS} = \frac{51(12)}{(9.4)(20+25.5)(0.1875)} = 7.6315$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(20)(25.5)} = 43.64$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

$$R_{16} = \frac{1}{\frac{1}{7.6315} + \frac{1}{43.64}} \; ; \quad \underline{R_{16} = 6.4955}$$

ELEMENT ⑰: (NODES 8,10)

$$R_{CS} = \frac{44(12)}{(26)(20)(0.25)} = 4.0615$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(20)(7.5)} = 144.00$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(20)(7.5)} = 32.00$$

$$R_{17} = \frac{1}{\frac{1}{4.0615} + \frac{1}{144.00+32.00}} \; ; \quad \underline{R_{17} = 3.9699}$$

ELEMENT ⑱: (NODES 8,9)

$$R_{CS} = \frac{40(12)}{(26)(22)(0.25)} = 3.3566$$

$$R_{7F} = \frac{40(12)^2}{(0.22)(22)(7.5)} = 158.68$$

$$R_{18} = \frac{1}{\frac{1}{3.3566} + \frac{1}{158.68}} \; ; \quad \underline{R_{18} = 3.2871}$$

ELEMENT ⑲: (NODES 9,11)

$$R_{CS} = \frac{44(12)}{(26)(20)(0.25)} = 4.0615$$

$$R_{SS} = \frac{44(12)}{(9.4)(4+5.5)(0.375)} = 15.7671$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(20+5.5)(7.5)} = 112.94$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(20+5.5)(7.5)} = 25.10$$

$$R_{19} = \frac{1}{\frac{1}{4.0615} + \frac{1}{15.7671} + \frac{1}{112.94+25.10}}; \quad \underline{R_{19} = 2.7907}$$

<u>ELEMENT (20)</u>: (NODES 10, 11)

$$R_{CS_1} = \frac{40(12)}{(26)(15/\sin 45°)(0.1875)} = 4.6415$$

$$R_{CS_2} = \frac{40(12)}{(26)(19+4)(0.25)} = 3.2107$$

$$R_{CS} = \frac{1}{\frac{1}{4.6415} + \frac{1}{3.2107}} = 1.8979$$

$$R_{SS} = \frac{40(12)}{(9.4)[(17.33)(0.19)+(13)(0.375)]} = 5.1067$$

$$R_{7F} = \frac{40(12)^2}{(0.22)(6.33)(7.5)} = 551.49$$

$$R_{16F_1} = \frac{40(12)^2}{(0.33)(11+18)(7.5)} = 80.25$$

$$R_{16F_2} = \frac{40(12)^2}{(0.33)(19)(18)} = 51.04$$

$$R_{16F} = \frac{1}{\frac{1}{80.25} + \frac{1}{51.04}} = 31.20$$

$$R_{20} = \frac{1}{\frac{1}{1.8979} + \frac{1}{5.1067} + \frac{1}{551.49} + \frac{1}{31.20}} \; ; \quad R_{20} = 1.3217$$

ELEMENT (21): (NODES 9, 13)

$$R_{CS} = \frac{38(12)}{(26)(26.67)(0.25)} = 2.6304$$

$$R_{7F} = \frac{38(12)^2}{(0.22)(26.67)(5.5)} = 169.57$$

$$R_{21} = \frac{1}{\frac{1}{2.6304} + \frac{1}{169.57}} \; ; \quad R_{21} = 2.5902$$

ELEMENT (22): (NODES 11, 16)

$$R_{CS_1} = \frac{38(12)}{(26)(5.5/\sin 45°)(0.1875)} = 12.0258$$

$$R_{CS_2} = \frac{38(12)}{(26)(17.33+20)(0.75)} = 1.8793$$

$$R_{CS} = \frac{1}{\frac{1}{12.0258} + \frac{1}{1.8793}} = 1.6253$$

$$R_{7F} = \frac{38(12)^2}{(0.22)(6.33)(5.5)} = 714.43$$

$$R_{16F_1} = \frac{38(12)^2}{(0.33)(11)(5.5)} = 274.08$$

$$R_{16F_2} = \frac{38(12)^2}{(0.33)(18)(20+5.5)} = 36.126$$

$$R_{16F} = \frac{1}{\frac{1}{274.08} + \frac{1}{36.126}} = 31.92$$

$$R_{22} = \frac{1}{\frac{1}{1.6253} + \frac{1}{714.43} + \frac{1}{31.92}} ; \quad \underline{\underline{R_{22} = 1.5432}}$$

ELEMENT (23): (NODES 10,15)

$$R_{CS} = \frac{38(12)}{(26)(20)(0.25)} = 3.5077$$

$$R_{16F} = \frac{38(12)^2}{(0.33)(20)(18)} = 46.0608$$

$$R_{23} = \frac{1}{\frac{1}{3.5077} + \frac{1}{46.0608}} ; \quad \underline{\underline{R_{23} = 3.2595}}$$

ELEMENT (24): (NODES 13,14)

$$R_{7F} = \frac{11(12)^2}{(0.22)(34)(26.67)} = 7.9404 ; \quad \underline{\underline{R_{24} = 7.9404}}$$

ELEMENT (25): (NODES 13,16)

$$R_{CS} = \frac{44(12)}{(26)(34)(0.25)} = 2.3891$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(34)(5.5)} = 115.51$$

$$R_{25} = \frac{1}{\frac{1}{2.3891} + \frac{1}{115.51}} ; \quad \underline{\underline{R_{25} = 2.3407}}$$

ELEMENT (26): (NODES 13, 21)

IDENTICAL GEOMETRY TO R_{21}; $R_{26} = 2.5902$

ELEMENT (27): (NODES 14, 17)

$$R_{SS} = \frac{40(12)}{(9.4)(34)(0.1875)} = 8.0100$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(34)(5.5)} = 115.51$$

$$R_{16F} = \frac{7(12)^2}{(0.33)(34)(5.5)} = 16.33$$

$$R_{27} = \frac{1}{\frac{1}{8.0100} + \frac{1}{115.51 + 16.33}} \; ; \quad R_{27} = 7.5512$$

ELEMENT (28): (NODES 14, 25)

IDENTICAL GEOMETRY TO R_6; $R_{28} = 12.3151$

ELEMENT (29): (NODES 16, 17)

$$R_{CS} = \frac{(11/\sin 45°)(12)}{(26)(34)(0.1875)} = 1.1263$$

$$R_{7F} = \frac{11(12)^2}{(0.22)(34)(6.33)} = 33.45$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(11+18)(34)} = 4.86$$

$$R_{29} = \frac{1}{\frac{1}{1.1263} + \frac{1}{33.45} + \frac{1}{4.8634}} \; ; \quad R_{29} = 0.8903$$

ELEMENT (30): (NODES 15,16)

$$R_{cs} = \frac{40(12)}{(26)(34)(0.25)} = 2.1719$$

$$R_{16F} = \frac{40(12)^2}{(0.33)(34)(18)} = 28.52$$

$$R_{30} = \frac{1}{\frac{1}{2.1719} + \frac{1}{28.52}}; \quad \underline{R_{30} = 2.0182}$$

ELEMENT (31): (NODES 16,19)

$$R_{16F} = \frac{36(12)^2}{(0.33)(34)(5.5+20)} = 18.1188; \quad \underline{R_{31} = 18.1188}$$

ELEMENT (32): (NODES 16,23)

IDENTICAL GEOMETRY TO R_{22}; $\underline{R_{32} = 1.5432}$

ELEMENT (33): (NODES 17,19)

$$R_{ss} = \frac{40(12)}{(9.4)(34)(0.1875)} = 8.0100$$

$$R_{16F} = \frac{40(12)^2}{(0.33)(34)(5.5)} = 93.34$$

$$R_{33} = \frac{1}{\frac{1}{8.0100} + \frac{1}{93.34}}; \quad \underline{R_{33} = 7.3769}$$

ELEMENT (34): (NODES 17,27)

$$R_{cs} = \frac{51(12)}{(26)(5.5/\sin 45^\circ)(0.1875)} = 16.1398$$

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(6.33)(5.5)} = 958.83$$

$$R_{16F_1} = \frac{51(12)^2}{(0.33)(20.33)(5.5)} = 199.03$$

$$R_{16F_2} = \frac{51(12)^2}{(0.33)(20.33-11)(20)} = 119.26$$

$$R_{16F} = \frac{1}{\frac{1}{199.03} + \frac{1}{119.26}} = 74.58$$

$$R_{34} = \frac{1}{\frac{1}{16.1398} + \frac{1}{13.0196} + \frac{1}{958.83} + \frac{1}{74.58}} \; ; \quad \underline{\underline{R_{34} = 6.5266}}$$

ELEMENT (35): (NODES 18, 19)

$$R_{SS} = \frac{51(12)}{(9.4)(34)(0.1875)} = 10.2128$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(34)(18)} = 36.36$$

$$R_{35} = \frac{1}{\frac{1}{10.2128} + \frac{1}{36.36}} \; ; \quad \underline{\underline{R_{35} = 7.9734}}$$

ELEMENT (36): (NODES 19, 29)

IDENTICAL GEOMETRY TO R_{16} ; $\underline{\underline{R_{36} = 6.4955}}$

ELEMENT (37): (NODES 6, 18)

$$R_{SS} = \frac{51(12)}{(9.4)(25.5)(0.1875)} = 13.6170$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(25.5)(18.0)} = 48.48$$

$$R_{37} = \frac{1}{\frac{1}{13.6170} + \frac{1}{48.48}} \ ; \quad \underline{\underline{R_{37} = 10.6312}}$$

ELEMENT (38): (NODES 15, 18)

$$R_{16F} = \frac{36(12)^2}{(0.33)(20)(34)} = 23.1012 \ ; \quad \underline{\underline{R_{38} = 23.1012}}$$

ELEMENT (39): (NODES 18, 28)

IDENTICAL GEOMETRY TO R_{37} ; $\underline{\underline{R_{39} = 10.6312}}$

ELEMENT (40): (NODES 15, 22)

IDENTICAL GEOMETRY TO R_{23} ; $\underline{\underline{R_{40} = 3.2595}}$

ELEMENT (41): (NODES 20, 21)

$$R_{2S} = \frac{40(12)}{(26)(26.67)(0.25)} = 2.7689$$

$$R_{7F} = \frac{40(12)^2}{(0.72)(26.67)(5.5)} = 178.49$$

$$R_{41} = \frac{1}{\frac{1}{2.7689} + \frac{1}{178.49}} \ ; \quad \underline{\underline{R_{41} = 2.7266}}$$

ELEMENT (42): (NODES 20, 22)

$$R_{CS} = \frac{44(12)}{(26)(20)(0.25)} = 4.0615$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(20)(5.5)} = 196.36$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(20)(5.5)} = 43.64$$

$$R_{42} = \frac{1}{\frac{1}{4.0615} + \frac{1}{196.36 + 43.64}} \; ; \quad \underline{\underline{R_{42} = 3.9939}}$$

ELEMENT (43): (NODES 20, 24)

$$R_{7F} = \frac{11(12)^2}{(0.22)(20)(26.67)} = 13.4988 \; ; \quad \underline{\underline{R_{43} = 13.4988}}$$

ELEMENT (44): (NODES 21, 23)

$$R_{CS} = \frac{44(12)}{(26)(20+21)(0.25)} = 1.9812$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(20+21)(5.5)} = 95.79$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(20+21)(5.5)} = 21.29$$

$$R_{44} = \frac{1}{\frac{1}{1.9812} + \frac{1}{95.79 + 21.29}} \; ; \quad \underline{\underline{R_{44} = 1.9482}}$$

ELEMENT (45): (NODES 21, 25)

$$R_{7F_1} = \frac{11(12)^2}{(0.22)(20+11)(26.67)} = 8.7084$$

$$R_{7F_2} = \frac{11(12)^2}{(0.22)(34)(36.67)} = 5.7744$$

$$R_{7F} = \frac{1}{\frac{1}{8.7084} + \frac{1}{5.7744}} = 3.4721 \; ; \quad R_{45} = 3.4721$$

ELEMENT (46): (NODES 23, 27)

$$R_{CS} = \frac{(11/\sin 45°)(12)}{(26)(34+25.5-11)(0.1875)} = 0.7895$$

$$R_{7F} = \frac{11(12)^2}{(0.22)(34+25.5-11)(6.33)} = 23.453$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(34+25.5-11)(20.33)} = 4.8684$$

$$R_{46} = \frac{1}{\frac{1}{0.7895} + \frac{1}{23.453} + \frac{1}{4.8684}} \; ; \quad R_{46} = 0.6602$$

ELEMENT (47): (NODES 23, 29)

$$R_{16F} = \frac{36(12)^2}{(0.33)(25.5)(34)} = 18.1188 \; ; \quad R_{47} = 18.1188$$

ELEMENT (48): (NODES 22, 23)

$$R_{CS_1} = \frac{40(12)}{(26)(5.5/\sin 45)(0.1875)} = 12.6587$$

$$R_{CS_2} = \frac{40(12)}{(26)(22+21)(0.25)} = 1.7174$$

$$R_{CS} = \frac{1}{\frac{1}{12.6587} + \frac{1}{1.7174}} = 1.5122$$

$$R_{7F} = \frac{40(12)^2}{(0.22)(5.5)(6.33)} = 752.03$$

$$R_{16F_1} = \frac{40(12)^2}{(0.33)(5.5)(11+18)} = 109.433$$

$$R_{16F_2} = \frac{40(12)^2}{(0.33)(18)(21)} = 46.176$$

$$R_{16F} = \frac{1}{\frac{1}{109.433} + \frac{1}{46.176}} = 32.474$$

$$R_{48} = \frac{1}{\frac{1}{1.5122} + \frac{1}{752.03} + \frac{1}{32.474}}; \quad \underline{R_{48} = 1.4421}$$

<u>ELEMENT (49):</u> (NODES 22, 28)

$$R_{16F} = \frac{36(12)^2}{(0.33)(25.5)(21+11)} = 19.2516; \quad \underline{R_{49} = 19.2516}$$

<u>ELEMENT (50):</u> (NODES 22, 26)

$$R_{CS} = \frac{(11/\sin 45^\circ)(12)}{(26)(20)(0.1875)} = 1.9146$$

$$R_{7F} = \frac{11(12)^2}{(0.22)(20)(6.33)} = 56.87$$

$$R_{16F} = \frac{11(12)^2}{(0.33)(20)(20.33)} = 11.806$$

$$R_{50} = \frac{1}{\frac{1}{1.9146} + \frac{1}{56.87} + \frac{1}{11.806}} \; ; \qquad \underline{R_{50} = 1.6010}$$

ELEMENT (51): (NODES 24, 25)

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(26.67)(5.5)} = 227.58$$

$$R_{51} = \frac{1}{\frac{1}{13.0196} + \frac{1}{227.58}} \; ; \qquad \underline{R_{51} = 12.3151}$$

ELEMENT (52): (NODES 24, 26)

$$R_{SS} = \frac{40(12)}{(9.[illegible])(25.[illegible])(0.1875)} = 10.6800$$

$$R_{7F} = \frac{[illegible]3(12)^2}{(0.22)(25.5)([illegible]5)} = 154.01$$

$$R_{16F} = \frac{7(12)^2}{(0.33)(25.5)(5.[illegible])} = 21.78$$

$$R_{52} = \frac{1}{\frac{1}{10.6800} + \frac{1}{154.[illegible]} + \frac{1}{[illegible]1.7[illegible]}} \; ; \qquad \underline{R_{52} = 10.0683}$$

ELEMENT (53): (NODES 25, [illegible]7)

$$R_{SS} = \frac{40(12)}{(9.4)(25.5+34)(0.1875)} = 4.577[illegible]$$

$$R_{7F} = \frac{33(12)^2}{(0.22)(25.5+34-11)(5.5)} = 80.97$$

$$R_{16F} = \frac{7(12)^2}{(0.33)(25.5+34-11)(5.5)} = 11.45$$

$$R_{53} = \frac{1}{\frac{1}{4.5772} + \frac{1}{80.97 + 11.45}} ; \quad \underline{R_{53} = 4.3612}$$

ELEMENT (54): (NODES 27, 29)

$$R_{SS} = \frac{40(12)}{(9.4)(25.5+34)(0.1875)} = 4.5772$$

$$R_{16F} = \frac{40(12)^2}{(0.33)(25.5+34-11)(5.5)} = 65.43$$

$$R_{54} = \frac{1}{\frac{1}{4.5772} + \frac{1}{65.43}} ; \quad \underline{R_{54} = 4.2779}$$

ELEMENT (55): (NODES 28, 29)

$$R_{SS} = \frac{51(12)}{(9.4)(26.67+34)(0.1875)} = 5.7233$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(34)(13)} = 36.36$$

$$R_{55} = \frac{1}{\frac{1}{5.7233} + \frac{1}{36.36}} ; \quad \underline{R_{55} = 4.9450}$$

ELEMENT (56): (NODES 26, 28)

$$R_{SS} = \frac{40(12)}{(9.4)(25.5)(0.1875)} = 10.6800$$

$$R_{16F} = \frac{40(12)^2}{(0.33)(25.5)(5.5)} = 124.45$$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

$$R_{56} = \frac{1}{\frac{1}{10.6800} + \frac{1}{124.45}} ; \quad \underline{R_{56} = 9.8359}$$

ELEMENT (57): (NODES 26, 27)

$$R_{CS} = \frac{51(12)}{(26)(5.5/\sin 45°)(0.1875)} = 16.1398$$

$$R_{SS} = \frac{51(12)}{(9.4)(26.67)(0.1875)} = 13.0196$$

$$R_{7F} = \frac{51(12)^2}{(0.22)(6.33)(5.5)} = 958.83$$

$$R_{16F} = \frac{51(12)^2}{(0.33)(20.33)(5.5)} = 199.03$$

$$R_{57} = \frac{1}{\frac{1}{16.1398} + \frac{1}{13.0196} + \frac{1}{958.83} + \frac{1}{199.03}} ; \quad \underline{R_{57} = 6.9045}$$

ELEMENT 10:

$$R_{SS} = \frac{40(12)}{(9.4)(25.5 + 7.5)(0.1875)} = 8.2527$$

$$R_{16F} = \frac{40(12)^2}{(0.33)(25.5)(7.5)} = 91.27$$

$$R_{10} = \frac{1}{\frac{1}{8.2527} + \frac{1}{91.27}} ; \quad \underline{R_{10} = 7.5684}$$

① TABLE A-1, KREITH, PRINCIPLES OF HEAT TRANSFER, 3RD ED, IEP

② GENERAL PLASTICS DATA, 4/9/85

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

EXTERNAL RADIATION ELEMENTS: (NORMAL CONDITIONS)

$K = \sigma A \epsilon$ BTU/HR-°R⁴

WHERE:

$\sigma = 0.1714(10)^{-8}$ (BTU/HR-FT²-°R⁴)

A = SURFACE AREA (FT²)

ϵ = SURFACE EMISSIVITY = 0.5 FOR STAINLESS STEEL (KRIETH, TABLE 5-2, AVERAGE) — NORMAL CONDITIONS ONLY (SEE P21a FOR ACCIDENT COND)

ELEMENT (NODES)	SURFACE AREA (FT²)	K (BTU/HR-°R⁴)
58 (1,2)	$(25.5)(26.67)/(12)^2 = 4.7228$	$4.0475(10)^{-9}$
59 (1,3)	$(26.67)(25.5+34)/(12)^2 = 11.0199$	$9.4441(10)^{-9}$
60 (1,4)	$(25.5)(26.67)/(12)^2 = 4.7228$	$4.0475(10)^{-9}$
61 (1,5)	$(26.67)(25.5+34)/(12)^2 = 11.0199$	$9.4441(10)^{-9}$
62 (1,6)	$(25.5)(26.67+34)/(12)^2 = 10.7436$	$9.2073(10)^{-9}$
63 (1,7)	$[(25.5)(26.67)+(34)(25.5+26.67)]/(12)^2 = 17.0407$	$1.4604(10)^{-8}$
64 (1,14)	$(26.67)(34)/(12)^2 = 6.2971$	$5.3966(10)^{-9}$
65 (1,17)	$(26.67)(34)/(12)^2 = 6.2971$	$5.3966(10)^{-9}$
66 (1,18)	$(25.5)(34)/(12)^2 = 6.0208$	$5.1599(10)^{-9}$
67 (1,19)	$(34)(25.5+26.67) = 12.3179$	$1.0556(10)^{-8}$
68 (1,24)	$(25.5)(26.67)/(12)^2 = 4.7228$	$4.0475(10)^{-9}$
69 (1,25)	$(26.67)(25.5+34)/(12)^2 = 11.0199$	$9.4441(10)^{-9}$
70 (1,26)	$(25.5)(26.67)/(12)^2 = 4.7228$	$4.0475(10)^{-9}$
71 (1,27)	$(26.67)(25.5+34)/(12)^2 = 11.0199$	$9.4441(10)^{-9}$
72 (1,28)	$(25.5)(26.67+34)/(12)^2 = 10.7436$	$9.2073(10)^{-9}$
73 (1,29)	$[(25.5)(26.67)+(34)(25.5+26.67)]/(12)^2 = 17.0407$	$1.4604(10)^{-8}$

TOTAL AREA = 149.4723 FT²

EXTERNAL RADIATION ELEMENTS: (ACCIDENT CONDITIONS)

$$K = \sigma A \epsilon \quad BTU/HR\text{-}°R^4$$

WHERE:

$\sigma = 0.1714(10)^{-8}$ (BTU/HR-FT²-°R⁴)

A = SURFACE AREA (FT²)

ϵ = 0.8 PER 10 CFR 71.73

ELEMENT (NODES)	SURFACE AREA (FT²)	K (BTU/HR-°R⁴)
58 (1,2)	4.7228	$6.4759(10)^{-9}$
59 (1,3)	11.0199	$1.5110(10)^{-8}$
60 (1,4)	4.7228	$6.4759(10)^{-9}$
61 (1,5)	11.0199	$1.5110(10)^{-8}$
62 (1,6)	10.7436	$1.4732(10)^{-8}$
63 (1,7)	17.0407	$2.3366(10)^{-8}$
64 (1,14)	6.2971	$8.6346(10)^{-9}$
65 (1,17)	6.2971	$8.6346(10)^{-9}$
66 (1,18)	6.0208	$8.2557(10)^{-9}$
67 (1,19)	12.3179	$1.6890(10)^{-8}$
68 (1,24)	4.7228	$6.4759(10)^{-9}$
69 (1,25)	11.0199	$1.5110(10)^{-8}$
70 (1,26)	4.7228	$6.4759(10)^{-9}$
71 (1,27)	11.0199	$1.5110(10)^{-8}$
72 (1,28)	10.7436	$1.4732(10)^{-8}$
73 (1,29)	17.0407	$2.3366(10)^{-8}$

22-141 50 SHEETS
22-142 100 SHEETS
22-144 200 SHEETS

AREA CHECK: $A_T = [2(51)(80) + (51)(102) + (80)(102)]/(12)^2$

$= 149.4583 \text{ FT}^2$

INTERNAL RADIATION ELEMENTS:

FROM EQUATION 8-29, HOLMAN, HEAT TRANSFER, MCGRAW-HILL, 1963:

$$K = \frac{\sigma A_i}{\left(\frac{1}{\epsilon_i}-1\right) + \frac{1}{F_{ij}} + \frac{A_i}{A_j}\left(\frac{1}{\epsilon_j}-1\right)} \quad \text{BTU/HR-°R}^4$$

WHERE:

$\sigma = 0.1714(10)^{-8}$ BTU/HR-FT²-°R⁴

A_i = SURFACE AREA OF BODY i, FT²

A_j = SURFACE AREA OF BODY j, FT²

F_{ij} = 1.0 FOR A BODY COMPLETELY ENCLOSED INSIDE ANOTHER BODY (KRIETH, TABLE 5-3)

ϵ_i = EMISSIVITY OF BODY i

ϵ_j = EMISSIVITY OF BODY j

FOR PURPOSES OF THIS ANALYSIS, ASSUME THE LGS RADIATION UNIT IS A 64" DIAMETER SPHERE OF CAST IRON, SUSPENDED WITHIN THE INTERNAL CAVITY OF THE ELEKTA TIGER. LET BODY "i" BE THE INTERNAL CAVITY OF THE ELEKTA TIGER, AND BODY "j" BE THE RADIATION UNIT. ASSUME THE RATIO OF AREAS IS HELD CONSTANT.

SURFACE AREA OF A QUARTER SPHERE:

$$A_{T_j} = \frac{1}{4}\left[4\pi(32)^2\right] = 3{,}217 \text{ IN}^2$$

SURFACE AREA OF ONE-QUARTER THE INTERNAL CAVITY:

$$A_{T_i} = 2(40)(44) + 76(40+44) = 9{,}904 \text{ IN}^2$$

$$\frac{A_{T_i}}{A_{T_j}} = \frac{9{,}904}{3{,}217} = 3.07865$$

THE SURFACE EMISSIVITIES ARE: (KRIETH, TABLE 5-2)

$\epsilon_i = 0.66$ (OXIDIZED CAST IRON)

$\epsilon_j = 0.80$ (OXIDIZED STEEL TUBE)

ELEMENT (NODES)	SURFACE AREA, A_i (FT^2)	K (BTU/HR-°R⁴)
74 (12,8)	$(20)(22)/(12)^2 = 3.0556$	$2.2922(10)^{-9}$
75 (12,9)	$(22)(25.33+20)/(12)^2 = 6.9259$	$5.1956(10)^{-9}$
76 (12,10)	$(20)(25.33+22)/(12)^2 = 6.5736$	$4.9313(10)^{-9}$
77 (12,11)	$[(20)(22)+(25.33)(20+22)]/(12)^2 = 10.4444$	$7.8351(10)^{-9}$
78 (12,13)	$(22)(25.33)/(12)^2 = 3.8704$	$2.9034(10)^{-9}$
79 (12,15)	$(20)(25.33)/(12)^2 = 3.5185$	$2.6395(10)^{-9}$
80 (12,16)	$(25.33)(20+22)/(12)^2 = 7.3889$	$5.5429(10)^{-9}$
81 (12,20)	$(20)(22)/(12)^2 = 3.0556$	$2.2922(10)^{-9}$
82 (12,21)	$(22)(25.33+20)/(12)^2 = 6.9259$	$5.1956(10)^{-9}$
83 (12,22)	$(20)(25.33+22)/(12)^2 = 6.5736$	$4.9313(10)^{-9}$
84 (12,23)	$[(20)(22)+(25.33)(20+22)]/(12)^2 = 10.4444$	$7.8351(10)^{-9}$

CONVECTION ELEMENTS:

$$R = hA$$

WHERE, FROM HOLMAN, TABLE 7-4:

$h_V = 0.19(\Delta T)^{1/3}$ FOR VERTICAL PLATES, BTU/HR-FT²-°F

$h_H = 0.22(\Delta T)^{1/3}$ FOR HORIZONTAL PLATES, BTU/HR-FT²-°F

A = SURFACE AREA, FT²

ELEMENT (NODES)	$h_V A_V$ (BTU/HR-°F)	$h_H A_H$ (BTU/HR-°F)	hA (BTU/HR-°F)
85 (1,2)	—	(0.22)(4.7228)	1.0390
86 (1,3)	(0.19)(6.2971)	(0.22)(4.7228)	2.2355
87 (1,4)	—	(0.22)(4.7228)	1.0390
88 (1,5)	(0.19)(6.2971)	(0.22)(4.7228)	2.2355
89 (1,6)	(0.19)(6.0208)	(0.22)(4.7228)	2.1830
90 (1,7)	(0.19)(12.3179)	(0.22)(4.7228)	3.3794
91 (1,14)	(0.19)(6.2971)	—	1.1964
92 (1,17)	(0.19)(6.2971)	—	1.1964
93 (1,18)	(0.19)(6.0208)	—	1.1440
94 (1,19)	(0.19)(12.3179)	—	2.3404
95 (1,24)	—	(0.22)(4.7228)	1.0390
96 (1,25)	(0.19)(6.2971)	(0.22)(4.7228)	2.2355
97 (1,26)	—	(0.22)(4.7228)	1.0390
98 (1,27)	(0.19)(6.2971)	(0.22)(4.7228)	2.2355
99 (1,28)	(0.19)(6.0208)	(0.22)(4.7228)	2.1830
100 (1,29)	(0.19)(12.3179)	(0.22)(4.7228)	3.3794

AIR CONDUCTION: (k VARIES WITH TEMPERATURE, T)

FROM KREITH, TABLE A-3:

AIR TEMPERATURE, T (°F)	CONDUCTIVITY, k (BTU/HR-FT-°F)
0	0.0133
32	0.0140
100	0.0154
200	0.0174
300	0.0193
400	0.0212
500	0.0231
600	0.0250
700	0.0268
800	0.0286
900	0.0303
1,000	0.0319
1,500	0.0400
2,000	0.0471

$$R = \frac{L}{kA}$$ FOR AXIAL HEAT FLOW, HR-°F/BTU

FOR PURPOSES OF THIS ANALYSIS, ASSUME THE AVERAGE LENGTH AND AREA ARE UTILIZED.

AVERAGE AREA:

$$A_a = \frac{A_i + A_j}{2} = \frac{\left(\frac{A_i}{A_j} + 1\right)A_j}{2}$$

$$A_a = \frac{(3.07865 + 1)A_j}{2} = (0.49036)A_j$$

AVERAGE LENGTH:

$$L_a = \frac{(\text{MINIMUM LENGTH}) + (\text{MAXIMUM LENGTH})}{2}$$

ELEMENT (NODES)	A_a (FT²)	L_{MIN} (IN)	L_{MAX} (IN)	L_a (IN)	L_a/A_a (FT⁻¹)
101 (12,8)	1.4983	6.0000	16.2494	0.9271	0.6188
102 (12,9)	3.3962	9.9577	27.3970	1.5564	0.4583
103 (12,10)	3.2234	11.9090	29.4817	1.7246	0.5350
104 (12,11)	5.1215	15.3756	38.5691	2.2477	0.4389
105 (12,13)	1.8979	8.0000	15.3756	0.9740	0.5132
106 (12,15)	1.7253	10.0000	17.9644	1.1652	0.6754
107 (12,16)	3.6232	13.6508	23.7984	1.7687	0.4882
108 (12,20)	1.4983	6.0000	16.2494	0.9271	0.6188
109 (12,21)	3.3962	9.9577	27.3970	1.5564	0.4583
110 (12,22)	3.2234	11.9090	29.4817	1.7246	0.5350
111 (12,23)	5.1215	15.3756	38.5691	2.2477	0.4389

INTERNAL HEAT LOADING: (NODE 12 IS SOURCE)

FOR ONE-QUARTER SECTION:

$$q_{12} = \left(\frac{104 \text{ WATTS}}{4}\right)\left(3.412 \text{ BTU/HR-WATT}\right)$$

$$= 88.7 \text{ BTU/HR}$$

EXTERNAL HEAT LOADING:

NORMAL CONDITION - SOLAR LOADS PER 10 CFR 71.71(c)(1)
ASSUME THE SURFACE ABSORPTIVITY IS EQUIVALENT TO THE SURFACE EMISSIVITY, OR:

$$\alpha = \epsilon = 0.50$$

VERTICAL PLATES = 737 BTU/FT² PER 12 HOURS
= 61.42 BTU/HR-FT²

HORIZONTAL PLATES = 2,950 BTU/FT² PER 12 HOURS
= 245.83 BTU/HR-FT²

BASE PLATES = 0 BTU/FT² PER 12 HOURS

NODE	A_V (FT²)	q_V (BTU/HR)	A_H (FT²)	q_H (BTU/HR)	q_{TOTAL} (BTU/HR)
2	—	—	4.7228	580.5	580.5
3	6.2971	193.4	4.7228	580.5	773.9
4	—	—	4.7228	580.5	580.5
5	6.2971	193.4	4.7228	580.5	773.9
6	6.0208	184.9	4.7228	580.5	765.4
7	12.3179	378.3	4.7228	580.5	958.8
14	6.2971	193.4	—	—	193.4
17	6.2971	193.4	—	—	193.4
18	6.0208	184.9	—	—	184.9
19	12.3179	378.3	—	—	378.3
24	—	—	—	—	0
25	6.2971	193.4	—	—	193.4
26	—	—	—	—	0
27	629.71	193.4	—	—	193.4
28	6.0208	184.9	—	—	184.9
29	12.3179	378.3	—	—	378.3

THERMAL CAPACITANCES:

$$C = c_p \rho V \quad BTU/°F$$

WHERE, V, IS THE MATERIAL VOLUME IN CUBIC INCHES (IN^3).

MATERIAL	C_p (BTU/LB-°F)	ρ (LB/IN^3)
STAINLESS STEEL	0.11	0.2824
CARBON STEEL	0.11	0.2836
CAST IRON	0.11	0.2633
7 pcf FOAM	0.30	0.00405
16 pcf FOAM	0.30	0.00926

NODE 2:

$$C_{SS} = (0.2824)(0.4375)(25.5)(26.67)(0.11) = 9.2427$$

$$C_{7F} = (0.00405)(7.5)(25.5)(26.67)(0.30) = 6.1973$$

$$C_2 = 15.4400$$

NODE 3:

$$C_{SS} = (0.2824)(0.4375)(25.5+34.0+5.5)(26.67)(0.11) = 23.5598$$

$$C_{7F} = (0.00405)[(7.5)(25.5)(26.67) + (5.5)(34.0-7.5)(26.67)](0.30)$$

$$= 10.9202$$

$$C_3 = 34.4800$$

NODE 4:

$$C_{SS} = 9.2427 \text{ (SAME AS NODE 2)} - (0.2824)(0.25)(25.5)(20.33)(0.11)$$

$$= 5.2167$$

$$C_{CS} = (0.2836)(0.1875)(7.5/\sin 45°)(25.5)(0.11) = 1.5820$$

$C_{7F} = (0.00405)(7.5)(25.5)(6.33)(0.30) = 1.4709$

$C_{16F} = (0.00926)(7.5)(25.5)(20.33)(0.30) = 10.8012$

$\underline{C_4 = 19.0708}$

NODE 5:

$C_{SS} = 23.5598$ (SAME AS NODE 3) $- (0.2824)(0.25)(25.5+34)(20.33)(0.11)$
$= 14.1658$

$C_{CS} = (0.2836)[(0.1875)(7.5/\sin 45°)(25.5) + (0.1875)(5.5/\sin 45°)(34.0-7.5)](0.11) = 2.7877$

$C_{7F} = (0.00405)[(7.5)(25.5)(6.33)+(5.5)(34.0-7.5)(6.33)](0.30)$
$= 2.5919$

$C_{16F} = (0.00926)[(7.5)(25.5)(20.33)+(5.5)(34.0-7.5)(20.33)](0.30)$
$= 19.0327$

$\underline{C_5 = 38.5780}$

NODE 6:

$C_{SS} = (0.2824)[(3)(0.1875)(25.5)(26.67)+(0.4375)(25.5)(34)](0.11)$
$= 23.6664$

$C_{16F} = (0.00926)(25.5)(26.67)(34)(0.30) = 64.2354$

$\underline{C_6 = 87.9018}$

NODE 7:

$C_{SS} = 23.6664$ (SAME AS NODE 6) $+ (0.2824)(0.1875)(26.67)(34)(0.11)$
$= 28.9480$

$C_{16F} = 64.2354$ (SAME AS NODE 6)

$\underline{\underline{C_7 = 93.1834}}$

NODE 8:

$$C_{CS} = (0.2836)(0.25)(20.0)(26.67)(0.11) = 4.1600$$

$$C_{7F} = (0.00405)(7.5)(20)(26.67)(0.30) = 4.8606$$

$\underline{\underline{C_8 = 9.0206}}$

NODE 9:

$$C_{SS} = (0.2824)(0.375)(5.5)(26.67)(0.11) = 1.7087$$

$$C_{CS} = (0.2836)(0.25)(26.67)(20 + 25.33 + 4)(0.11) = 10.2606$$

$$C_{7F} = (0.00405)\left[(7.5)(26.67)(20) + (5.5)(26.67)(25.33 + 7.5)\right](0.30)$$
$$= 10.7116$$

$\underline{\underline{C_9 = 22.6809}}$

NODE 10:

$$C_{SS} = (0.2824)(0.375)(20)(36 - 26.67)(0.11) = 2.1737$$

$$C_{CS} = (0.2836)\left[(0.25)(20)(25.33 + 17.33 + 4) + (0.1875)(20)(7.5/\sin 45^\circ)\right](0.11) = 8.5188$$

$$C_{7F} = (0.00405)(7.5)(20)(6.33)(0.30) = 1.1536$$

$$C_{16F} = (0.00926)\left[(7.5)(20)(11) + (36 - 26.67)(20)(25.33 + 7.5)\right](0.30)$$
$$= 21.6019$$

$\underline{\underline{C_{10} = 33.4480}}$

IMAGE EVALUATION
TEST TARGET (MT-3)

150mm

6"

IMAGE EVALUATION TEST TARGET (MT-3)

150mm

6″

NODE 11:

$$C_{SS} = (0.2824)(0.375)\left[(17.33)(5.5) + (36-26.67)(20+5.5)\right](0.11)$$
$$= 3.8818$$

$$C_{CS} = (0.2836)\left\{(0.1875)\left[(7.5/\sin 45°)(20) + (5.5/\sin 45°)(25.33+7.5)\right] + (0.25)\left[(20)(26.67) + (25.33+4+4)(20+17.33)\right]\right\}(0.11)$$
$$= 16.5980$$

$$C_{7F} = (0.00405)\left[(7.5)(6.33)(20) + (5.5)(6.33)(25.33+7.5)\right](0.30)$$
$$= 2.5424$$

$$C_{16F} = (0.00926)\left[(7.5)(11)(20) + (5.5)(11)(25.33+7.5) + (25.33+7.5)(20+5.5)(36-26.67)\right](0.30)$$
$$= 31.7997$$

$$\underline{\underline{C_{11} = 54.8219}}$$

NODE 12:

TOTAL PAYLOAD ASSEMBLY WEIGHT = 41,000 LBS

$C_{12} = (41,000)(0.11) = 4,510$ $\underline{\underline{C_{12} = 4,510.00}}$

NODE 13:

$$C_{CS} = (0.2836)(0.25)(25.33)(22)(0.11) = 4.3461$$

$$C_{7F} = (0.00405)(5.5)(25.33)(22)(0.30) = 3.7239$$

$$\underline{\underline{C_{13} = 8.0700}}$$

NODE 14:

$$C_{SS} = (0.2824)(0.4375)(34)(26.67)(0.11) = 12.3236$$

$C_{7F} = (0.00405)(5.5)(34)(26.67)(0.30) = 6.0596$

$\underline{C_{14} = 18.3832}$

NODE 15:

$C_{cs} = (0.2836)(0.25)(20)(25.33)(0.11) = 3.9510$

$C_{16F} = (0.00926)(18)(20)(25.33)(0.30) = 25.3320$

$\underline{C_{15} = 29.2830}$

NODE 16:

$C_{cs} = (0.2836)\big[(0.25)(25.33)(17.33+20) + (0.1875)(5.5/\sin 45^\circ)(25.33)\big](0.11) = 8.5269$

$C_{7F} = (0.00405)(5.5)(6.33)(25.33)(0.30) = 1.0715$

$C_{16F} = (0.00926)\big[(5.5)(11)(25.33) + (18)(20+5.5)(25.33)\big](0.30) = 36.5555$

$\underline{C_{16} = 46.1539}$

NODE 17:

$C_{ss} = (0.2824)\big[(0.4375)(6.33)(25.33) + (0.1875)(20.33)(25.33)\big](0.11) = 5.1785$

$C_{cs} = (0.2836)(0.1875)(5.5/\sin 45^\circ)(25.33)(0.11) = 1.1524$

$C_{7F} = (0.00405)(5.5)(6.33)(25.33)(0.30) = 1.0715$

$C_{16F} = (0.00926)(5.5)(20.33)(25.33)(0.30) = 7.8681$

$\underline{C_{17} = 15.2704}$

NODE 18:

$C_{SS} = (0.2824)(0.4375)(25.5)(34)(0.11) = 11.7830$

$C_{16F} = (0.00926)(18)(25.5)(34)(0.30) = 43.3535$

$\underline{\underline{C_{18} = 55.1364}}$

NODE 19:

$C_{SS} = (0.2824)[(0.4375)(25.5)(34) + (0.1875)(26.67)(34)](0.11)$
$= 17.0638$

$C_{16F} = (0.00926)(25.5)(34)(26.67)(0.30) = 64.2354$

$\underline{\underline{C_{19} = 81.2992}}$

NODE 20:

$C_{CS} = (0.2836)(0.25)(26.67)(20)(0.11) = 4.1600$

$C_{7F} = (0.00405)(5.5)(26.67)(20)(0.30) = 3.5644$

$\underline{\underline{C_{20} = 7.7244}}$

NODE 21:

$C_{CS} = (0.2836)(0.25)(26.67)(25.33 + 20)(0.11) = 9.4286$

$C_{7F} = (0.00405)(5.5)(26.67)(20 + 25.33 - 5.5)(0.30) = 7.0986$

$\underline{\underline{C_{21} = 16.5272}}$

NODE 22:

$$C_{CS} = (0.2836)(20)\left[(0.25)(44-26.67+25.33) + (0.1875)(5.5/\sin 45^\circ)\right](0.11) = 7.5640$$

$$C_{7F} = (0.00405)(20)(6.33)(5.5)(0.30) = 0.8460$$

$$C_{16F} = (0.00926)(20)\left[(5.5)(11) + (5.5+25.33)(18)\right](0.30) = 34.1938$$

$$\underline{\underline{C_{22} = 42.6039}}$$

NODE 23:

$$C_{CS} = (0.2836)\left\{(0.25)\left[(25.33)(20+17.33) + (20)(17.33)\right] + (0.1875)(20+5.5)(5.5/\sin 45^\circ)\right\}(0.11) = 11.2378$$

$$C_{7F} = (0.00405)(6.33)(5.5)(20+25.33-5.5)(0.30) = 1.6848$$

$$C_{16F} = (0.00926)\left[(5.5)(20+25.33-5.5)(11+18) + (18)(20)(25.5)\right](0.30) = 43.1504$$

$$\underline{\underline{C_{23} = 56.0730}}$$

NODE 24:

$$C_{SS} = (0.2824)(0.4375)(25.5)(26.67)(0.11) = 9.2427$$

$$C_{7F} = (0.00405)(5.5)(25.5)(26.67)(0.30) = 4.5447$$

$$\underline{\underline{C_{24} = 13.7874}}$$

NODE 25:

$$C_{SS} = (0.2824)(0.4375)(25.5+34)(26.67)(0.11) = 21.5663$$

$$C_{7F} = (0.00405)(5.5)(25.5+34-5.5)(26.67)(0.30) = 9.624$$

$$C_{25} = 31.1903$$

NODE 26:

$$C_{SS} = (0.2824)(25.5)\left[(0.4375)(6.33) + (0.1875)(20.33)\right](0.11) = 5.2132$$

$$C_{CS} = (0.2836)(0.1875)(5.5/\sin 45°)(25.5)(0.11) = 1.1602$$

$$C_{7F} = (0.00405)(5.5)(25.5+34-5.5)(6.33)(0.30) = 2.2842$$

$$C_{16F} = (0.00926)(5.5)(20.33)(25.5)(0.30) = 7.9209$$

$$C_{26} = 16.5785$$

NODE 27:

$$C_{SS} = (0.2824)(25.5+34)\left[(0.4375)(6.33)+(0.1875)(20.33)\right](0.11) = 12.1642$$

$$C_{CS} = (0.2836)(0.1875)(5.5/\sin 45°)(25.5+34-5.5)(0.11) = 2.4568$$

$$C_{7F} = (0.00405)(5.5)(6.33)(25.5+34-5.5)(0.30) = 2.2842$$

$$C_{16F} = (0.00926)(5.5)(20.33)(25.5+34-5.5)(0.30) = 16.7736$$

$$C_{27} = 33.6788$$

NODE 28:

$$C_{SS} = (0.2824)(25.5)[(0.1875)(26.67) + (0.4375)(34)](0.11)$$
$$= 15.7441$$

$$C_{16F} = (0.00926)(25.5)[(5.5)(26.67) + (18)(34-5.5)](0.30)$$
$$= 46.7314$$

$$C_{28} = 62.4755$$

NODE 29:

$$C_{SS} = (0.2824)[(0.1875)(26.67)(25.5+34) + (0.4375)(25.5)(34)](0.11) = 21.0257$$

$$C_{16F} = (0.00926)[(5.5)(26.67)(25.5+34-5.5) + (18)(25.5)(34)](0.30) = 65.3580$$

$$C_{29} = 86.3836$$

4.0 CONTAINMENT

This section describes the containment configuration of the ELEKTA TIGER Package.

4.1 Containment Boundary

4.1.1 Containment Vessel

The ELEKTA TIGER packaging does not provide a containment boundary for the package payload. The only containment boundaries associated with the ELEKTA TIGER Package are the stainless steel boundaries provided with each of the 201 special form sources.

4.1.2 Containment Penetrations

There are no containment penetrations into the doubly encapsulated special form sources.

4.1.3 Seals and Welds

There are no seals associated with the special form sources. Welded closures are used for each stainless steel boundary.

4.1.4 Closure

There are no closure devices used on the special form sources. Closure is maintained via welds, per Section 4.1.3, above.

4.2 Requirements for Normal Conditions of Transport

4.2.1 Release of Radioactive Materials

The special form sources are designed to assure no release of radioactive material in excess of limits prescribed in NRC Regulatory Guide 7.4, Leakage Tests on Packages for the Shipment of Radioactive Materials, under Normal Conditions of Transport.

4.2.2 Pressurization of the Containment Vessel

The special form sources are designed to comply with the requirements of 10 CFR 71.75 and 10 CFR 71.77.

4.2.3 Coolant Contamination

This section is not applicable as no coolants are used in the ELEKTA TIGER Package.

4.2.4 Coolant Loss

This section is not applicable as no coolants are used in the ELEKTA TIGER Package.

4.3 Containment Requirements for the Hypothetical Accident Conditions

4.3.1 Fission Gas Products

This section is not applicable as no fission gas products are associated with the ELEKTA TIGER Package.

4.3.2 Release of Contents

The special form sources are designed to assure no release of radioactive material in excess of limits prescribed in NRC Regulatory Guide 7.4, Leakage Tests on Packages for the Shipment of Radioactive Materials, under Hypothetical Accident Conditions.

5.0 SHIELDING EVALUATION

Adequate shielding is provided in the LGS radiation unit itself, without consideration of the ELEKTA TIGER packaging, to maintain external radiation dose rates below the limits set forth in 10 CFR 71.47 and 49 CFR 173.441. Assurance that these limits will be met is provided by requiring radiation monitering of the package prior to shipment per Section 7.0. The remainder of this section presents an evaluation of expected dose rates associated with the ELEKTA TIGER Package.

5.1 Discussion and Results

Primary shielding for the 201, 33 curie maximum (6,600 maximum total curies), Cobalt-60 sources is provided by a monolithic assemblage of cast iron. Each of the sources is highly collimated resulting in mostly scattered radiation at any point surrounding the unit.

Normal and hypothetical accident condition shielding requirements for the package are determined by the following criteria:

Normal Condition: maximum dose rates of 200 millirem per hour at any point in contact with the package, and 10 millirem per hour at any point two (2) meters from the package are the requirements of 10 CFR 71.47(a) and (c), respectively, and 49 CFR 173.441(2) and (3), respectively, for design-basis normal conditions.

Accident Condition: a maximum dose rate of 1000 millirem per hour at any point one (1) meter from the package is the requirement of 10 CFR 71.51(a)(2) for design-basis accident conditions.

The shielding design for the package is governed by normal conditions as no permanent deformation of the LGS radiation unit is expected per the results of the analyses presented in Sections 2.6 and 2.7.

Radiation dose rates for the Model 23016, LGS radiation unit are determined at various locations one (1) meter from the curvilinear surface defined by the location of the source capsules, with the door in the closed position, by comparison using measured dose rates from an earlier model (Model Karolinska H.). Illustrations of the Model 23016, LGS radiation unit with the door in the open and closed positions are provided in Figures 5.1-1 and 5.1-2, respectively.

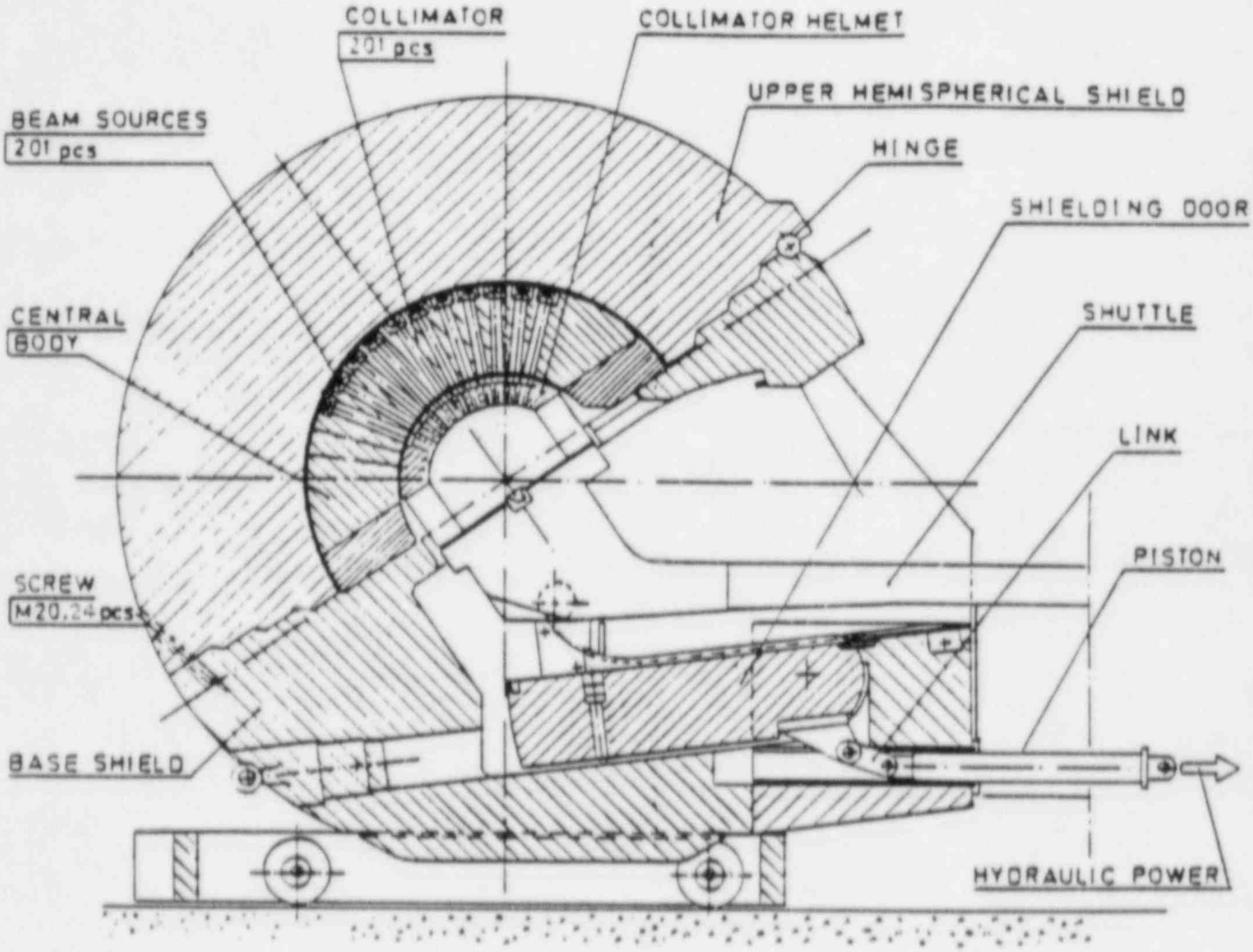
The new Model 23016, LGS radiation unit is designed to carry a higher curie loading than that of the Model Karolinska H. Therefore, additional cast iron shielding of varying thicknesses was added in different locations to reduce the gamma transmission to surrounding bodies. At each of the locations referenced, the amount of additional shielding in the current Model 23016 unit, as compared to the earlier Model Karolinska H. unit, is provided in Table 5.1-1. Additionally, the activity of the new loaded unit at Karolinska Hospital, Model Karolinska H., was approximately 5,500 curies of Cobalt-60, compared to a maximum of 6,600 curies for the Model 23016.

The measured dose readings for the Model Karolinska H. were taken 119 months after initial loading. The following calculations consider the decay of Cobalt-60 over the 119 month time period from initial loading.

Radiation dose rates at the surface of the ELEKTA TIGER packaging, and two meters from the package surface, are estimated by applying a square inverse of the ratioed distance ($d^2_{estimated}/d^2_{measured}$) to the measured dose rate. This results in a maximum dose of 11.1 mR/hr at the surface and 1.02 mR/hr at two meters.

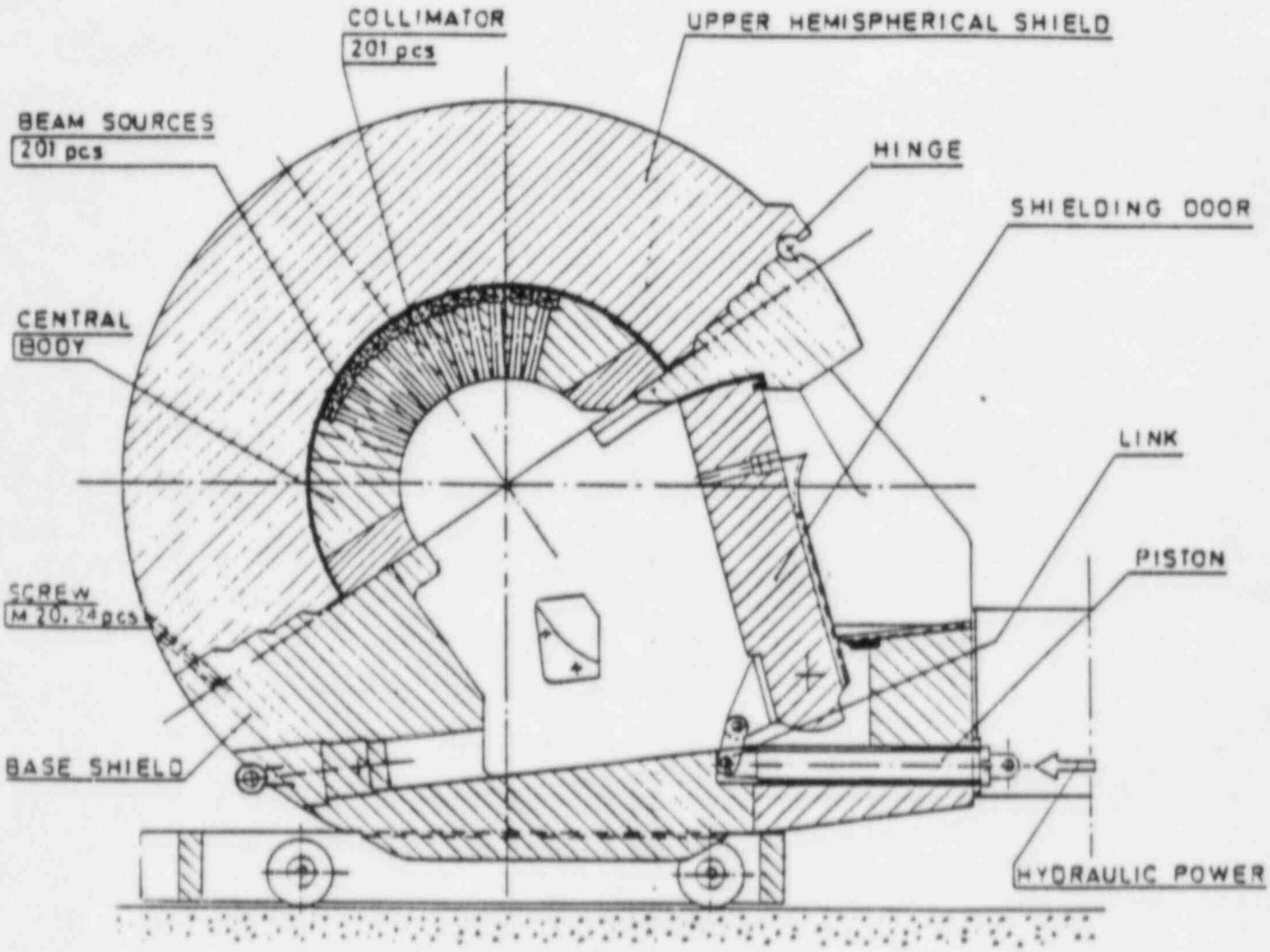
With reference to Table 5.1-1, the 'Measurement Location' is a location one meter from the surface of the Model Karolinska H. unit, in the orientation as illustrated in Figure 5.1-3. The 'Karolinska H. Dose Rate Reading' is the dose rate at one meter from the surface, as previously discussed. The 'Load and Time Corrected Dose Rate Reading' is the dose rate one meter from the Model Karolinska H. unit after being corrected from 5,500 curies to 6,600 curies of Cobalt-60 and taking into account the decay for dose rate readings

FIGURE 5.1-1
Model 23016, LGS Radiation Unit
(door in open position, operation)



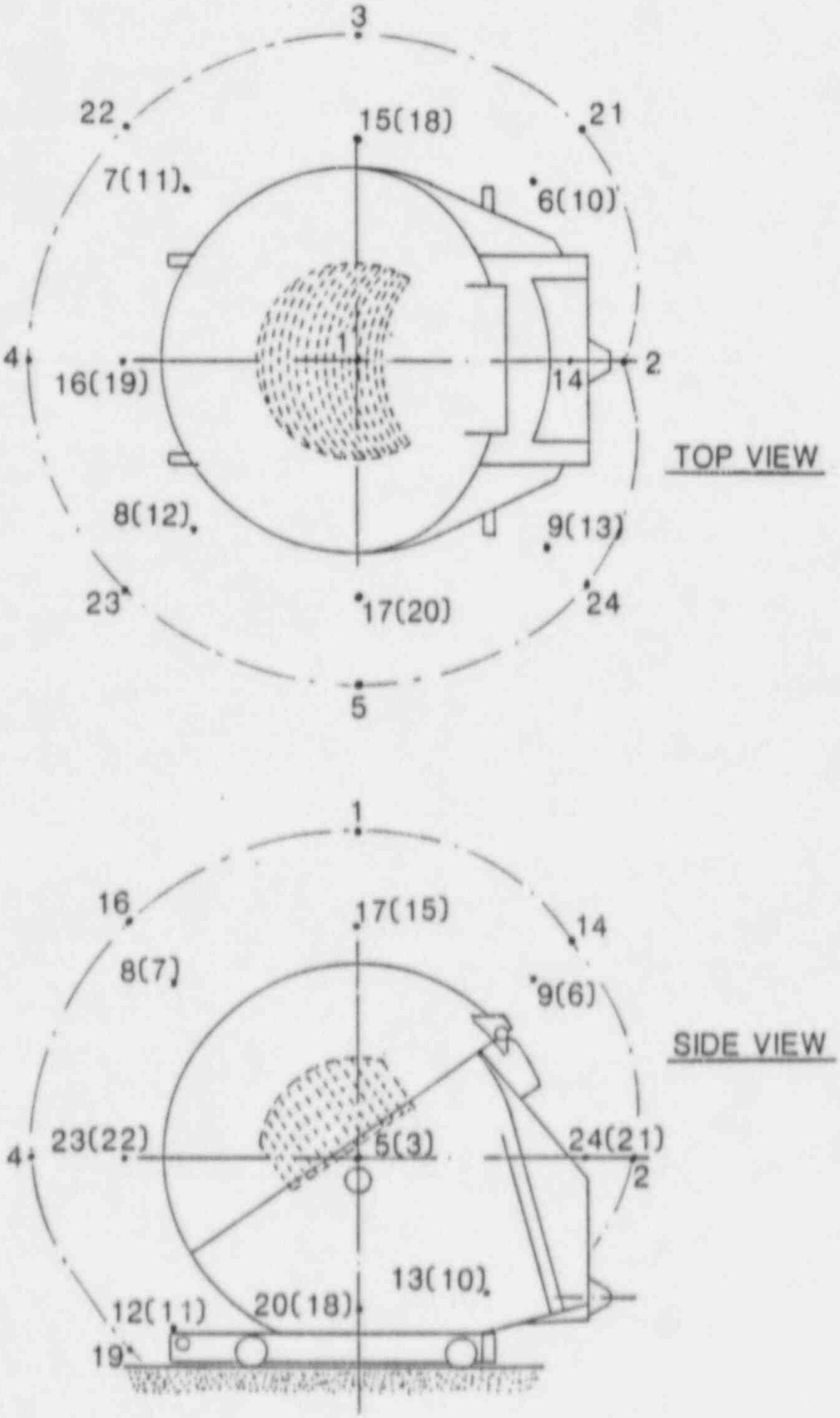
LEKSELL GAMMA UNIT
CROSS SECTION
OPEN POSITION

FIGURE 5.1-2
Model 23016, LGS Radiation Unit
(door in closed position, transport)



LEKSELL GAMMA UNIT
CROSS SECTION
CLOSED POSITION

FIGURE 5.1-3
Model Karolinska H.
(Measurement Locations)



LEKSELL GAMMA UNIT, 23016
Measurement points NCRP 33

TABLE 5.1-1

Summary of Dose Rates

Measurement Location (Figure 5.1-3)	Karolinska H. Dose Rate Reading [1 meter] (mR/hr)	Load and Time Corrected Dose Rate Reading (mR/hr)	Model 23016 Additional Shielding (cm)	Model 23016 Expected Dose Rate [1 meter] (mR/hr)
1	1.6	7.1	3.0	2.5
2	6.5	29.0	3.5	8.4
3	1.0	4.5	3.0	1.6
4	1.5	6.7	3.0	2.3
5	1.0	4.5	3.0	1.6
6	0.8	3.6	3.0	1.2
7	1.3	5.8	3.0	2.0
8	1.3	5.8	3.0	2.0
9	0.8	3.6	3.0	1.2
10	3.0	13.4	8.0	0.8
11	0.8	3.6	3.0	1.2
12	0.8	3.6	3.0	1.2
13	3.0	13.4	8.0	0.8
14	0.7	3.1	3.0	1.1
15	1.4	6.2	3.0	2.2
16	1.4	6.2	3.0	2.2
17	1.4	6.2	3.0	2.2
18	0.6	2.7	4.0	0.7
19	0.6	2.7	3.0	0.9
20	0.6	2.7	4.0	0.7
21	0.6	2.7	5.0	0.5
22	1.5	6.7	3.0	2.3
23	1.5	6.7	3.0	2.3
24	0.6	2.7	5.0	0.5

taken 119 months after initial loading. The 'Model 23016 Additional Shielding' is the additional cast iron shielding thickness of the Model 23016 compared to the Model Karolinska H. for each measurement location. The 'Model 23016 Expected Dose Rate' summarizes the effects of the previous two entries.

5.2 Source Specification

Radiation is emitted via 201, Special Form sources, each containing a maximum of 33 curies of Cobalt-60, a pure gamma emitter, with a half-life of 5.26 years. The total maximum activity within the package is 6,600 curies. There are no sources of neutron emission from within the package.

5.3 Model Specification

Radiation attenuation by the Model 23016, LGS radiation unit is determined by comparison, using actual measurements taken from a similar, but earlier model, Model Karolinska H. Measurement locations are presented in Figure 5.1-3.

5.3.1 Description of the Radial and Axial Shielding Configuration

A complete description of the Model 23016, LGS radiation unit is provided in Section 1.2.3.1. As stated earlier, the entire unit is constructed of cast iron (with exception of the door which is constructed of cast steel).

5.3.2 Shield Regional Densities

In order to more accurately determine the expected radiation dose rate at one (1) meter from the surface of the Model 23016, LGS radiation unit, an attenuation experiment was performed on a 'mock-up' sample of the unit. An experimental setup simulating an exact copy of one of the 201 channels in the LGS radiation unit was built to produce a Cobalt-60 beam 14 millimeters in diameter. A sample shield, 30 millimeters thick, of the same 7.3 g/cm^3 cast-

iron was utilized for determining the gamma ray attenuation. The charge (nano-Couloumbs) induced in a small semiconductor placed at the center of the beam was collected, both with and without the cast-iron sample shield. The result of three experiments is presented below:

Experiment 1: without shield - 5.447 nC
(2 minutes) with shield - 1.895 nC
transmission = 1.895/5.447 = 0.3479

Experiment 2: without shield - 13.556 nC
(5 minutes) with shield - 4.747 nC
transmission = 4.747/13.556 = 0.3502

Experiment 3: without shield - 5.382 nC
(2 minutes) with shield - 1.845 nC
transmission = 1.845/5.382 = 0.3428

Average transmission = (0.3479 + 0.3502 + 0.3428)/3 = 0.3470

Therefore, the attenuation coefficient may be determined as follows:

$$T = e^{-\mu t}$$

Where:

T = transmission = 0.347

μ = attenuation coefficient, cm^{-1}

t = shield thickness = 30 mm = 3.0 cm

Then,

$$\mu = -(\ln T)/t = -(\ln 0.347)/3.0 = 0.35285$$

Therefore, for additional cast iron shield thicknesses of 3.5, 4.0, 5.0, and 8.0 centimeters, the transmissions are:

Thickness (cm)	Transmission
3.0	0.347
3.5	0.291
4.0	0.244
5.0	0.171
8.0	0.060

The above transmissions, reflecting the additional cast iron shielding provided on the Model 23016 as compared to the Model Karolinska H., are utilized to adjust the corrected dose rate reading, presented in Table 5.1-1, to the expected dose rate.

5.4 Shielding Evaluation

To determine the radiation dose rates one (1) meter from the Model 23016, LGS radiation unit, a dose rate correction factor was determined by accounting for the 119 month decay time of the Cobalt-60 (5.26 year half-life) used within the Model Karolinska H. unit. The dose rate correction factor, ξ, including the difference in source strengths between the two models (6,600 versus 5,500 curies), is determined from the following expression:

$$\xi = (6{,}600/5{,}500)e^{-(\ln 0.5)[119/12(5.26)]} = 4.4332$$

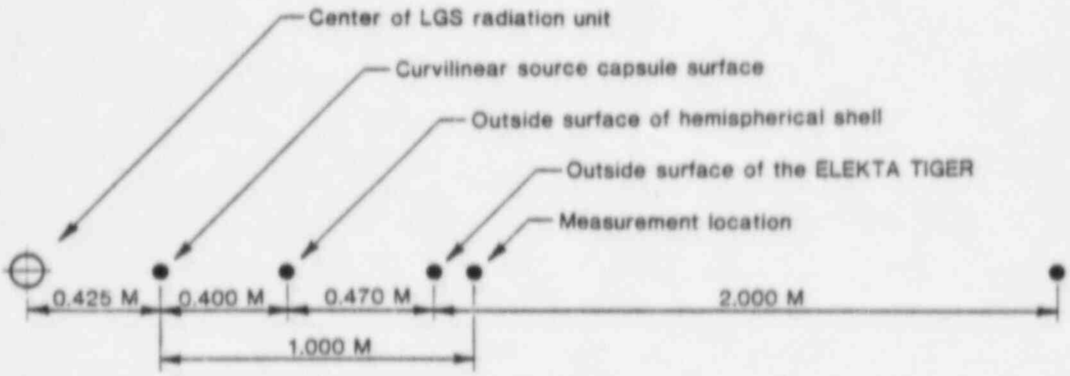
Utilizing the above relationships, the radiation dose rate values presented in Table 5.1-1 may be determined. For example, for measurement location 1, the measured dose rate is 1.6 mR/hr. If the Model Karolinska H. were initially loaded with 6,600 total curies of Cobalt-60, the corrected dose rate at measurement location 1 would be:

$$D = (1.6)(4.4332) = 7.1 \text{ mR/hr}$$

Finally, the expected dose rate from the Model 23016, LGS radiation unit is reduced to 0.347 the corrected value by accounting for the additional 3.0 centimeters of cast iron shielding, or:

$$D = (7.1)(0.347) = 2.5 \text{ mR/hr}$$

As presented in Table 5.1-1, the maximum expected dose of 8.4 mR/hr occurs at measurement location 2, one meter from the curvilinear surface formed by the 201 Cobalt-60 sources. The LGS radiation unit surface is a minimum of 0.47 meters inside the outside surface of the ELEKTA TIGER and the outer radius of the Model 23016 LGS radiation unit is 0.825 meters, as illustrated below. Conservatively ignore the attenuation properties of the steel and polyurethane foam comprising the wall of the ELEKTA TIGER packaging.



The dose rate at the surface of the ELEKTA TIGER packaging is:

$$D_{surface} = (8.4)(1.0)^2/(0.40 + 0.47)^2 = 11.1 \text{ mR/hr}$$

Similarly, the dose rate at two (2) meters from the ELEKTA TIGER surface is:

$$D_{2\ meters} = (8.4)(1.0)^2/(0.40 + 0.47 + 2.0)^2 = 1.02 \text{ mR/hr}$$

In summary, the radiation dose rates determined are well below the limits established in 10 CFR 71 and 49 CFR 173.

6.0 CRITICALITY EVALUATION

As the ELEKTA TIGER Package contains no fissile material, this section does not apply.

7.0 OPERATING PROCEDURES

7.1 Procedures for Loading the Package

Figures 1.2.3-1 and 1.2.3-2 presented in Section 1.2.3 show the LGS radiation unit prepared for shipping (i.e., sources loaded, but without the operating table and control panel).

7.1.1 The shield door restraint mechanism is installed via two M42-3.0 bolts tightened to 350-500 ft-lbs torque each.

7.1.2 Install the prepared LGS radiation unit within the support dunnage. The support dunnage must meet the requirements delineated in Section 1.2.3.2.

7.1.3 Remove the lid from the ELEKTA TIGER Package.

7.1.4 Install the LGS radiation unit/support dunnage assembly within the ELEKTA TIGER. Shim/shore as specified in Section 1.2.3.2.

7.1.5 Replace the ELEKTA TIGER lid, tightening the 30, 1 1/2 - 6 UNC bolts to 350-500 ft-lbs each.

7.1.6 Radiation monitor the ELEKTA TIGER Package per the requirements of 49 CFR 173.441 and determine that surface contamination levels meet the requirements of 49 CFR 173.443.

7.1.7 Install the tamper-indicating devices for the lid and the drain.

7.1.8 Load the ELEKTA TIGER Package onto the transport vehicle and secure using appropriate tiedown devices (see Section 2.5.2).

7.1.9 Install the required labels and placards.

7.1.10 Complete all necessary shipping papers as required.

7.2 Procedures for Unloading the Package

Upon receipt of the package, radiation monitor per the requirements of 10 CFR 20.205. Unloading the ELEKTA TIGER package is the reverse sequence of loading, discussed in Section 7.1.

7.3 Preparation of an Empty Package for Transport

Previously used, empty packages are handled per the requirements of 49 CFR 173.427.

8.0 ACCEPTANCE TEST AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

This section discusses the tests to be performed prior to first use of the ELEKTA TIGER packaging.

8.1.1 Visual Inspection

Visually inspect the ELEKTA TIGER packaging per the requirements delineated on the General Arrangement Drawing, Section 1.3.

8.1.2 Structural and Pressure Tests

Perform all structural tests per the requirements delineated on the General Arrangement Drawing, Section 1.3. No pressure testing is required on the ELEKTA TIGER packaging.

8.1.3 Leak Tests

Since the weather seal is not considered to be a level of containment, leak testing is not required on the ELEKTA TIGER packaging.

8.1.4 Component Tests

All component testing is performed as described in Sections 8.1.2 and 8.1.3, above.

8.1.5 Tests for Shielding Integrity

The primary shielding of the LGS radiation unit is cast iron in four very large sections: (1) the upper hemispherical shield, (2) the lower base section and treatment cavity, (3) the central body which contains the sources and beam channels, and (4) the shielding door. Due to the heavy thickness and size of these sections, there is no inspection technique available that can provide complete assurance against internal voids. However, testing of the shielding will be done by surveying the unit at the hot cell after the Cobalt-60 sources are loaded. This survey will be done in accordance with the procedures recommended in Section 4.2.2(1) of NCRP Report No. 33. Any unit which does not meet the leakage radiation limits recommended by NCRP 33, i.e., 2 mR/hr average at one meter and 10 mR/hr maximum at one meter, will not be shipped from the hot cell until the leakage radiation is reduced to specification limits by repair or reloading or until such discrepancies are determined to be acceptable. In all cases, the radiation dose limits shall not exceed the requirements of 10 CFR 71.47.

8.1.6 Thermal Acceptance Tests

Material properties established in Section 3.0 are consistently conservative for the analyses performed. As such, acceptance tests for material thermal properties are not performed.

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the packaging.

8.2.1 Structural and Pressure Tests

Other than the tests required prior to first use, no structural or pressure tests are necessary to ensure continued performance of the packaging.

8.2.2 Leak Tests

Since the weather seal is not considered to be a level of containment, leak testing is not required on the ELEKTA TIGER packaging.

8.2.3 Subsystems Maintenance

This section describes the inspection and replacement schedule for packaging subsystems.

8.2.3.1 Fasteners

All threaded parts utilized within the ELEKTA TIGER packaging shall be inspected annually and prior to each use for deformed or stripped threads. Any damaged parts shall be replaced prior to further use.

8.2.3.2 Gaskets

All gaskets (i.e., the weather seal) shall be inspected annually and prior to each use for damage. Replace any damaged gaskets prior to further use.

8.2.3.3 Painted Surfaces

A. Painted surfaces may be wiped clean using standard chemical solutions and procedures.

B. Chipped or scratched surfaces shall be repaired by removing the rust and/or loose coatings and sanding the edges so they fair into the sound coating. Apply two coats of Mobil Chem '78 Series' or suitable equivalent to the surface, following the manufacturer's recommendations.

8.2.4 Valves, Rupture Discs, and Gaskets on the Containment Vessel

Since none of these components are utilized within the ELEKTA TIGER packaging, this section does not apply.

8.2.5 Shielding

Other than the tests required prior to first use, prior to shipment, and on receipt of the packaging, no shielding tests are necessary to ensure continued performance of the ELEKTA TIGER package.

8.2.6 Thermal

No thermal tests are necessary to ensure the continued performance of the ELEKTA TIGER package.

9.0 QUALITY ASSURANCE

The ELEKTA TIGER packaging has been designed and will be fabricated by Nuclear Packaging, Inc., (NuPac) Federal Way, Washington. The Quality Assurance Program used for the design, fabrication, assembly, testing, use and maintenance of the ELEKTA TIGER packaging satisfies the eighteen (18) criteria of 10 CFR 71, Suopart H in its entirity. NuPac's Quality Assurance Program meeting these criteria has been submitted to the United States Nuclear Regulatory Commission and has been awarded Approval Number 0192, Revision 1.

In addition, the QA program and the implementation of it during the design and fabrication phases will adhere to NuReg CR-3854, Category III requirements.

A synopsis of the Pacific Nuclear Systems, Inc./Nuclear Packaging, Inc. Quality Assurance Program follows:

9.1 Introduction

Pacific Nuclear Systems, Inc. (PNSI) has developed a quality program to (1) assure traceability, and (2) control the quality of all materials and processes utilized in the production of radioactive shielding, casks, containers, and other equipment pertaining to shipping packages for irradiated fuel, high level waste, and plutonium.

A Quality Manual delineates requirements and procedures necessary to exercise control over design, documentation, procurement, material, fabrication, inspection, operational testing, equipment operation and use, maintenance, repair, modification, inventory, shipment and quality data retention.

The PNSI Quality Program is implemented by Quality Procedures which are designed and administered to meet the 18 criteria of 10 CFR 71, Subpart H. The Quality Program is implemented throughout the company and its subsidiaries. The Subsidiaries include: Pacific Nuclear Systems, Inc., Nuclear Packaging, Inc., NuPac Leasing, Inc., and Pacific Nuclear Systems and Services, Inc.

9.2 Description of the PNSI, 10 CFR 71, Subpart H Quality Program

9.2.1 Organization

Full responsibility for the Quality Assurance (QA) Program adherence to 10 CFR 71, Subpart H criteria rests with PNSI. Quality Program activities include calibration of measuring equipment, non-destructive examination (NDE), and materials testing. PNSI surveys and qualifies all organizations performing these services to assure adherence to the 18 criteria prior to their use. All other quality activities are performed by PNSI quality personnel. However, the responsibility of the control of quality in the other organizations continues to rest with PNSI.

PNSI's President has full authority over all functions of the company, and delegates authority and responsibility for selected functions to other personnel within the company.

The administrative function includes financial, legal, and marketing activities.

Procurement department personnel perform purchasing activities and maintain supplier performance records. The Engineering Department is responsible for research and development of shipping container technology, design of casks for licensing and fabrication, and design documentation.

The PNSI Quality Department has sufficient authority and organizational freedom to identify quality programs, implement corrective action, and verify corrective action effectiveness.

Additionally, the Quality Department is independent from other organizations within PNSI and reports directly to the President of PNSI. The Quality Department is headed by the Corporate Quality Director who is responsible for the development, implementation, and administration of the entire PNSI Quality Program. He must have sufficient expertise in the entire field of Quality to enable him to direct the entire quality function in close adherence to the 18

criteria of 10 CFR 71 and the PNSI Quality Manual. Responsibility for development of quality acceptance requirements, inspections, and NDE activities rests with the Corporate Quality Director. It is his responsibility to delegate and evaluate the performance of all quality related tasks for PNSI through the authority of the president.

It is delineated in writing through the Corporate Quality Director that designated QA personnel have the authority to prevent the continued processing, fabrication, installation, or delivery of unsatisfactory work.

This authority also extends to the quality monitoring of special processes utilizing PNSI equipment, personnel and procedures such as waste processing, in-service inspections, etc.

Production responsibilities include scheduling or in-service inspection and administration of all fabrication activities, both within PNSI and at qualified suppliers. The shipping and receiving function is also the responsibility of the Production Department.

On-site activities such as waste processing, in-service inspections, etc. are administered as a joint effort of the operations and engineering personnel. Quality supports these activities with written procedures that provide methods, process controls and check points. Inspection personnel perform monitoring activities and verifications of regulatory, contractual, and technical requirements during these operations.

The Corporate Quality Director and all other quality personnel and/or organizations within, or utilized by PNSI, are fully qualified for their quality responsibilities. Qualification records are maintained in the PNSI Quality Record File.

9.2.2 Quality Assurance Program

PNSI has established and implemented a QA Program for the control of quality in the design, fabrication, operation, and maintenance of shipping containers for nuclear products. Training and/or evaluation of personnel qualifications are required for all QA functions in accordance with written procedures and are approved by the Quality Manager. The QA Program assures that all quality requirements, engineering specifications, and specific provisions of any package design approval are met. Those characteristics critical to safety are emphasized.

The President of PNSI regularly evaluates the PNSI QA program for adherence to the 18 criteria in scope, implementation, and effectiveness. Further, the President requires that the Quality System, including the QA Manual Policies and Procedures, be implemented and enforced on all applicable programs at PNSI.

A Material Review Board, consisting of Engineering, Procurement Production, and Quality Personnel has been established to resolve all discrepancies or disagreements pertaining to the acceptability of material, hardware, or safety related operations. Their dispositions are final and binding.

9.2.3 Design Control

PNSI Quality Procedures (QP's) have been developed, approved, and implemented to control design review in such a manner to assure that the following occur:

9.2.3.1 Design activity is planned, controlled, and documented.

9.2.3.2 Regulatory and design requirements are correctly translated into specification, drawings, and procedures.

9.2.3.3 Design documents contain quality requirements.

9.2.3.4 Deviations from quality requirements are controlled.

9.2.3.5 Design verification is performed by Quality Assurance personnel independent of the design activity. These verifications may include tolerance studies, alternate calculations or tests. Qualification tests are conducted in accordance with approved test programs and procedures

9.2.3.6 Interface control is established and adequate.

9.2.3.7 Design and specification changes are reviewed and approved by the same organization(s) as the original issue.

9.2.3.8 Design errors and deficiencies are documented and corrective action is taken to prevent recurrence.

9.2.3.9 Design organization(s) and their responsibilities and authorities are delineated and controlled via written procedure.

9.2.4 Procurement Document Control

The PNSI QA Program assures that all purchased material, components, equipment, and services adhere to design specifications.

Supplier evaluation and selection, objective evidence of supplier quality, assignment of quality requirements to procurement documents and related design documents, and source, in-process, and receiving inspections are all administered and controlled in accordance with approved PNSI QA procedures.

All procurement activity is performed in accordance with written procedures delineating requirements for preparation, review, approval, and control of procurement documentation. Particular emphasis is placed on assuring that revisions to procurement documentation are reviewed and approved by the same cognizant groups as the original.

Quality Assurance clause sheets are included with all request for quotes and purchase orders. Quality Assurance personnel assign clauses from the sheets to the procurement document referencing 10 CFR 71, Subpart H requirements appropriate to the contract. In addition, material information including grade, type, size, and special physical or chemical data requirements is included on the procurement documents. Other documentation and information such as drawings, procedures, inspection and test requirements, hold points, welding and other process qualification requirements are delineated on the procurement documents by the Quality Assurance personnel as appropriate to the contract.

Quality Assurance personnel assure that requirements for acceptance of hardware and documentation appropriate to the contract are included in procurement documentation.

PNSI Quality Assurance personnel maintain the right of access to all supplier facilities and documentation for source inspection and/or audit activities. A statement to this effect is included on procurement documentation when it is appropriate to the contract.

9.2.5 Instruction, Procedures and Drawings

Quality planning is developed by qualified Quality Engineers (QE's) for all activities requiring quality participation in accordance with approved PNSI QA procedures and is approved by the Corporate Quality Director.

All design documents (i.e., drawings, specifications, special processes, etc.) affecting quality are reviewed by the Quality Department and referenced in quality planning as necessary to assure adherence to package design approvals and the applicable criteria of 10 CFR 71, Subpart H.

All instructions, procedures, and drawings are developed, reviewed, approved, utilized, and controlled in accordance with the requirements of written quality assurance procedures.

9.2.6 Document Control

Policy and procedure for review, approval, release and change control of all controlled, quality related documents are delineated in approved PNSI QA Procedures. Provisions are provided in the QA Procedures for identification of individuals/organizations responsible for review, approval, and issuance of documents. Document control responsibilities, facilities, and distribution requirements are also addressed.

Controlled documents include, but are not limited to:

(a) Design specifications
(b) Design manufacturing drawings
(c) Special process specifications and procedures
(d) Procurement documents
(e) QA Procedures and manuals
(f) Quality Planning for receiving, in-process, source and in-service inspections
(g) Source surveillance and evaluation reports
(h) Test procedures
(i) Audit reports
(j) Operational test procedures and data.

When revised documents appear in other documents as references, supplements, or exhibits, appropriate revisions are made to those documents prior to the release of the basic approved change.

Documentation listings are maintained delineating the title, number and current revision for all drawings, procedures, specifications, and purchase orders.

The Quality Personnel assure that all required support documentation is available at the work area prior to the initiation of the work effort.

9.2.7 Control of Purchased Materials, Parts and Components

Procurement documents are reviewed for acceptability of suggested suppliers based on the PNSI approved supplier lists.

In addition, and as required, supplier surveys are conducted by qualified PNSI personnel to further assure supplier acceptability. These evaluations are based on one or all of the following criteria:

(a) The supplier's capability to comply with the requirements of 10 CFR 71, Subpart H, that are applicable to the contract.

(b) A review of previous records and performance of the supplier.

(c) A survey of the supplier's facilities and QA program to determine his capability to supply a product which meets the design, manufacturing, and quality requirements.

Results of all supplier evaluations are recorded on Supplier Evaluation forms and are retained in the Quality Data File.

Quality requirements and standard clauses are added to procurement documents to require suppliers to identify material, provide test reports, control special processes, certify equipment and personnel, etc. As a minimum, requirements are imposed on suppliers to identify materials, specific codes, specifications and/or design not adhered to during fabrication. Justifications for 'accept-as is' or 'repair' dispositions are also required to be sumitted to the Material Review Board for review and acceptance.

Quality planning is prepared and approved by the Quality Department for performance of all source, test, shipping and/or receiving inspections in accordance with approved design requirements, applicable 10 CFR 71 criteria, procurement document requirements, and contract specifications.

Receiving inspection is performed to determine that the following, as appropriate to the contract, are assured:

(a) The material, component, or equipment is properly identified and corresponds with the identification on receiving documentation.

(b) Material, components, equipment, and acceptance records are inspected and are acceptable in accordance with inspection instructions, prior to installation or use.

(c) Inspection records and/or certificates of conformance attesting to the acceptance of material and components are available prior to installation or use.

(d) Items accepted and released are identified as to their inspection status prior to forwarding them to a controlled storage area or releasing them for further work.

All described activities are delineated in approved PNSI QA procedures.

9.2.8 Identification and Control of Materials, Parts, and Components

The identification and control of materials, parts, components, and completed and in-process assemblies is administered by the Quality Department in accordance with approved PNSI QA Procedures. These procedures address quality status tags, maintenance of material identification and traceability, part identification, and related documentation. Some of the details of these procedures follow:

(a) Material identification procedures included in inspection planning and fabrication drawings require that identification of material, components, and/or hardware be maintained on the item or in traceable records to prevent use of incorrect or defective items.

(b) When appropriate, due to contractual or safety related concerns requiring specific identification and Material Review Board action, Quality Assurance personnel assure that identification of materials, components, specifications, procurement documentations, manufacturing, and inspection records, discrepancy reports, and material test data is provided and is complete.

(c) Quality Assurance personnel assure, via drawings and inspection planning requirements, that identification locations do not affect the fit-up, interfacing capability, performance or overall quality of the finished product. Identification, in accordance with drawings and inspection planning requirements, is verified prior to releasing the item for further processing or delivery.

9.2.9 Control of Special Processes

PNSI approved QA Procedures delineate the policies and procedures established to control such special processes as: welding, heat treating, lead pouring, non-destructive examination, waste processing, etc. in accordance with applicable codes, standards, specifications, 10 CFR 71 criteria, and other requirements. Special processes developed by PNSI suppliers and by PNSI are documented.

All procedures for special processes and the personnel required to perform them are qualified under the cognizance of the Quality Department in accordance with applicable codes, standards, specifications, and contract requirements.

All qualification records and support data are retained in the Quality Data file, and are maintained in a current status by Quality Assurance personnel.

These documents are controlled as delineated in Section 9.2.6 of this Quality System description.

9.2.10 Inspection

All receiving, source, in-process, and in-service inspection activities are performed in accordance with approved PNSI QA procedures. All inspection personnel and/or organization qualifications are reviewed and accepted by the Quality Manager prior to inspection activity. The inspection activity is performed in strict accordance with approved quality planning prepared by qualified QA personnel (See also Section 9.2.5 discussion).

Quality Inspection personnel are independent from all other organizations within PNSI and report directly to the Corporate Quality Director or the Subsidiary Quality Manager.

Inspection personnel qualifications are based on their capability to perform the required inspection functions in accordance with applicable codes, standards, professional society programs such as the ASQC quality technician certification, and PNSI training programs. Qualification reviews are performed periodically to maintain personnel proficiency and assure current qualification.

Mandatory hold points, inspection equipment requirements, accept reject criteria, personnel requirements, characteristics to inspect, variable/attributes recording instructions, reference documentation, and other requirements are included in the inspection planning.

The Quality Assurance department assures that any replacements, modifications, or repairs performed after final acceptance of material, components or hardware are inspected in accordance with the original inspection planning or new planning prepared as appropriate.

9.2.11 Test Control

A test control program, as it applies to quality, is addressed in approved PNSI QA Procedures and assures, via required planning, that all required testing, such as proof and acceptance tests, are identified and performed in

accordance with test procedures, design requirements, and limitations. Prerequisites, accept/reject criteria, data recording criteria, instrumentation calibration, environmental conditions, documentation and evaluation requirements, etc. are delineated in the test procedures. Changes to the test procedures are required to be reviewed/approved by the same organization(s) as the original issue.

Whenever equipment, components, and/or assemblies require modification, repairs, or replacement which could result in requirements for re-test or additional testing, Quality Assurance personnel assure, as appropriate, that original or new test inspection planning is prepared and adhered to.

In any case, test results are documented, evaluated, and accepted by qualified personnel as required by the test inspection plan prepared for the test under the cognizance of Quality Assurance personnel.

9.2.12 Control of Measuring and Testing Equipment

Administration of the calibration of measuring equipment and instrumentation is performed by the Quality Department in accordance with approved PNSI QA Procedures. The calibration system assures that all standard measuring instruments (SMI) used in the acceptance of material, equipment, and assemblies are calibrated and properly adjusted at specified intervals to maintain accuracy within pre-determined limits. Calibration is performed using equipment traceable to national standards. All calibrated equipment is identified and is traceable to the calibration test data.

Whenever SMI are found to be out of calibration during or immediately after use, all items inspected during that period are rejected by inspection and are submitted to review action for possible re-inspection or other appropriate corrective action.

9.2.13 Handling, Storage, and Shipping

PNSI approved QA Procedures require that handling, storage, and shipping requirements adherence verification criteria be included in quality planning. These requirements are designed to prevent damage or deterioration of material and equipment. Information pertaining to shelf life, environment, packaging, temperature, cleaning, handling, preservation, etc., is included as required to meet design, NRC package approval and/or U.S. Department of Transportation shipping requirements.

Shipping documentation preparation, departure and arrival time, and destination data recording are also addressed in the planning, when applicable. Shipping requirements in quality planning must be met prior to release for shipment.

9.2.14 Inspection, Test and Operating Status

The use of inspection status tags, quality inspection stamps, and other means to indicate inspection and test status at, or for, PNSI are delineated in approved PNSI QA Procedures.

The clarity of the status indication, prevention of inspection, and/or test step by-passing, and prohibition of removal or modification of status indications, except with Quality Department approval/Material Review disposition, is assured via these procedures. The Quality Assurance Department assures via Quality Procedure, interoffice memoranda, training sessions, and audit that all PNSI personnel are aware of and understand the meaning and uses of status tags on all hardware, material, and test set-ups (see also Section 9.2.15 discussion).

9.2.15 Non-conforming Material, Parts, or Components

PNSI approved QA Procedures require that material, components, and equipment that do not conform to requirements are controlled to prevent their inadvertent use. Identification, segregation, discrepancy reporting, disposition of non-conformances by authorized individuals, and re-inspection activities are performed and controlled in strict accordance with these procedures.

Quality Discrepancy Reports (QDR) are utilized by the PNSI quality department to identify discrepant items, describe the discrepancy, and provide disposition and re-inspection requirements. The signatures of authorized cognizant personnel are placed on the QDR to signify approval of the disposition. These personnel must be approved by the Corporate Quality Director and President and must be from the same groups approving the original design. In conjunction with repair or re-work dispositions, quality assurance personnel provide supplemental inspection planning to verify proper implementation of the QDR disposition. This assures that the item is re-tested and/or re-inspected to a degree at least equal to the original acceptance activity.

9.2.16 Corrective Action

Failures, malfunctions, and deficiencies in material, components, equipment, and services are identified and reported to the Corporate Quality Director and the President. The cause of the condition and corrective action necessary to prevent recurrence is identified, implemented and then followed up to verify corrective action effectiveness. All reporting requirements of applicable contractual and regulatory specifications and regulations are adhered to as part of any corrective action activity. Detail requirements for this activity are delineated in approved PNSI QA Procedures.

9.2.17 Quality Assurance Records

A quality records system is in effect at PNSI and is administered in accordance with approved PNSI QA procedures. The purpose of the quality record system is to assure that documented evidence pertaining to quality related activities is maintained and available for use by PNSI, its customers, and/or regulatory agencies as applicable. Quality Records include, but are not limited to, inspection and test records, audit reports, quality personnel qualifications, design reviews, quality related procurement data, supplier evaluation reports, etc. All records are identified by work order number, part number, contract number, or drawing number as appropriate to the record type. A complete list of all quality records is maintained and provides cross reference between the different identity methods described above and pinpoints the record location.

Design related records such as calculations, drawings, research and development test reports, etc., are retained in the Quality Assurance records system for the life of the shipping package. All other quality related records are retained for the life of the shipping package in accordance with 10 CFR 71.91(c) unless otherwise specified in related contractual or regulatory requirements.

Inspection records retained in the Quality Assurance records system provide the following data when applicable:

(a) Inspection type, i.e., in-process, in-service, testing, receiving, and shipping.

(b) Evidence of completion and verification of manufacturing, inspection, or test operation.

(c) The date and results of the inspection or test.

(d) Information related to noted discrepancies.

(e) Inspector or data recorder identification.

(f) Evidence of acceptance.

9.2.18 Audits

Quality program audits are performed on a periodic, scheduled basis by personnel without direct responsibilities in the areas being audited. Audit personnel are certified quality assurance lead auditors who have met all requirements of ANSI N 45.2.23. Written planning sheets and check lists are utilized. Audit results and corrective action activity are reported to management, in writing, and are retained in the quality assurance record file. Responsible management personnel are required to respond to audit findings with the necessary action to correct the noted deficiencies. Current PNSI practice is to audit all quality functions on an annual basis. Areas found deficient during audits are reaudited on a first priority basis to verify corrective action implementation and effectiveness. Details of the PNSI Audit System are delineated in approved PNSI QA Procedures.

9.3 References

9.3.1 Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), Subpart H, Criteria 1-18 dated August 24, 1983, Quality Assurance Criteria for Shipping Packages for Radioactive Material.

9.3.2 PNSI Corporate Quality Manual, dated August 13, 1984