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DEVELOPMENT OF NUPAC 140B 100 TON RAIL/BARGE CASK

PRELIMINARY DESIGN REPORT VOLUME II

APRIL 1990

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Idaho Operations Office
Under Contract DE-AC07-88ID12700

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DISCLAIMER

SECTION B.1
140-B
CASK ANCILLARY
EQUIPMENT

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B.1 140-B CASK ANCILLARY EQUIPMENT

The 140-B Cask Ancillary Equipment includes all cask-related hardware necessary for a complete transportation package and for handling of the cask at shipping and receiving facilities. The transportation package equipment includes the cask tiedown system, the railcar and the sunshield/personnel barrier. The cask handling systems include both single and dual load path cask lifting fixtures, a cask uprighting system, an intermodal transfer system, and the cask drain and fill system.

This section describes the individual systems in terms of their purpose, their function, and their mechanical features. Structural analyses are provided for the cask lifting and tiedown devices. A structural analysis of the railcar has been performed in order to size its structural components and ensure that the gross vehicle weight is within 263,000 pounds. The AAR requirements for railcar analysis has not been included in this package. The cask ancillary equipment will also include special tools and equipment such as seal surface protection device, special torque wrenches, leak test equipment, etc. for handling the cask at a reactor site.

Although final design work remains to be completed, the ancillary equipment design information presented in this document ensures that the 140-B cask transportation package will meet or exceed all structural, functional, and operational requirements, within the specified gross vehicle weight limit. Additionally, the cask and its lifting fixtures are shown to meet or exceed the requirements for critical lifts at a nuclear power plant with a gross weight on the crane hook of less than 200,000 pounds.

B.1.1 140-B Cask Lifting Devices

This section describes the lifting devices that are to be used to upright and lift the cask by its upper trunnions. The cask can also be lifted horizontally, intact with its tiedown system, for intermodal transfer. The intermodal lifting devices are described in Section B.1.4.

The family of cask lifting devices has been designed so that the cask can be handled at virtually any facility with a 100-ton crane and 22 feet of clearance available under the main hook. Three types of lifting devices comprise this system. The primary lifting device is a single load path, double safety factor fixture shown in Figure B.1.1-1. A dual load path fixture is available for facilities or applications where it may be required and is shown in Figure B.1.1-2. The cask uprighting Yoke is similar to the single load path lifting fixture, and is shown in Figure B.1.1-3. The uprighting fixture's trunnion stirrups are longer, allowing the cask to pivot under the main load beam as the cask is uprighted from its cradle.

Each lifting fixture is designed according to the requirements of ANSI N14.6. The design of the single load path fixture allows a transverse load beam with an extra pair of trunnion stirrups to be added. This combination of lifting fixtures creates a true dual load path to satisfy the requirements for a fully redundant lifting device. A structural analysis of the single load path fixture is provided in Section B.1.7.

Both single and dual path lifting fixtures include an innovative arrangement for handling the cask lid. The main load beam carries a set of lid lifting bolts which are used to remove and replace the cask lid once the cask has been positioned to receive or discharge fuel. The beam also carries a system of blocks and wedges that secures the cask lid after the lid fasteners have been removed. This feature assures that the cask lid will remain in place even in the event of a postulated drop accident.

B.1.1.1 <u>System Requirements</u>

The lifting fixtures will be used during cask handling operations both at the utility and at the repository sites. The lifting fixtures have the following functions:

1) Upright the cask to a vertical position on the railcar

2) Lift the cask off the railcar and place it at a work station.
   Note: (Will have to disconnect cask rotating lift fixture and insta dual lifting system where redundant crane is used.)

3) Transfer the cask in a vertical position to and from the preparation area and fuel pool

4) Remove and replace cask lid

5) Secure lid in place during vertical transfer operations

Two preliminary design approaches are presented to accommodate operating preferences and requirements of the individual utilities. The first approach consists of two fixtures: The cask uprighting fixture is used to upright the cask from horizontal to a vertical position and place it at a work station. Then the single load path lift fixture is used to lift the cask in the vertical position and move it to the cask preparation area or spent fuel pool. A single fixture with changeable trunnion stirrups can be used to perform the same functions. In either case the main load beam incorporates both cask lid holddown and lid lifting devices.

Critical lifts that require a dual load-path system have been addressed by designing the single load path lifting fixture to accept an additional load beam and hardware that attaches to a duplex hook at 90° to the primary load beam. This configuration is designated as the dual load-path lifting fixture.

B.1.1.2 Component Description

Major components that comprise the lifting fixtures are described below and identified in Figures B.1.1-1 through B.1.1-3.

B.1.1.2.1 Load Beam - Steel weldment made from two parallel beams with spacer plates welded to the beam webs. Beams are centrally drilled for hook attachment. Ends of the beams support pivot pins to which the trunnion stirrups attach.

B.1.1.2.2 Trunnion Stirrups - Steel weldments which attach to the lift beam and engage trunnions on the cask. Stirrups swing in an arc to engage and disengage the trunnions.

B.1.1.2.3 Crane Hook Pin - Steel pin(s) used to attach the lifting fixture to the overhead crane hook.

B.1.1.2.4 Trunnion Stirrup Pins - Steel pivot pins that attach the trunnion stirrups to the load beam and allow the stirrups to swing toward and away from the cask trunnions.

B.1.1.2.5 Stirrup Actuators - Air cylinders of sufficient size and stroke for actuation of the trunnion stirrups.

B.1.1.2.6 Lid Lifting Hardware - Brackets and captive bolts that attach the lid to the lifting fixture for removal and installation.

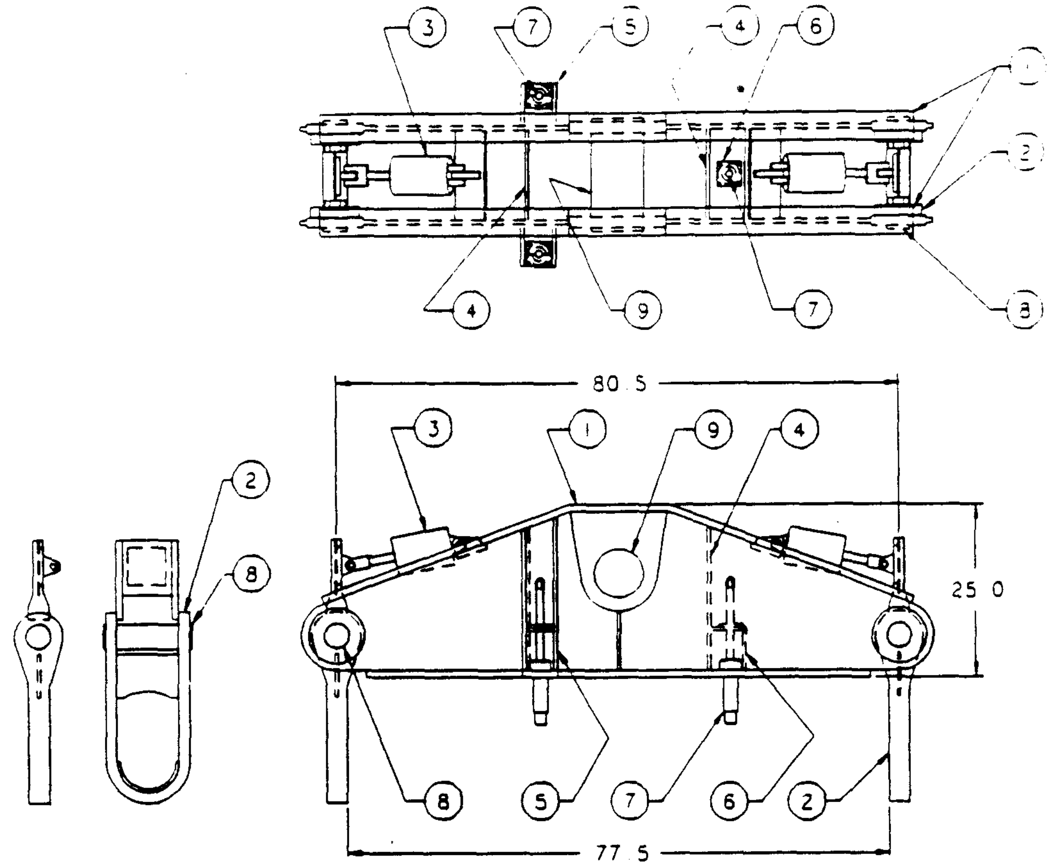
B.1.1.2.7 Lid Blocking Hardware - A system of blocks and wedges that secure the lid to the cask. An air cylinder is used to position the wedges into place in the secured and unsecured positions.

B.1.1.3 Operational Description

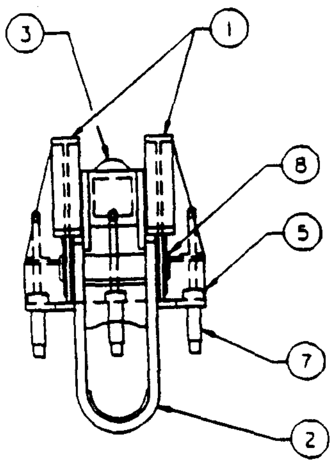
This section describes the basic operation of the lifting fixtures for cask lifting and lid removal/installation. The method of attachment to the overhead crane and engagement of trunnions is the same for all fixtures. In cases where a single fixture is used for all functions, a change of trunnion stirrups between cask uprighting and vertical transfer operations will convert the uprighting fixture to a critical lifting fixture. Facilities requiring a redundant lift will have to install the additional transverse lift beam after the cask has been uprighted.

The use of the single load path lifting fixture is shown in Figure B.1.1-5. The first frame of that figure shows the fixture installed on the crane hook, with pneumatic hoses connected, being lowered onto the cask. The stirrup actuators are retracted so that the stirrups fit over the cask trunnion. The fixture is lowered until the lid blocks under the load beam rest on the cask lid. The lid lifting bolts are then manually started into their tapped holes in the cask lid and run down by manual or power ratchet. The stirrup actuators are extended, centering the stirrups under the cask trunnions, as shown in the second frame of Figure B.1.1-5. The lifting fixture is then raised, as shown in the third frame, until the stirrup journals are firmly in contact with the cask trunnions. As the fixture is lifted, the lid lifting bolts slide vertically in their brackets until their flanges bottom out on the load beam flange. The lid is then supported by these bolts. In a similar manner, the lid load blocks are free to slide vertically in their pins so that when the fixture is raised, they remain in position on top of the cask lid. Prior to lifting the cask, the load block wedges are positioned between the load beam and the lid blocks by their actuator. The wedges preclude the lid blocks from retracting. The load path is complete through the trunnions, stirrups, load beam, wedges and lid blocks, to the cask lid. The wedges are shown in place in the third frame.

To remove the cask lid, the cask is set down, the lid blocking wedges retracted and the trunnion stirrups opened, as shown in the fourth frame of Figure B.1.1-5. When the lifting fixture is raised, as shown in the last frame, the cask lid is removed and raised by the lid lifting bolts.



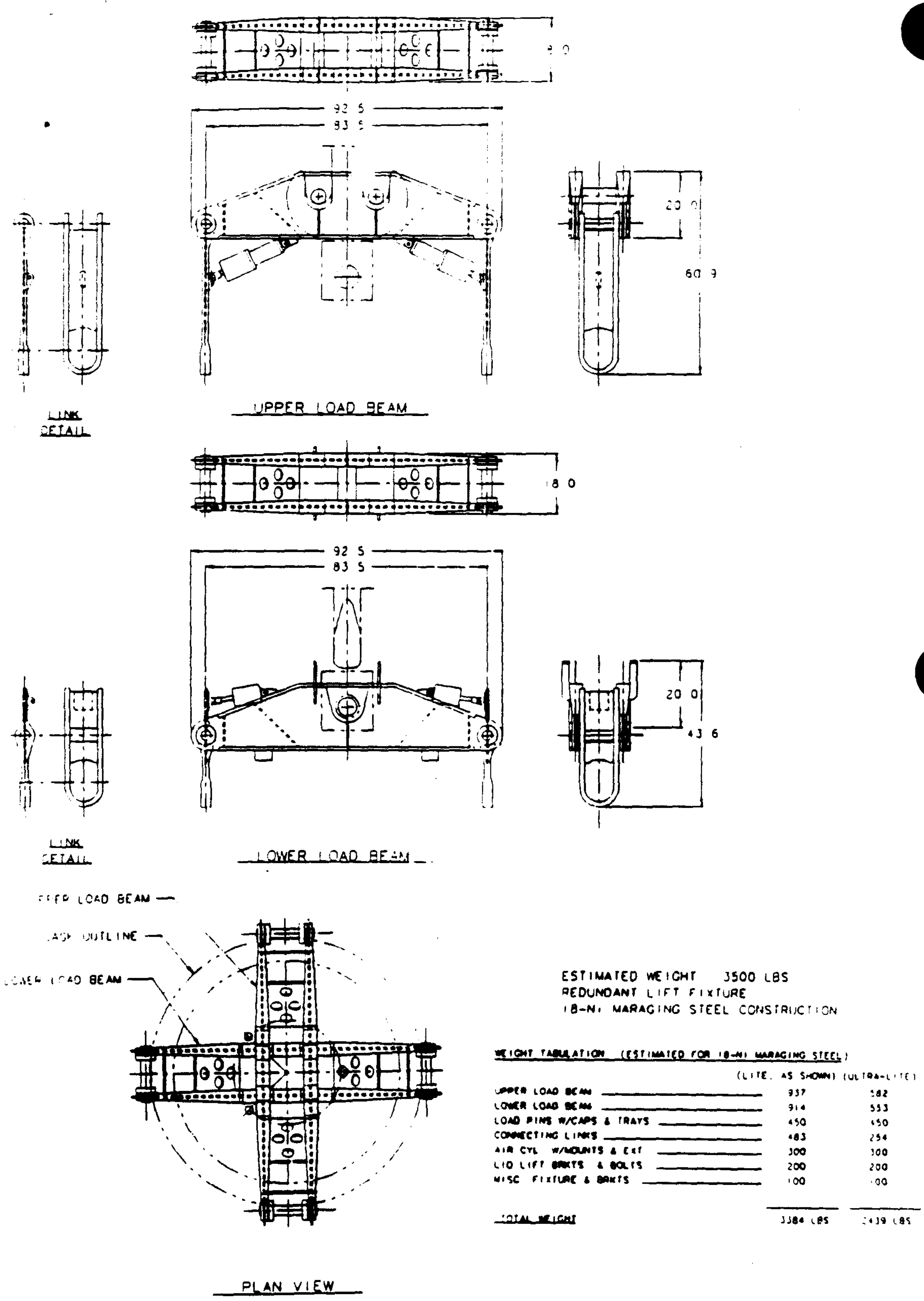
TRUNNION
STIRRUP
DETAIL



COMPONENT IDENTIFICATION

1 MAIN LIFT BEAMS
2 TRUNNION STIRRUPS
3 STIRRUP ACTUATORS
4 SPACER PLATE
5 LID LIFTING SIDE BRACKET
6 LID LIFTING CENTER BRACKET
7 LID LID LIFTING BOLTS
8 STIRRUP PIN
9 CRANE HOOK PIN

FIGURE B.1.1-1
SINGLE LOAD PATH LIFTING FIXTURE



ESTIMATED WEIGHT 3500 LBS
REDUNDANT LIFT FIXTURE
18-Ni MARAGING STEEL CONSTRUCTION

WEIGHT TABULATION (ESTIMATED FOR 18-Ni MARAGING STEEL)

	(LITE, AS SHOWN)	(ULTRA-LITE)
UPPER LOAD BEAM	937	582
LOWER LOAD BEAM	914	553
LOAD PINS W/CAPS & TRAYS	450	450
CONNECTING LINKS	483	254
AIR CYL W/MOUNTS & EXT	300	300
LID LIFT BRKTS & BOLTS	200	200
MISC FIXTURE & BRKTS	100	100
TOTAL WEIGHT	3384 LBS	2439 LBS

FIGURE B1.1-2

DUAL LOAD PATH LIFTING FIXTURE

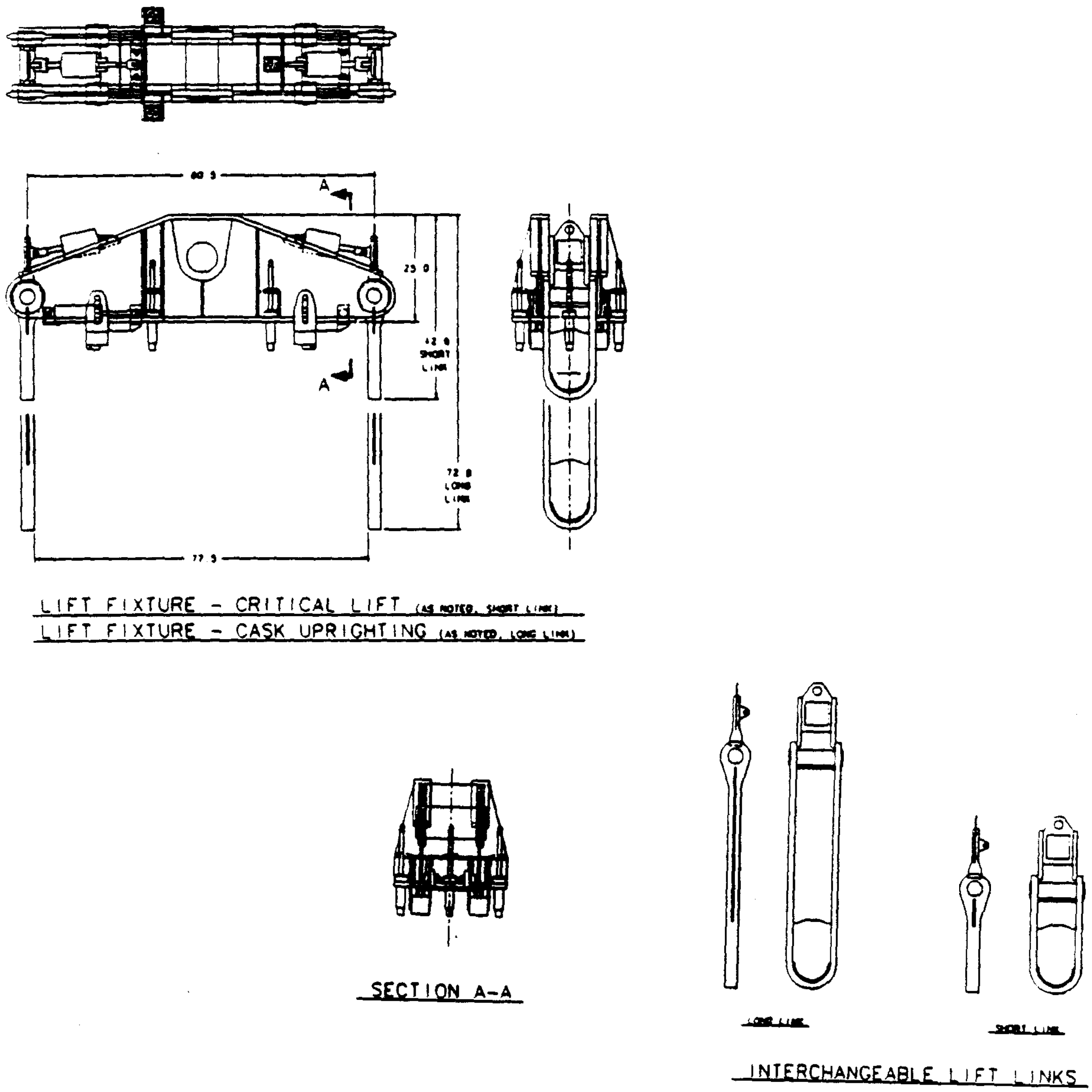


FIGURE B.1.1-3

UPRIGHTING FIXTURE

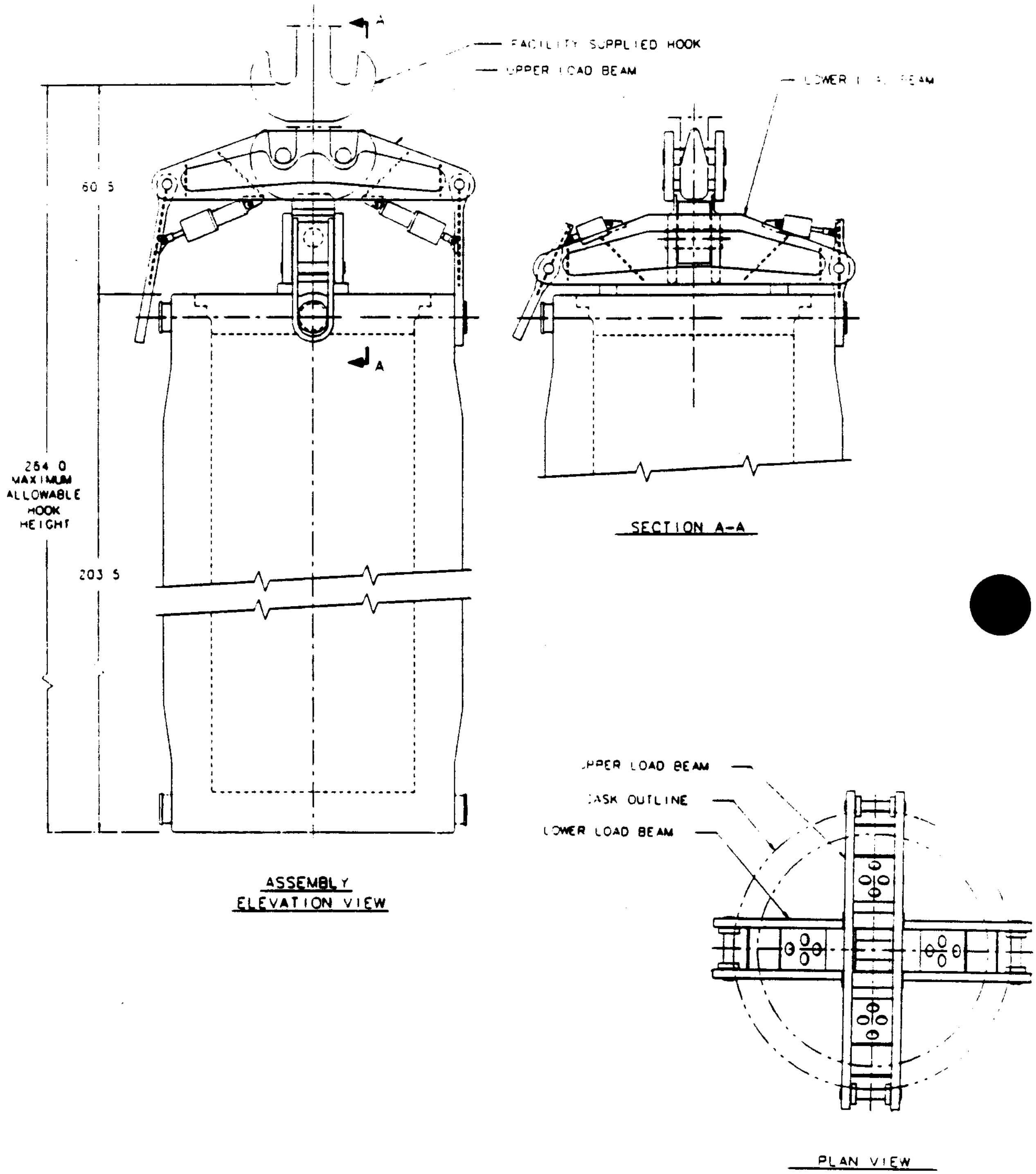


FIGURE B.1.1-4
OPERATION OF DUAL LOAD PATH FIXTURE

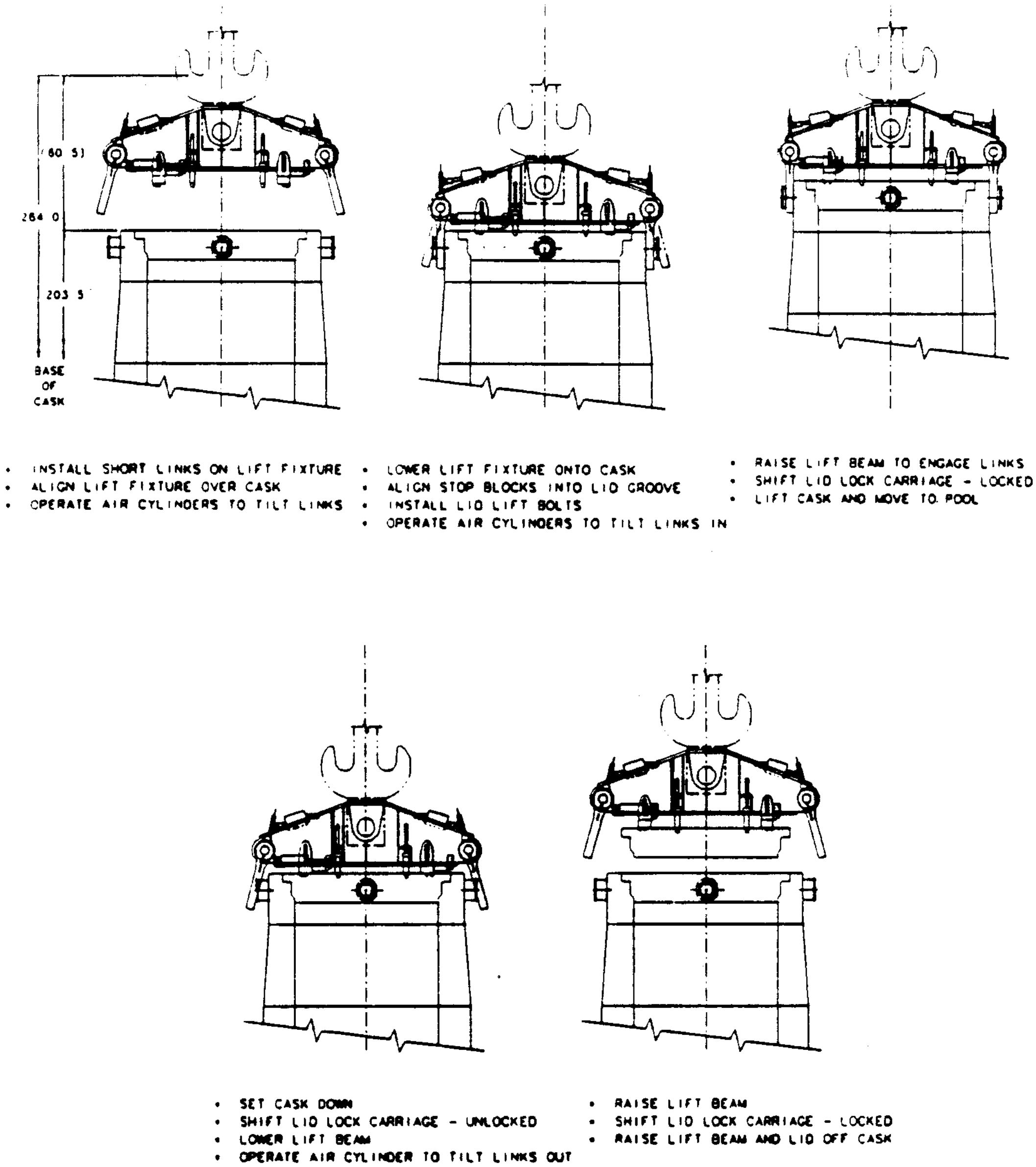


FIGURE B.1.1-5

CRITICAL LIFT - LIFT BEAM OPERATION

B.1.1.4 <u>140-B Cask Lifting Fixture Structural Analysis</u>

This section covers the structural analysis of a single load path lifting fixture to be used for lifting the upright cask in the fuel pool area of a power plant. This constitutes a critical lift, thus the fixture is built accordingly per ANSI N14.6 (Reference 1). The components are made of high strength ASTM A538 maraging steel. This choice of material was found to produce the lightest possible fixture in order to meet the maximum hook weight requirement of 200,000 lbs. The results of this section verify the weight of the optimum (lightest weight) single load path lift fixture that was presented in Section 2.2 of the preliminary design report. The weight of this optimum fixture is 2325 lbs.

A standard crane hook does not exist for all the power plants where the 140-B abovecask might be used. Thus, the fixture configuration presented herein is intended only to show the feasibility of building a satisfactory lifting device and to estimate its potential weight. The fixture for each particular plant may need some degree of customizing so it will fit the hook in that plant. However, the design presented in this analysis can be easily adapted to most 100 ton single or duplex hooks.

The critical lift fixture is shown in Figure B.1.1-6. It consists of a single pair of parallel main load beams (1) with trunnion stirrups (2) on the ends for connecting to the trunnions on the casks. The stirrups, which swing in and out to attach to or release from the cask trunnions, are pneumatically actuated for remote operation. The fixture also includes a lid lifting system (5,6,7) for removing and replacing the cask lid in the fuel pool. Alignment fixtures will have to be installed on the cask prior to the removal/replacement operations.

This section also covers the estimated weights of the other critical lift fixture designs which were considered using ASTM A537 and/or a dual load path configurations.

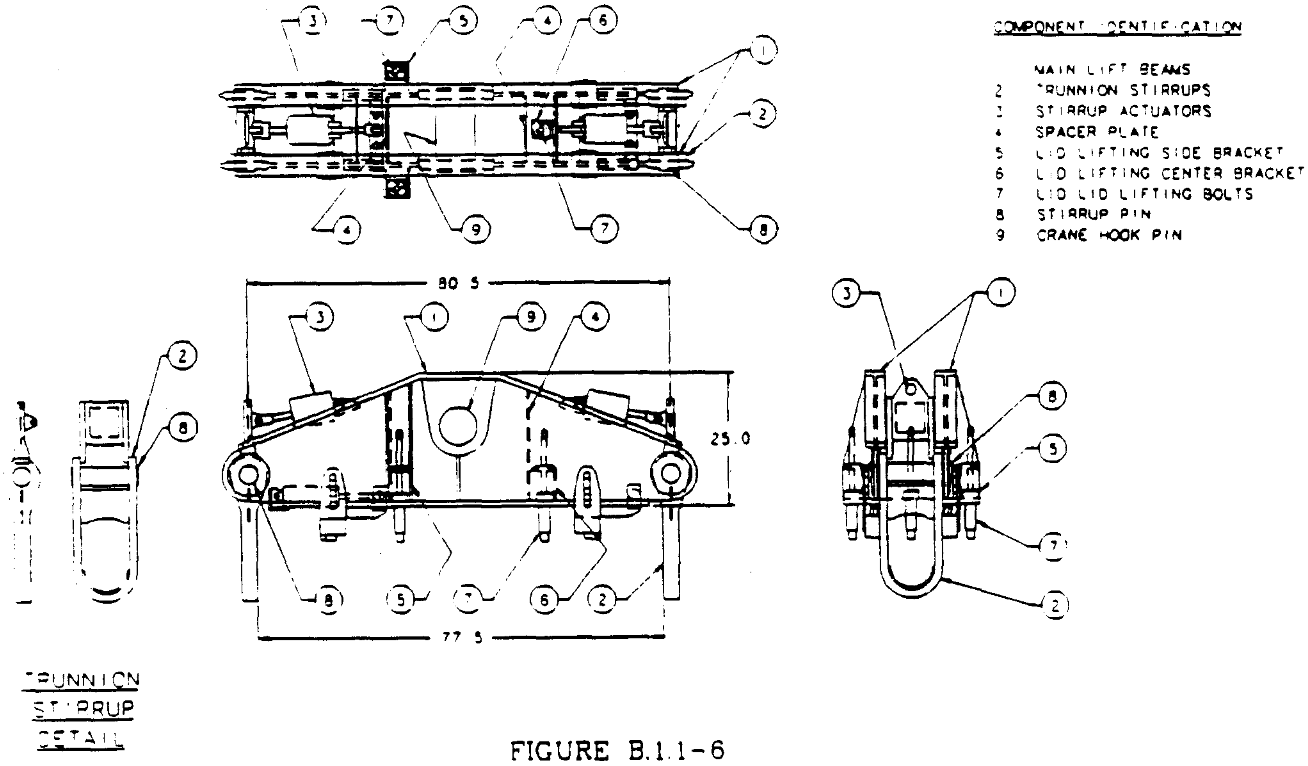


FIGURE B.1.1-6
Single Load Path Lifting Fixture

B.1.1.4.1 Analytical Results

Analysis shows that under the required loading conditions all components of the lift fixture will have positive margins of safety and that the system will perform all the required functions. The stresses in some portions of the lift fixture are relatively low. Thus, the fixture could be made lighter but care must be taken in the process in order to negate buckling in the thin sections. The minimum margin of safety is .10. The maximum reduction in material strength due to elevated temperatures is about 8% so the structure will still be adequate at its maximum operating temperature.

It is estimated the finished fixture will weight 2,235 lbs, and this value includes the integral lid lifting system. A factor of 10% is included in this weight to account for miscellaneous items, such as weld metal, reinforcing plates, nuts, bolts, etc.

	Weight
Beams (1)	1,365 lbs
Stirrups (2)	156 lbs
Pins (8,9)	378 lbs
Lid lifting equipment (5,6,7)	226 lbs
Actuators (assumed) (3)	200 lbs
	2,325 lbs.

The following table gives the weight estimates for the other combinations of materials and configurations which were also considered.

TABLE B.1.1.1
ALTERNATIVE FIXTURES

No. Load Path	Material	Weight
Single	ASTM-538	2,325 lbs
Single	ASTM-537	3,903 lbs
Dual	ASTM-538	3,075 lbs
Dual	ASTM-537	4,725 lbs

B.1.1.4.2 Future Recommended Studies

The following items need to be addressed in more detail in the final design process:

- The details of the hook attachment area need to be customized for each different hook in use.
- The details of the beam span and the stirrups where they fit the trunnions need to be updated when the trunnion design is finalized.
- Alignment fixtures which will ensure the proper engagement of the cask trunnions and the lid lifting bolt holes must be developed.

B.1.1.4.3 Structural Verification Studies

This section includes design requirements, assumptions, loads, material properties and references. The detailed calculations are presented in Appendix A1.

Design Requirements

Applicable documents are given below:

- Contract No. DE-AC07-88ID12700, D.O.E./NuPac
- ANSI N14.6
- American Iron and Steel Institute (AISI) Specifications
- American Welding Society, AWS D1.1-80 "Structural Welding Code"

Functional Requirements are as follows:

- Fast and easy operation during fuel loading
- Capable of remote operation

Assumptions

- o The cask and contents weighs 200 kips
- o The cask lid weighs 11 kips

Loads

Normal Operation

- o This is a lifting conditio.. for the cask. Thus the analysis will be based on a 1. g. down load with the safety factors as required by ANSI N14.6 (Reference 8)

- o The "W" used will include the impact load factor references in 7.2 of ANSI N14.6.

- o Since this is a single load path fixture on a critical lift the normal safety factors are doubled to 6 on yield and 10 on ultimate. Buckling is considered to be an ultimate condition.

Design Temperature Range *

- o Maximum: 130 F
- o Minimum: -40 F

(*) Defined by NuPac

B.1.1.4.4 Material/Allowable Stresses

ASTM A538 maraging steels, grades 200 and 250, are to be used (Reference 7). This type of steel provides high strength along with reasonable ductility. Thus it is suitable for building light weight structures. It is easily welded and moderate post heat treatment produces essentially full base metal strength in the welds. The structure can be welded after the original heat treatment and then reheat treated back to its original strength. Reheat treating can be done a limited number of times before the base metal properties begin to degrade. Due to the high strength of the material, the cross sections of the members may be quite thin. Care must be taken to avoid buckling in the thin sections. The material contains 18% nickel and does not have a nil ductility temperature in the range of temperatures to be considered in this design. The nil ductility temperature for the material is -150°F. The material has moderate ductility and high Charpy and knotch strength. Fracture analysis may be necessary to verify that the ASTM A538 steel has sufficient ductility.

ASTM A538 - Maraging Steel (Reference 7)
(Room Temperature properties)

	T-200 grade	T-250 grade
Ftu =	210 ksi	260 ksi
Fty =	205 ksi	255 ksi
Fsu =		155 ksi
E =	26.5E6 psi	26.5E6 psi
elongation =	14%	11%
Charpy strength =	81 ft-lbs	25 ft-lbs

The values of the material properties vary with temperature. In the range of -40 F to 250 F the tensile strength of ASTM A538 varies almost linearly from 92% of the room temperature value at 250 F to 105% at -40 F (Reference 11).

All margin calculations will be based on the Stress Intensity.

B.1.1.4.5 <u>References</u>

1. Contract No. DE-AC07-88ID12700, D.O.E./NuPac
2. Roark, 4th ed., Formulas for Stress and Strain, McGaw-hill
3. Timoshenko and Young, Elements of Strength of Materials, 5th Ed., D. Van Nostrand Co., Princeton, NJ
4. The Crosby Group, P.O. Box 3128, Tulsa, OK
5. AISC Manual of Steel Construction, 7th Ed, AISC, 101 Park Avenue, New York, NY
6. ANSI N14.6 - American National Standards for Shipping Containers Weighing 10,000 Pounds or more for Nuclear Materials, 1986, American National Standards Institute, Inc., 1420 Broadway, New York, NY 10018
7. VascoMax, T-200 and T-250, 1985, Teledyne Vasco, P.O. Box 151, Latrobe, PA 15650, 800/537-5551
8. Mil-Hdbk-5E, Metallic Materials and Elements for Aerospace Structures, Department of Defense, Washington, D.C., June 1, 1987

B.1.2 140-B Cask Tiedown System

This section describes the arrangement, the operation, and the structural analysis of the cask tiedown system for the 140-B rail/barge cask. The tiedown system supports the cask and provides for attachment of the cask to a special railcar or a barge deck. It provides for the breakaway of the cask, without damage to the cask from the railcar, if the AAR tiedown loads are exceeded. In addition, it functions as a lift fixture for the intermodal transfer of the cask from the railcar to a barge.

B.1.2.1 General Description

The cask cradle consists of a light weight, high strength steel frame which carries the weight of the cask through its support lugs. The cradle is secured to the railcar by separate vertical and longitudinal tiedown bolts which are designed to shear in a severe accident. The tiedown system is shown assembled in Figure B.1.2-1 and in an exploded view in Figure B.1.2-2. Details of the system are shown in Figures B.1.2-3 through B.1.2-5. The cask is secured in the cradle by four tiedown clamps. This clamping system, shown in Figure B.1.2-5, allows the cask and cradle to be lifted horizontally for intermodal transfer between the railcar and a barge.

The results of the structural analysis verify the preliminary weight for this tiedown system to be 7,400 pounds. Thus, when combined with a maximum cask weight of 206,600 pounds, and 2,000 pounds sunshield/personnel barrier discussed in Section 2.2 of the preliminary design report, the total weight on the transport vehicle will be 216,000 pounds. This leaves 47,000 pounds as a maximum allowable for the railcar weight based upon the limit specified in Reference (1) for "gross weight on rails".

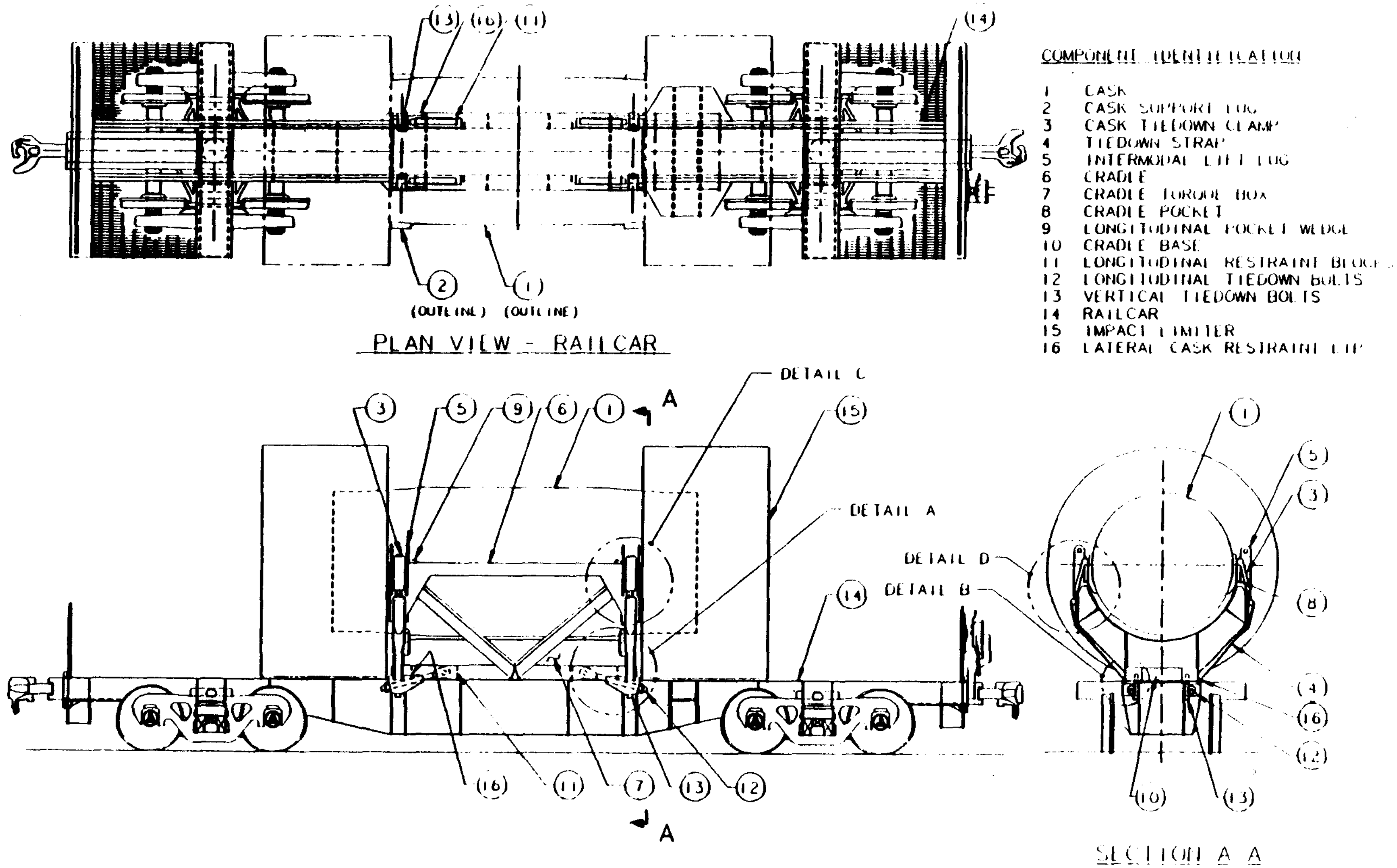
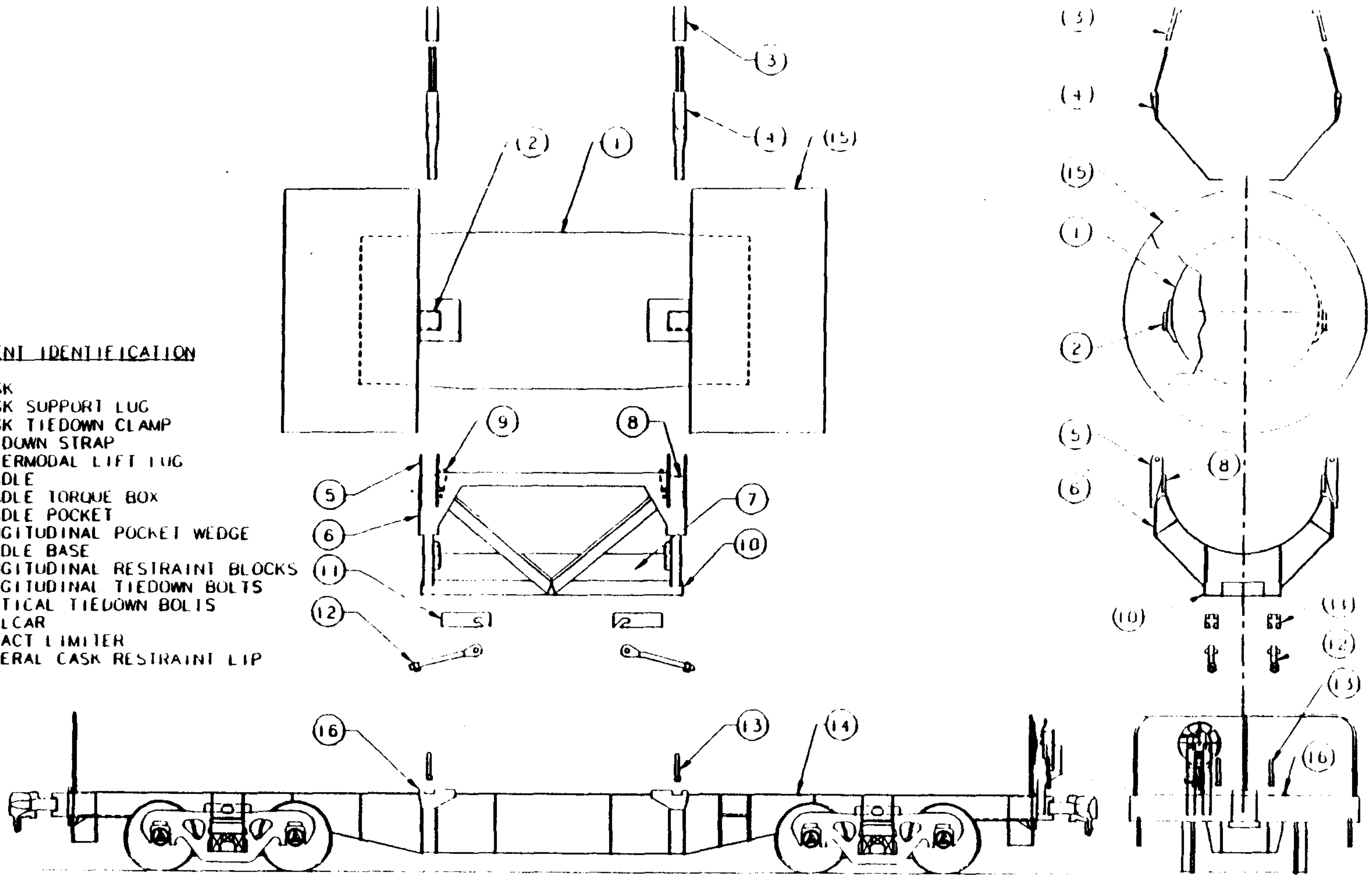


FIGURE B[illegible]1
Cask Railcar Tiedown Sy[illegible]tem Schematic



COMPONENT IDENTIFICATION

1 CASK
2 CASK SUPPORT LUG
3 CASK TIEDOWN CLAMP
4 TIEDOWN STRAP
5 INTERMODAL LIFT LUG
6 CRADLE
7 CRADLE TORQUE BOX
8 CRADLE POCKET
9 LONGITUDINAL POCKET WEDGE
10 CRADLE BASE
11 LONGITUDINAL RESTRAINT BLOCKS
12 LONGITUDINAL TIEDOWN BOLTS
13 VERTICAL TIEDOWN BOLTS
14 RAILCAR
15 IMPACT LIMITER
16 LATERAL CASK RESTRAINT LIP

FIGURE B.1.2-2
Cask Railcar Tiedown System — Exploded View

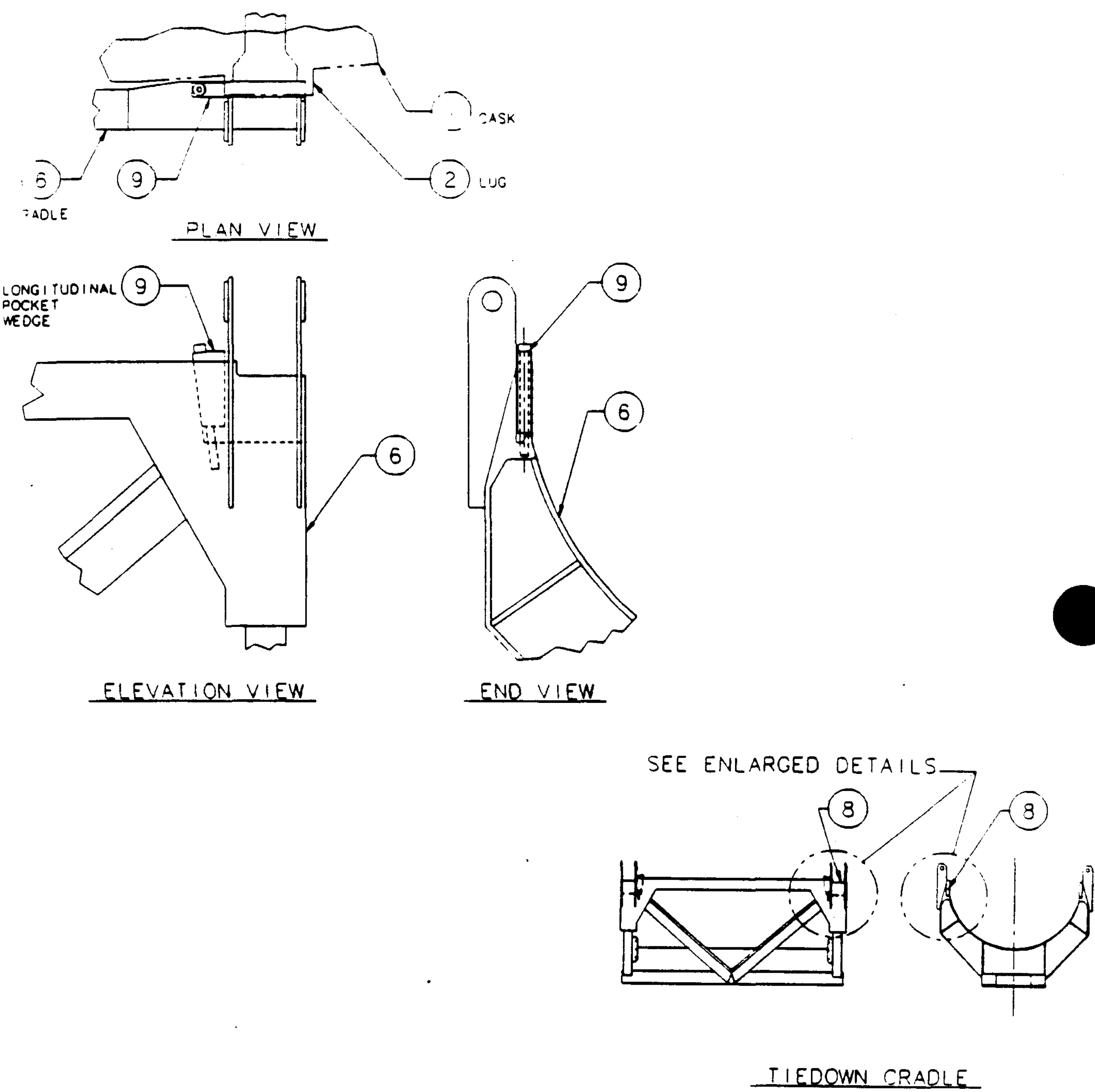


FIGURE B.1.2-3
Tiedown System Cradle Pocket Details

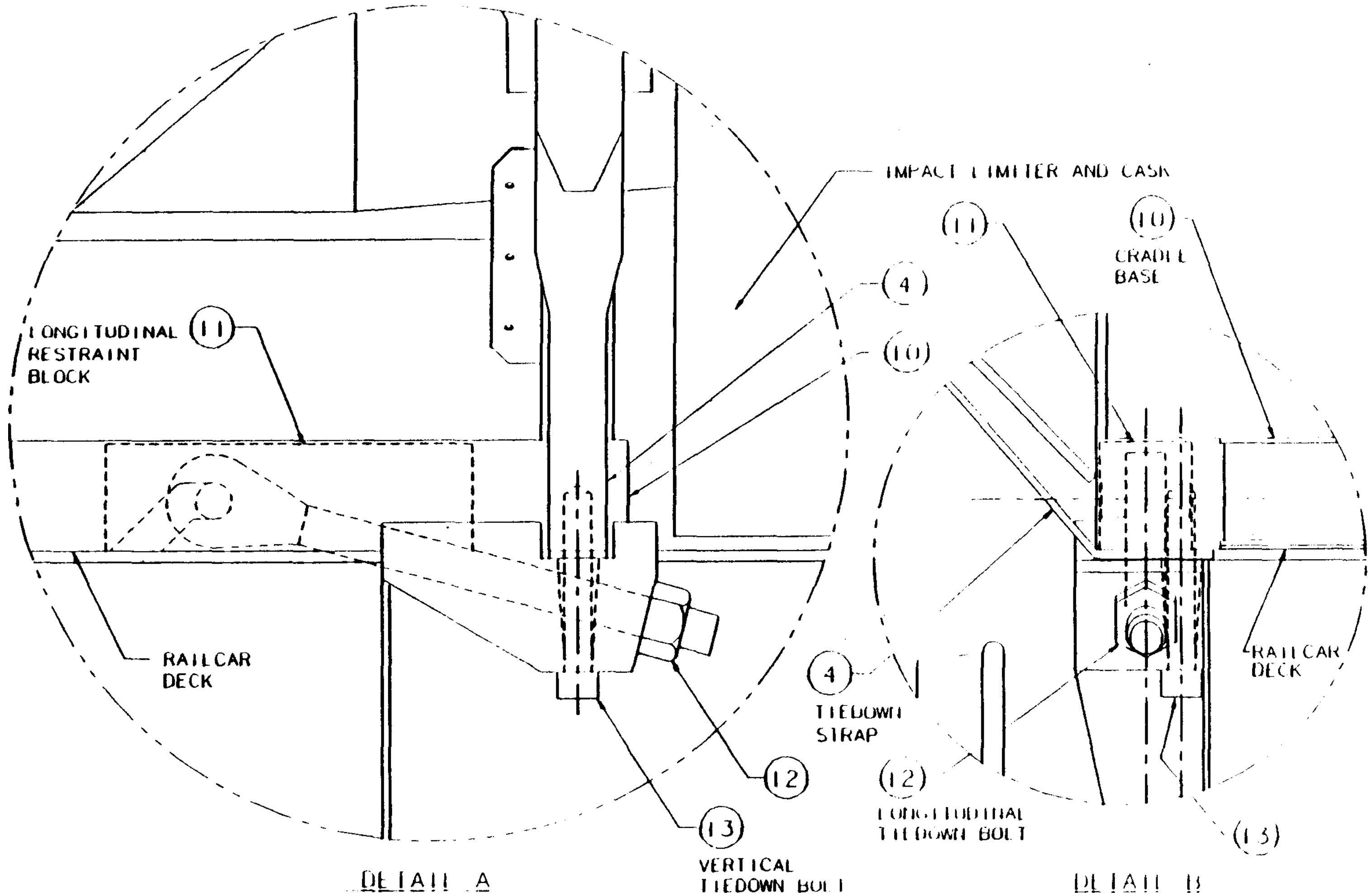


FIGURE B.1.2-4
Tiedown System Cradle Attachment Details

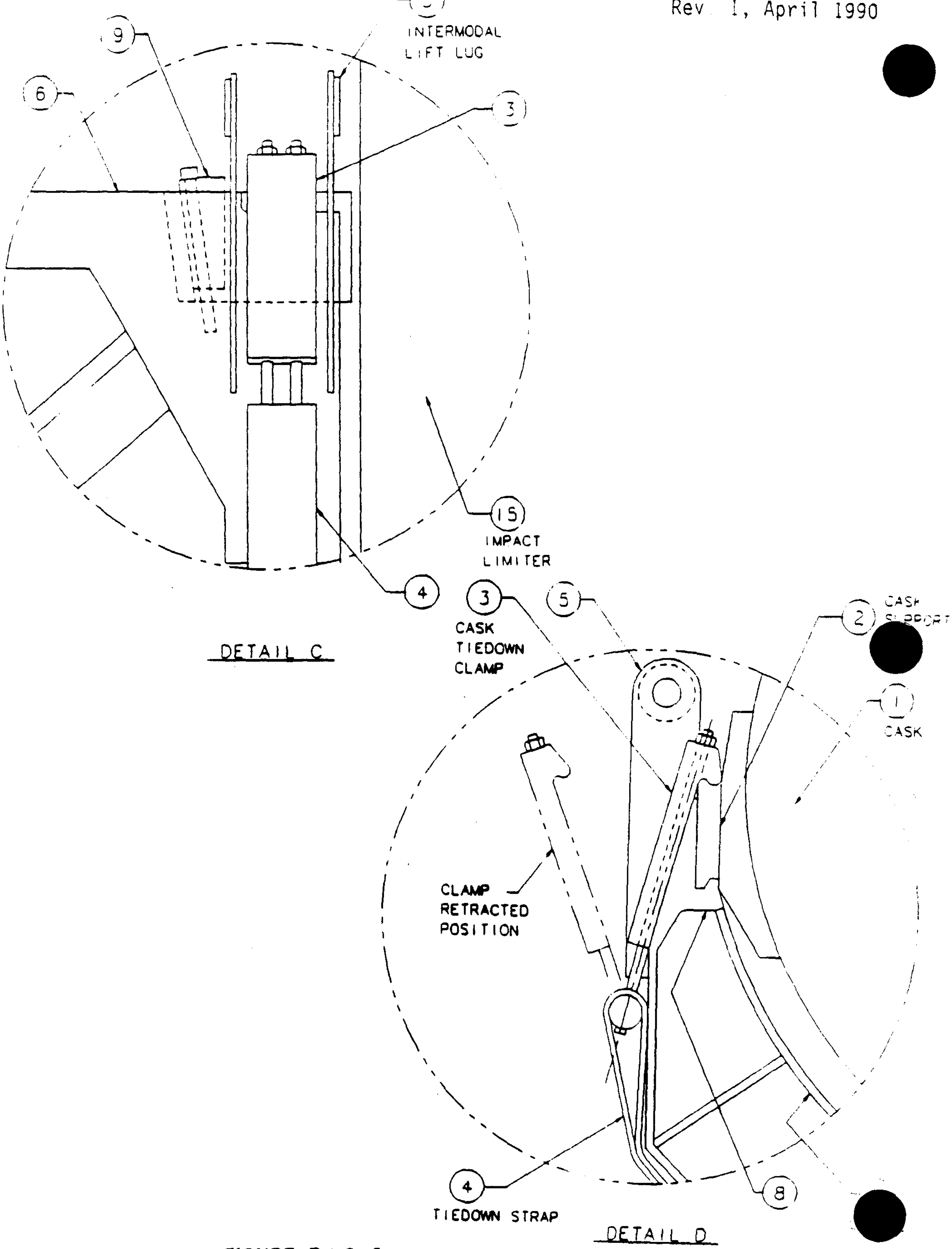


FIGURE B.1.2-5
Tiedown System Clamp Details

B.1.2.2 Operational Details

Operational details include loading and unloading site, rail transport, breakaway, strength, intermodal transfer and other considerations.

B.1.2.2.1 Operation at a Fuel Loading/Unloading Site

The cradle (6) consists of a light weight high strength steel space frame which supports the cask (1) and impact limiter (15) assembly on a special railcar (14). Four cask support lugs (2) on the cask rest in pockets on the upper corners of the cradle. These pockets provide longitudinal, lateral and vertical downward support. Cask tiedown clamps (3) over the top of the cask lugs retain the cask in the cradle for vertical upward loads. The clamp, lug and pocket mating surfaces are also contoured so that the pockets can exert a radial outward pull on the lugs. This allows lateral loads to be shared by all 4 pockets.

The longitudinal attachment of the cradle to the railcar is made with four tiebolts (12). The tiebolts are pinned in longitudinal restraint blocks (11) which lie on the car deck and are trapped horizontally inside the corners of the cradle base. The tiebolts slope down through the car deck at an angle of 15 degrees from the horizontal along the longitudinal axis of the car and pass through plates which are attached to the car frame. Nuts on the tiebolts hold them in place and allow for adjustment of any slack in the system. Two tiebolts slope each way so that the four bolts provide restraint in both directions. The two bolts at each end straddle the centerline symmetrically. The blocks are not intended to provide any vertical or lateral restraint.

Longitudinal slack in the restraint of the cask in the cradle pockets is enhanced by the use of longitudinal restraint wedges (9). These wedges fit in the cradle pockets behind the cask support lugs. Tightening down the bolts which hold the wedges in position removes slack from the system and accommodates any manufacturing tolerances in the assembly.

Vertical upward retention of the cask/cradle assembly on the car is accomplished by 4 tiedown straps (14) near the corners of the cradle base. Vertical tiedowns secure the straps and are strong enough to resist any of the required AAR upward loads. The cask is retained in the cradle by the cask tiedown clamps which attach to the upper end of the tiedown straps (4). The clamps (3) go over the four cask support lugs (2) which locate in the cradle pockets (8). These are tightened down with bolts to remove vertical slack from the system. Downward loads are applied to the cradle pockets by the cask support lugs. The cradle is then supported by the car deck.

During normal fuel loading and unloading operations the cask and cradle are subjected to nominal loads of 1 g due to gravity. Appropriate safety factors, to be discussed subsequently, cover potential impacts or acceleration loads. The cradle facilitates the operation of the cask in a minimum amount of time during the fuel loading and unloading processes. The central location negates any preparation of the cradle prior to removing the impact limiters. Removal of the tiedown clamps and the longitudinal pocket wedges clears the way for the cask to be lifted out of the cradle. The rest of the cask operation is independent of the cradle design.

Vertical and lateral positioning of the cask in the cradle is provided by a close fit of the cask lugs in the cradle pockets. This fit is not adjusted during normal operation of the cask. Permanently installed shims can be used to take up the manufacturing tolerances in such cases.

Longitudinal positioning of the cask in the cradle is done by the trunnions in the turning fixture when the cask is placed in the cradle. The trunnion supports are moved longitudinally to align the cask with the cradle axis and to adjust the position of the cask in the cradle. Once the cask is resting on its lugs in the cradle pockets the longitudinal wedges are installed to take longitudinal slack out of the system. The wedges are pulled into place with bolts which prevent them from shifting during transport.

B.1.2.2.2 Rail Transport

The tiedown system is required to provide secure attachment of the cask to the railcar up to a minimum of the AAR tiedown requirements per Rule 88 (Reference 2). The required inertial restrains are for 7.5 g's longitudinal, 4.0 g's vertical, 1.8 g's lateral based on the cargo weight. These loads are applied independently rather than concurrently.

B.1.2.2.3 Breakaway

During an accident when the loads exceed the AAR tiedown requirements the breakaway feature of the tiedown system allows the cask to separate from the railcar without any damage or impairment to the cask's safety functions. All tiedown equipment are free to separate from the cask during the breakaway process. The upper bound for the breakaway loads is the requirement to not degrade the cask safety functions during the breakaway. The NRC requires the cask to withstand 10 longitudinal, 5 lateral, and 2 vertical g's. Thus, a sharp spike load is not likely to cause the cask to be released even if the peak load exceeds the breakaway load momentarily. This provides insurance against an unintended release of the cask.

During a longitudinal breakaway the cask is released from the railcar by the tensile rupture of the longitudinal tiedown bolts due to the inertial loads. The vertical tiedown bolts initially prevent longitudinal overturning. After the longitudinal bolts break the vertical bolts are sheared as the cradle base slides along the car deck. This releases the tiedown straps (4) which thus release the cask tiedown clamp. The tiedown equipment is no longer fastened to the cask.

The lateral breakaway mechanism is independent of the longitudinal breakaway process. The lateral system requires lips (16) on the edges of the railcar deck to prevent the cradle from sliding laterally. The lateral breakaway is accomplished by the vertical tiedown bolts breaking in tension when the cradle/cask assembly tries to overturn laterally. The longitudinal tiedown blocks are not fastened to the cradle base so the cradle can lift vertically off the blocks during a lateral breakaway. The minimum strength for the vertical tiedown bolts is based on the requirement to prevent longitudinal overturning. The ratio of height of the cask CG to the distance of the vertical tiedown bolt form the edge of the cradle base determines the relative load applied to the bolt. This ratio and the necessary tolerances preclude a 1.8 g lateral breakaway. Thus, a maximum design value of 3.0 g's is used. This is acceptable for the cask which must be built to withstand a 5.0 g lateral load. The separation of the functions of the different sets of bolts during the two types of breakaway allows the bolts to be tailored to a precise strength. A section of the shank of the bolt above the threads can be turned to a proper diameter, depending on the strength of the bolt material, to provide the required tensile strength.

The actual lateral breakaway will be a sequential failure. The bolt at one end will probably break before the bolt at the other end. Thus, the cradle must be torsionally strong enough to prevent it from twisting and damaging the cask before the second bolt breaks. This is done by building a torque box (7) to connect the two end bulkheads.

The vertical upward breakaway is accomplished by the tensile rupture of the bolts in the cask tiedown clamps. These are different from the cradle tiedown bolts. The required vertical breakaway load is less than the tensile strength of the vertical cradle tiedown bolts so the failure occurs first in cask tiedown bolts. The separation of the cask tiedown bolts releases the tiedown clamps and thus the cask. Since the cask is supported by the cask lugs near the cask centerline the vertical load components created by the lateral and longitudinal loadings are less than the vertical breakaway loads.

There is no vertical downward breakaway mechanism. Excessive downward loads will eventually cause the impact limiters to contact the deck of the railcar.

During a lateral or longitudinal breakaway, the ends of the tiedown straps are released at the car deck so that the cask is no longer fastened to the cradle. Holes in the end of the straps fit over the vertical tiedown bolts so the strap is captive between the cradle and the railcar. When the vertical tiedown bolts are sheared or broken during a breakaway the ends of the straps slip off the lower portion of the bolt and the tiedown system is released from the cask and railcar.

B.1.2.2.4 Strength

Due to the large weight of the cask assembly relative to the car weight the AAR Rule 88 tiedown requirements make the tiedown system stronger than the railcar. Only an unusually severe accident could create loads sufficient to cause the cask to breakaway. Normal operating loads will be far below the breakaway load levels (.7 to 1.5 g's longitudinal, < 1 g lateral, < 1 g vertical - Reference (9)). Thus, the breakaway conditions are considered to be "accident" conditions and only minimal margins are required. Also the tiedown bolt materials can be tested on an individual part basis and machined to size to provide a specific strength. This will reduce the need for large factors to cover the variations in the materials.

The cradle is designed just under yield for the maximum breakaway loads. This is done to minimize the weight of the tiedown system and still retain a known geometry for the cradle. Minimum weight is required because of the 263,000 lbs gross weight on rails limitation of the loaded railcar.

The cradle is to be constructed with ASTM A538 maraging steel. The 200 and 250 grades are to be used (Reference 10). This type of steel provides high strength along with reasonable ductility. Thus, it is suitable for building light weight structures. It is easily welded and moderate post heat treatment produces full base metal strength in the welds. The structure can be welded after the original heat treatment and then heat treated back to its original strength. Heat treating can be done a limited number of times before the base metal properties begin to degrade. Due to the materials high strength the cross sections of the members may be quite thin. Care must be taken to avoid buckling in the thin sections. The material contains 18% nickel and has nil ductility temperature of -150°F which is below the range of temperatures to be considered in this design. The material has moderate ductility and high Charpy and knotch strength. Fracture analysis may be necessary to show that the ASTM A538 steel has sufficient ductility.

The cradle pockets are not intended to fail during a breakaway. The remain intact until the cask is clear of the cradle.

B.1.2.2.5 Intermodal Transfer

The cradle also functions as a lifting fixture for the cask/impact limiter assembly when it is to be moved in a horizontal attitude for transfer to a barge (see Figure B.1.2-6). The tiedown straps must be removed and the cask tiedown clamps fastened to the cradle so they will function while the cradle is not on the railcar. A breakaway function is not required during this lifting process. Lifting lugs are built into the cradle for attachment of the lifting beam.

The cradle/cask assembly can be fastened to the barge deck, trailer, or storage stand in the same manner as it is fastened to the railcar or by any other suitable means. Specifications are not available for the attachment to the barge deck or the minimum strength of such tiedowns.

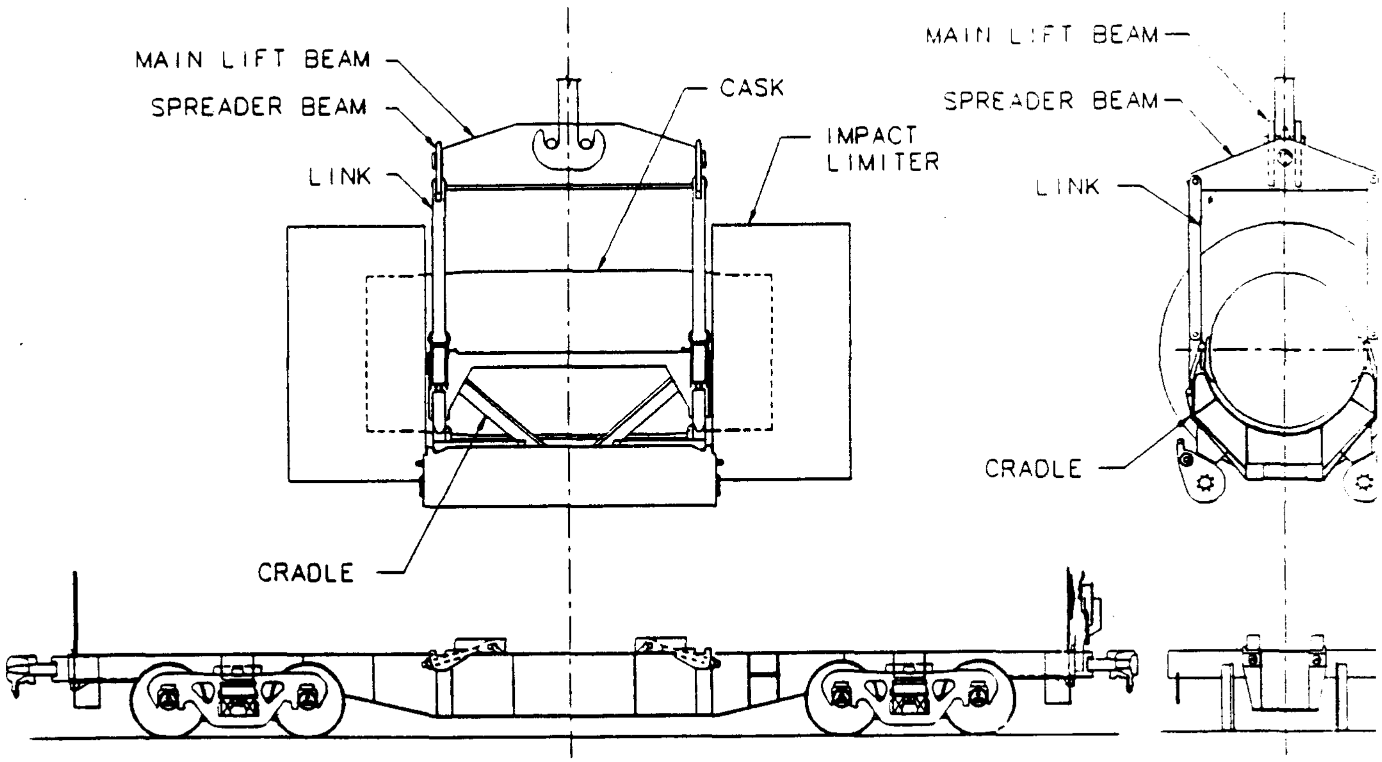


FIGURE B.1.2-6
Intermodal Transfer from Railcar

B.1.2.2.6 Other Considerations

The cradle/cask system design must be coordinated with the railcar design. Attachment and support points for the cradle must be provided in the car deck at the required locations and have sufficient strength. The weight of the cask/tiedown system and location of its supports will greatly influence the car design. Also, the CG location and dynamic properties of the cask/tiedown assembly will influence the railcar dynamic stability.

B.1.2.3 Analytical Results

Analysis shows that under the required loading conditions all components of the tiedown system will have positive margins of safety and that the system will preform all the required functions. The maximum stress indicated in the cradle is 131.4 ksi. Thus, the cradle can be made lighter but care must be taken in the process to prevent buckling in the thin sections. Also the pocket area needs more detailed analysis when the cask support lug configuration is finalized. Both of these items will be addressed during final design.

It is estimated the finished tiedown system will weight 7,373 lbs. A factor of 10% is included in this weight to account for weld metal, reinforcing plates, nuts, bolts, etc.

	Weight	CG *
Cradle	4,547 lbs	33.7"
Cask tiedown clamps	620 lbs	48.6"
Tiedown bolts/blocks	2,215 lbs	3.0"
Total:	7,373 lbs	25.7"
(For overall wt calculations	7,400 lbs)	

* The CG is measured up from the car deck.

The maximum interface loads applied to the railcar by the tiedown system during the worst case (maximum breakaway) conditions are shown in Figure B.1.2-7 and Table B.1.2.1. The loads can occur in any one of 6 possible combinations depending on the directions of the applied inertial loads. These are the loads which should be used for designing the attachments for the tiedown components to the railcar. It is required that the attachment points on the railcar shall not separate from the tiedown system components at loads lower than those specified herein. The railcar itself will be designed to a different set of requirements. The lateral spacing geometry of the cradle base and the vertical tiedown bolts are show in Figure B.1.2-8.

TABLE B.1.2.1
MAXIMUM INTERFACE LOADS

Location	X	Y	Z
Longitude bolt	930 kips	249 kips	0.0
Vertical bolts	0.0	580 kips	0.0
Cradle base corner	0.0	-580 kips	330 kips

The lateral natural frequency of the cask/cradle assembly is estimated to be 3.3 Hz. From conversations with railcar manufacturers, it is desired to avoid a natural frequency of 1 Hz to avoid excessive excitation during rail transportation. This is based on the car deck being rigid.

The internodal lift lugs (5) on the cradle are adequately strong for lifting the cask/impact limiter/cradle assembly per the requirements of ANSI N14.6

LOAD CASE #1 *

LONGITUDINAL, +X OR -X DIRECTION
(TOWARDS EITHER END OF RAILCAR)

LOAD CASE #2 *

LATERAL, +Z OR -Z DIRECTION
(TOWARDS EITHER SIDE OF RAILCAR)

LOAD CASE #3 *

VERTICAL, -Y DIRECTION
(UP)

LOAD CASE #4 *

VERTICAL, -Y DIRECTION
(DOWN)

* ALL LOADS EXPRESSED IN POUNDS

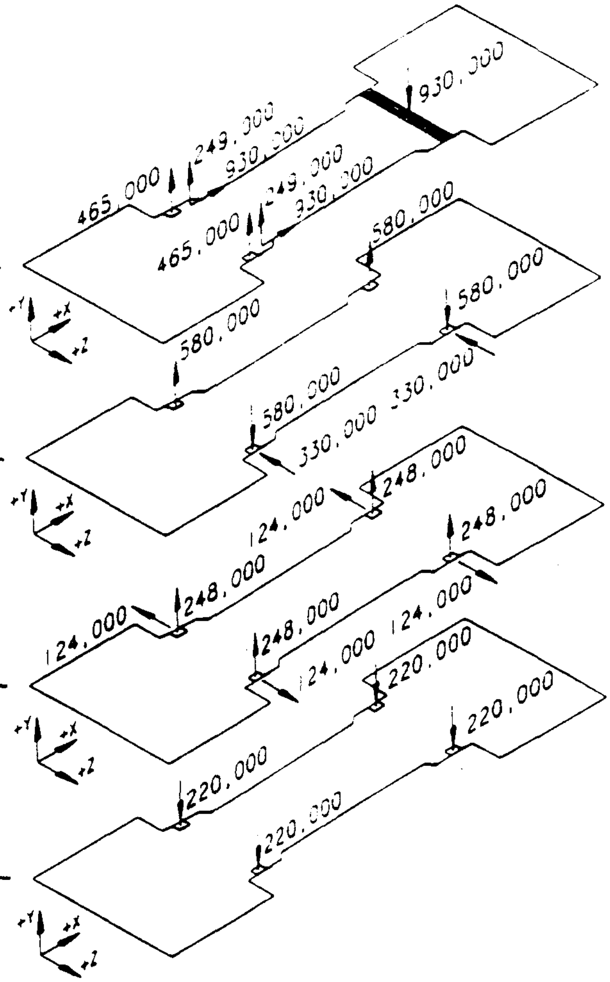


FIGURE B.1.2-7

Maximum Railcar Interface Load Container

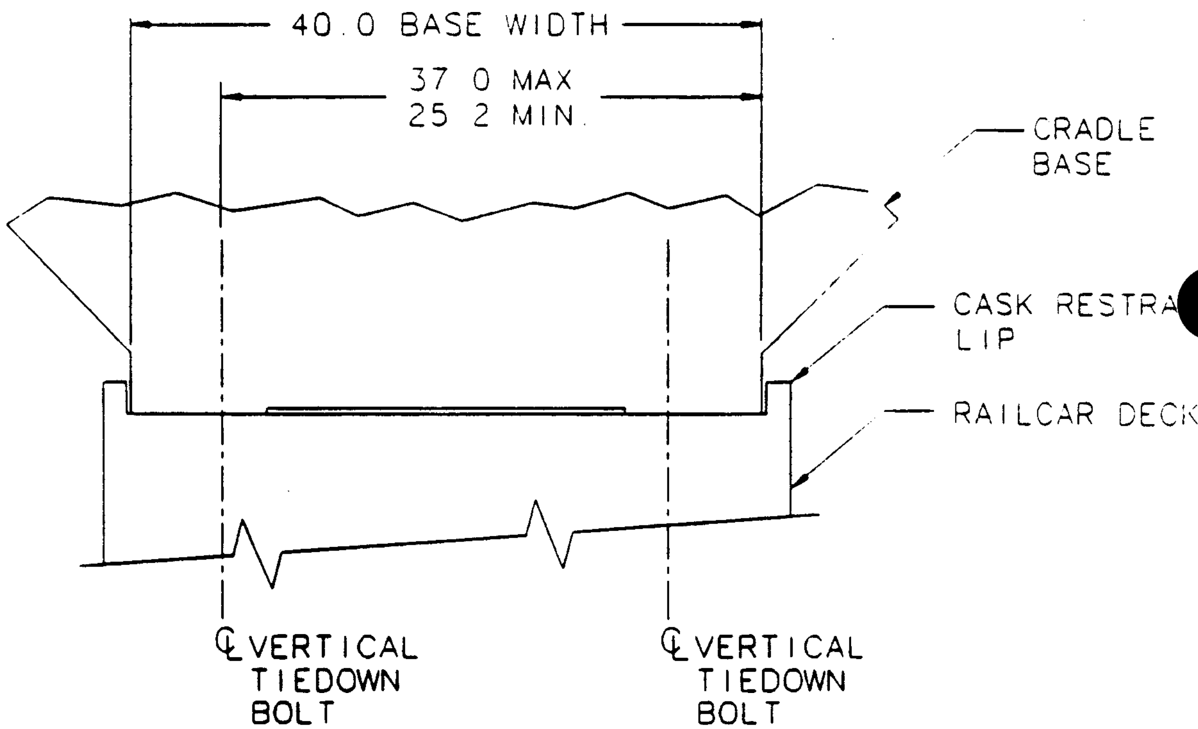


FIGURE B.1.2-8

Lateral Spacing Requirements for Vertical Tiedown Bolts and Cradle Width

B.1.2.4 Future Recommended Studies

The following items need to be addressed in more detail in the final design process:

a) The present cradle analysis is a 2-D pin jointed model except for the end bulkhead. A 3-D analysis using beam members should be done to determine the joint moments. The cradle joint designs should then be revised to accommodate the applicable moments.

b) The torque box should be addressed in more detail. Stiffeners will be required to prevent buckling.

c) A fatigue analysis should be done. It should be based on the normal railroad operating loads.

d) A more detailed analysis of the cradle pocket area should be done when the cask support lug details are completed.

e) Complete the tiedown bolt attachment in the cradle base. The tiedown design must be coordinated with the railcar design.

f) Provide justification for the acceptability of the ductility of the ASTM A538 steel if it is required.

g) All calculations should be updated to the final cask and railcar parameters and a final weight assessment should be accomplished.

h) The design will be reviewed and may need to be modified to meet DOE remote-automated handling methods.

B.1.2.5 Structural Verification

The section contains information concerning design requirements, assumptions, loads, material properties and references. The detailed calculations are presented in Appendix A2.

B.1.2.5.1 Design Requirements

Applicable Documents

- Contract No. DE-AC07-88ID12700, D.O.E./NuPac
- Field Manual of the AAR - Interchange Rules
- Office Manual of the AAR - Interchange Rules
- Manual of Standards and Recommended Practices, Section C - Part III, M-1001 (AAR)
- American Iron and Steel Institute (ANSI) Specifications
- American Welding Society, AWS D1.1-80 "Structural Welding Code"

Functional Requirements

- Fast and easy operation during fuel loading
- No breakaway at less than AAR requirements
- No impairment of cask safety during breakaway
- Capable of intermodal transfer between railcar and barge.

B.1.2.5.2 Assumptions

- The rail car deck is rigid
- The cask is rigid
- The tiedown loads are applied independently in each direction

B.1.5.5.3 Loads

Normal Operation

- 1 g gravity forces

Rail Transport Loads

- AAR tiedown loads per Rule 88 (ref.2)
  - 7.5 g's longitudinal
  - 4.0 g's vertical (up or down)
  - 1.8 g's lateral
  - These loads are based on the inertial loads times the weight of the cask package, W=220.Kips (see Table B.1.2.2)

TABLE B.1.2.2

INERTIAL CASK LOADS

Description	Tiedown	Minimum	Maximum
Longitudinal	1,650 K	1,690 K	1,859 K
Vertical, Fy	880 K	901 K	992 K
Lateral, Fz	396 K	406 K	446 K
3.g's Fz	-	-	660 K *

* This is the maximum acceptable load at which the actual lateral breakaway is assured based on the strength and geometric requirements of the cask and tiedown system.

Railcar transport load definitions:

- o Minimum tiedown loads
  - The specified minimum AAR tiedown requirements
  - No breakaway at loads below this level
  - The tiedown system components must not yield at these loads
- o Minimum breakaway loads
  - The least load at which a breakaway might occur
  - Based on the ratio of the ultimate strength of the tiedown bolts to their yield strength
- o Maximum breakaway loads
  - The maximum load required to assure breakaway
  - Based on the minimum breakaway load plus 10% plus any other load increasing factors
  - The maximum breakaway load must be less than any load which will impair the safety functions of the cask
  - The tiedown system, except for the tiedown bolts, must not yield at these loads.

Design temperature range *

- o Maximum: 130°F
- o Minimum: -40°F

* Defined by NuPac

Intermodal transfer loads *

- o This is a lifting condition for the cask. Thus the analysis will be based on a 1. g down load plus safety factors as required by ANSI N14.6 (ref. 8)

- o The required safety factors are 3.0 on yield or 5.0 on ultimate. Buckling is considered to be an ultimate condition.

Barge tiedown and transfer loads

- o Will be developed during final design.

B.1.5.5.4 Material Properties (Allowable Stresses)

ASTM A538 - Marging steel (Reference 10)
(Room temperature properties)

	T-200 grade	T-250 grade
Ftu =	210 ksi	260 ksi
Fty =	205 ksi	255 ksi
Fsu =		155 ksi
E =	26.5E6 psi	26.5E6 psi
elong =	14%	11%
Charpy strength =	81 Ft - Lbs	25 Ft - Lbs

The values of the material properties vary with temperature. In the range of -40°F to 250°F the tensile strength of A538 varies almost linearly from 92% of the room temperature value at 250°F to 105% at -40°F (ref. 11). The temperature effects will cause variations in the rupture strength of the tiedown bolts. But the strength of the rest of the tiedown structures will also be varying in proportion to the temperature changes. So while the actual breakaway loads may vary with temperature, the tiedown system is still be adequately strong.

No specifications are given for the allowable stresses in the tiedown system. Thus, reasonable margins consistent weight a minimum with structure will be assumed for the breakaway conditions based on engineering judgement.

- A minimum margin of 0.0 on yield at the maximum breakaway loads will be used since this is an accident condition.
- A minimum safety factor of 1.2 on buckling at the maximum breakaway loads will be used.
- A minimum safety factor of 1.1 on yield at the maximum breakaway loads.
- All margin calculations will be based on the Stress Intensity.
- Allowable stresses for the Intermodal lift will be based on ANSI N14.6. The max allowable stresses will be least of 1/3 of yield or 1/5 of ultimate.

B.1.5.5.5 References

1. Contract No. DE-AC07-88ID12700, DOE/NuPac
2. Field Manual of the AAR Interchange Rules, 1985 Association of American Railroads, 1192 L Street NW Washington, D.C. 20036.
3. Office Manual of the AAR Interchange Rules, 1985 Association of American Railroads, 1192 L Street NW Washington, D.C. 20036.
4. Roark, 4th Ed., Formulas for Stress and Strain, McGraw-Hill.
5. Timoshenko and Young, Elements of Strength of Materials, 5th Ed., D. Van Nostand Co., Princeton, NJ.
6. The Crosby Group, P.O. Box 3128, Tulsa, OK AISC Manual of Steel Construction, 7th Ed., AISC, 101 Park Avenue, New York, NY.
7. AISC Manual of Steel Construction, 7th Ed., AISC, 101 Park Avenue, New York, NY.
8. ANSI N14.6 - American National Standards for Shipping Containers Weighing 10,000 Pounds or More for Nuclear Materials, 1986, American National Standards Institute, Inc., 1430 Broadway, New York, NY 10018.
9. Task 2.1 - Shock Loading Environments, F.D. Irani, Association of American Railroads, Pueblo, CO 81001
10. VascoMax, T-200 and T-250, 1985, Teledyne Vaco, P.O. Box 151, Labrobe, PA 5650, 800/537-5551
11. Mil-Hdbk-5E, Metallic Materials and Elements for Aerospace Structures, Department of Defense, Washington, D.C., June 1, 1987

B.1.3 140-B Cask Uprighting System

The cask uprighting system consists of the cask turning fixture and the impact limiter removal equipment. The cask uprighting Yoke to lift the cask is described in Section B.1.1.

B.1.3.1 General Description

The cask turning fixture provides support and pivot points for the lower trunnions when uprighting the cask from and lowering it onto the cradle. The turning fixture is shown in Figure B.1.3.1. is not carried on the cask railcar so that its substantial weight is not added to the gross vehicle weight, but would be at the facility prior to arrival of the cask.

The turning fixture consists of a welded steel frame which guides a pair of trunnion journal blocks. The blocks can slide up or down in the frame, and are supported by 50-ton hydraulic jacks. The jacks are used to raise the trunnion blocks up to the trunnions for uprighting and to lower the blocks after the cask is placed in the cradle so that the turning fixture can be removed

The impact limiter removal system consists of two dollies at either end of the railcar, which are used to roll the impact limiters away from the cask. A system of screw jacks on the dollies is used to lift the weight of the impact limiters so that the dollies can be rolled back from the cask.

B.1.3.2 Component Description

The uprighting fixture consists of the following components:

Uprighting Fixture Frame - Steel weldment of sufficient strength to react loads induced by the weight of the cask. Construction is of steel plate welded into a box beam configuration.

Trunnion Journal Blocks - Steel blocks machined to provide the following:

1) Lead-in during cask placement on railcar

2) Wear surface during pivoting

3) Elevation adjustment to properly position the trunnion pivot points

Hydraulic Jack System - System consisting of two 50-ton cylinders, hand pumps, and hydraulic hoses. The system is used to elevate and lower the trunnion journal blocks.

Ratchet Binders - Two ratchet binders and attachment hardware are provided as a means to locate the uprighting fixture longitudinally on the railcar.

Lifting Lugs - Two lugs that attach to the fixture for lifting the fixture on and off the railcar.

The impact limiter removal system consists of the following components:

Transfer Dollies - A dolly on either end of the railcar is used to remove the impact limiters from the cask and support them on the railcar during cask uprighting operations. The dollies roll on rails fastened to the railcar deck.

Impact Limiter Support Frames - A frame on each dolly forms a v-trough which supports the impact limiter in a stable arrangement on the dolly.

Impact Limiter Lifting Jacks - Manually-operated screw jacks on each dolly are used to raise the support frames to remove the weight of the impact limiters from the cask and the cask attachment bolts.

B.1.3.3 <u>Operational Description</u>

To prepare the cask for uprighting, the sunshield/personnel barrier (see Section B.1.4) must be retracted and the impact limiters removed. The impact limiter transfer dollies are placed on their tracks at each end of the railcar and rolled under the impact limiters. The dollies' screw jacks are raised until the weight of the impact limiters are supported on the dollies. The impact limiter fasteners are removed and the dollies, supporting the impact limiters, are rolled to each end of the railcar. If necessary, the ratchet binders used to align the turning fixture may be used to retract the dollies.

After the impact limiters have been removed from the cask, the turning fixture is then positioned onto the railcar and placed at the bottom end of the cask. The two ratchet binders are attached to the fixture and to the railcar deck. The binders are then operated to align the turning fixture underneath the cask's lower trunnions as shown in Figure B.1.3.2. When the fixture is located under the cask trunnions, it is then fastened to the deck of the railcar. The hydraulic hand pumps which operate the jacks are connected to the jack by flexible hoses and quick-connect fittings. The jacks are then raised to lift the turning fixture trunnion blocks into contact with the trunnions. Pilot-to-open check valves at the jack prevent any possibility of load drop when the cask is uprighted, even if the hydraulic hoses are disconnected or severed.

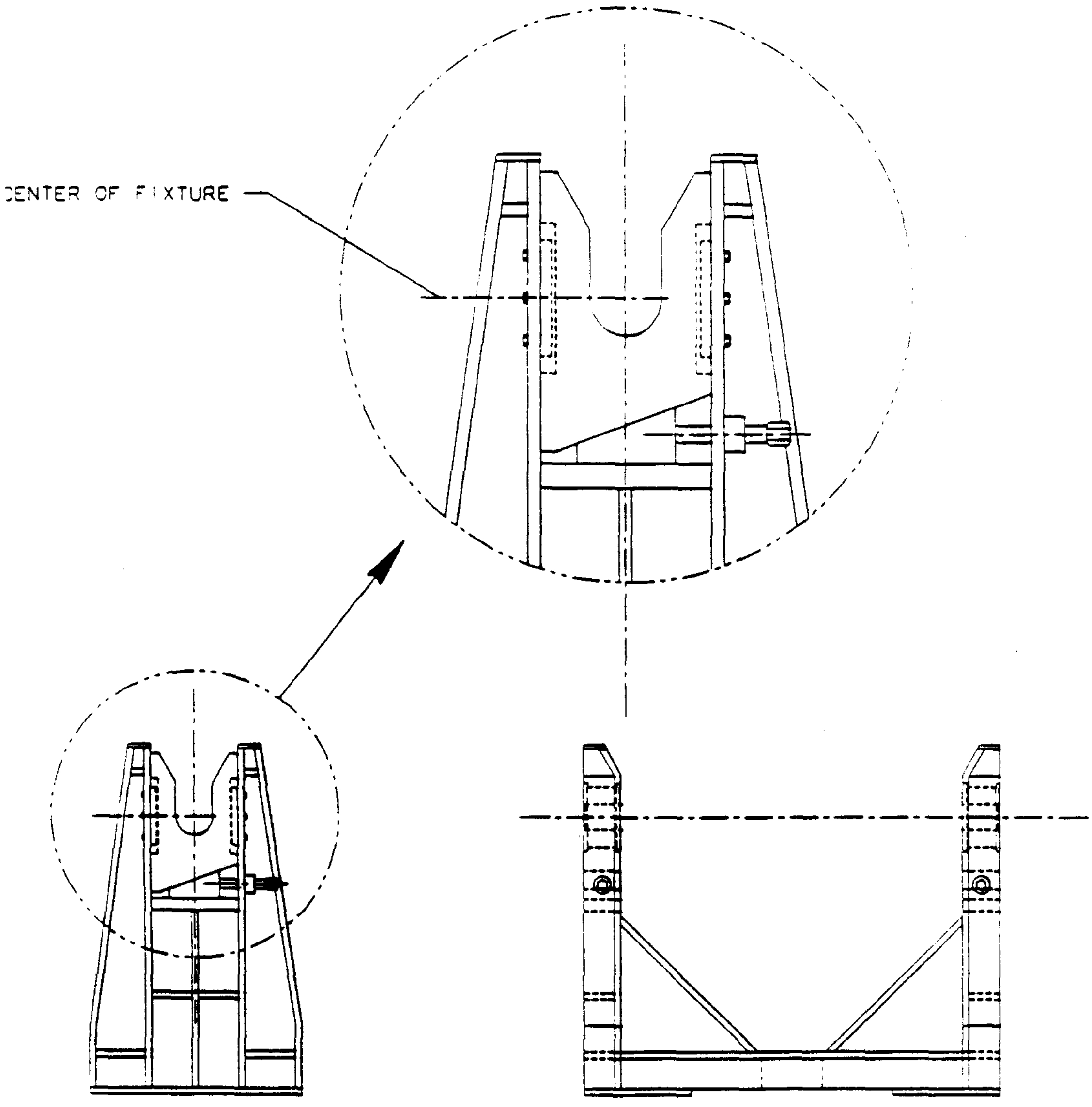


FIGURE B.1.3-1
Cask Uprighting Fixture

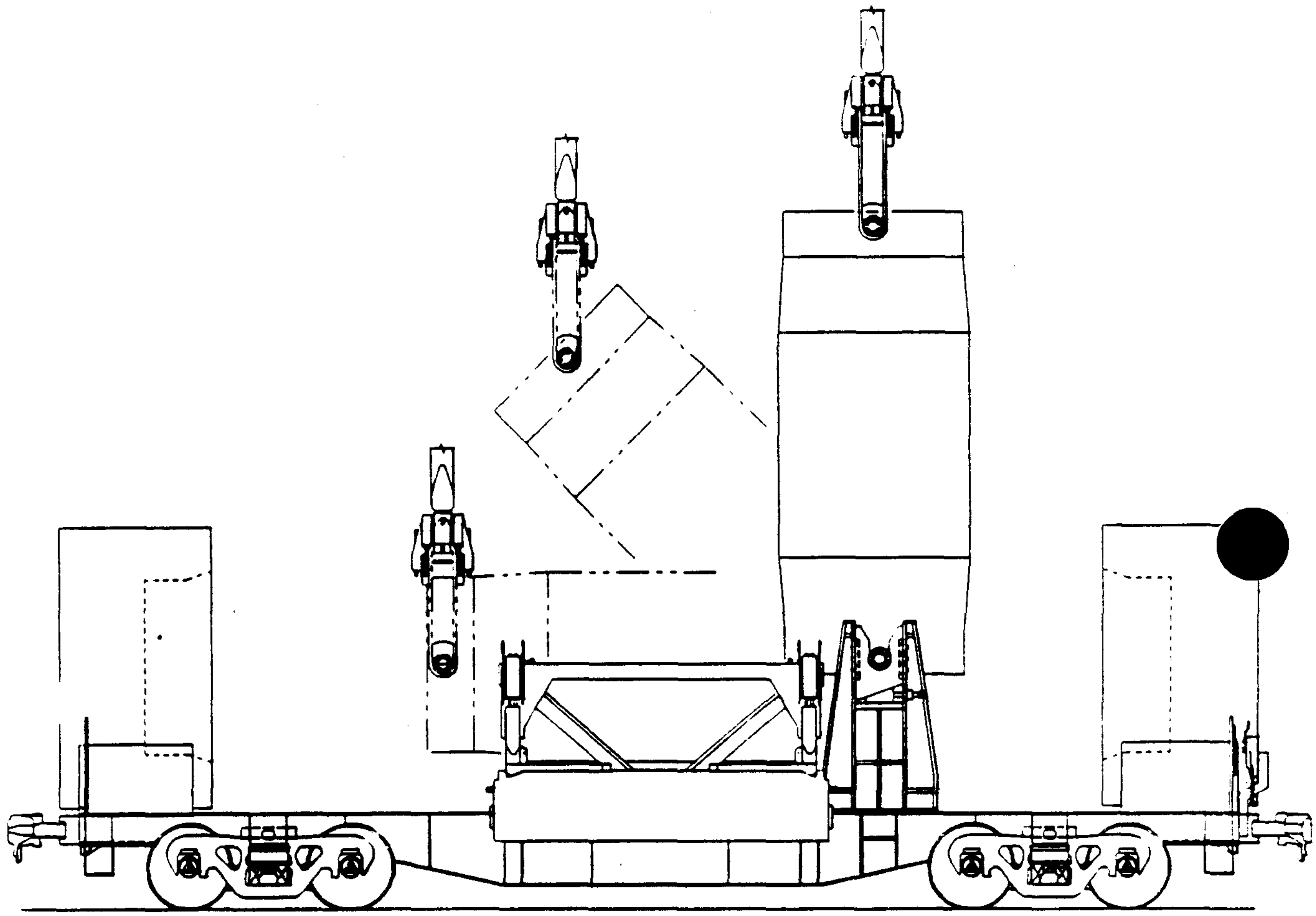


FIGURE B.1.3-2
Cask Assembly - Uprighting of Cask

B.1.4 140-B CASK SUNSHIELD/PERSONNEL BARRIER

The following section provides a description of the sunshield/personnel barrier. The sunshield/personnel barrier serves two primary functions. The barrier shields the cask and tie-down hardware from the elements including rain, dirt, vandalism, and incidental transportation hazards. The barrier also reduces the solar heat load on the cask surface while providing a flow path for air around the cask.

The second function of the sunshield/personnel barrier is to limit access to the cask surface and tie-down hardware by personnel. This serves to prevent unauthorized or accidental manipulation of the tie-down hardware. It also serves to protect railworkers from potentially hazardous surface temperatures of the cask, and to limit the minimum distance between personnel and the cask surface to maintain maximum dose rates in accordance with 10 CFR 71.

B.1.4.1 System Description

The sunshield/personnel barrier consists of two rolling door assemblies (one per side) mounted to the cradle near deck level of the railcar as shown in Figure B.1.4-1. The concept is similar to the rolling service doors used in commercial buildings and other structures. The components making up the sunshield/personnel barrier are based on standard design components used in the overhead door industry. Critical components such as rollers, bearings, and drive mechanisms are sealed and weatherproofed to ensure operation under adverse conditions. The drive mechanism, locks, and latches are operable from ground level.

Each barrier section is approximately 144 inches wide x 96 inches long, weighs approximately 1000 pounds and is rated for a 50 lbs/ft^2 wind load. The barrier sections are made up of stainless steel or aluminum interlocking slats coated with a zinc oxide base white paint. The sections follow grooved tracks, with sealed rollers spaced at the ends for guide. The top 30° of each door assembly is made up of solid slats, the following 60° is louvered, and the remaining vertical section is slotted to leave 30% of the barrier section open. This design is intended to provide a path for air circulation while minimizing solar heat input.

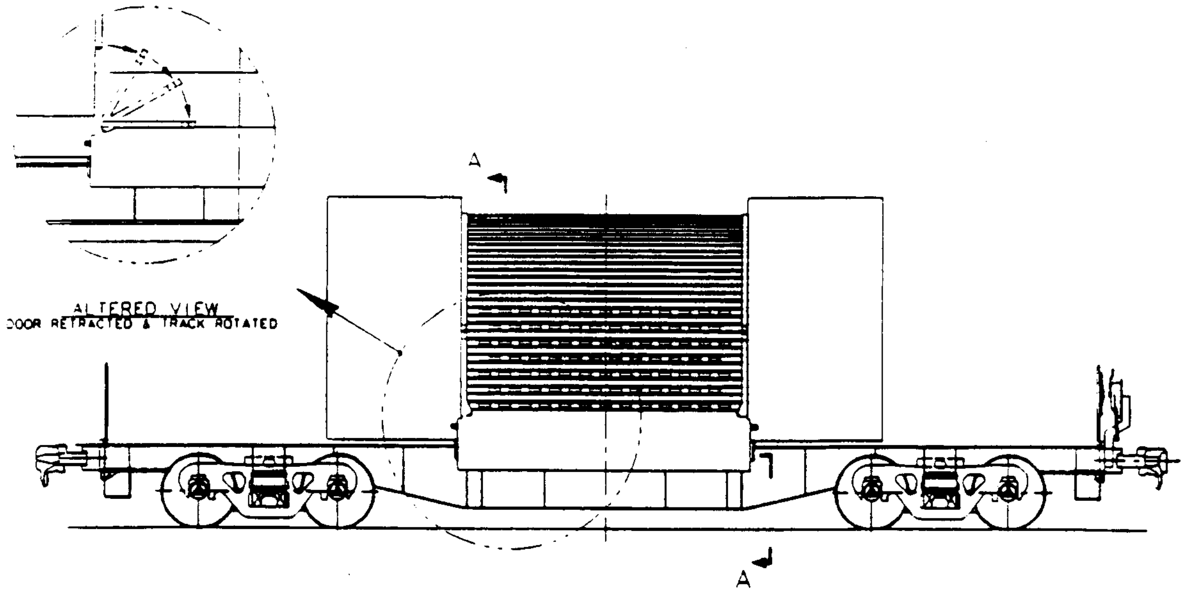
Grooved tracks are used to guide and contain the barriers during extending and retracting operations. Curved track sections are mounted on the impact limiters and remain in place when the limiters are detached from the cask. Vertical sections are mounted on the impact limiters and the take-up tubes, and fold down to allow access to the cask and tie-down hardware.

The take-up tube is a sheet metal housing that holds the barrier doors when they are retracted. The take-up tube assembly bolts to the cradle. The drive box includes a gear box, drive shaft, and sprockets that engage links in the barrier slats. It can be connected to an external power supply or to an impact wrench for manual operation of the barrier. The drive box is designed to extend or retract the barrier doors at 15-foot per minute.

B.1.4.2 Operational Description

Closing and opening the barrier requires an external power source to drive the closure mechanism, or an impact wrench for manual operation. With the cask and impact limiters in place, the vertical guide tracks are folded into place. The power supply to drive the barrier is connected to one drive box and activated to extend one barrier door into place. The power supply is then connected to the other side of the sunshield/personnel barrier and the operation repeated. The barrier is secured by locking the drive mechanism in the closed position and limiting access to the drive connection. The barrier is retracted in a similar fashion.

In the event that the sunshield/personnel barrier is damaged and cannot be retracted, it can be removed by removing the impact limiters and folding the barrier section out of the way. The drive mechanism has provisions for manual operation when a power source is not available.



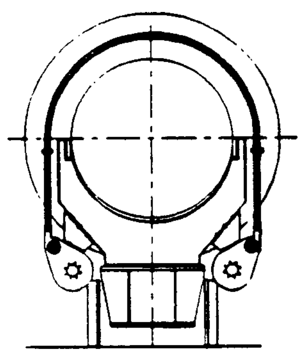


FIGURE B.1.4-1
Sunshield/Personnel Barrier Assembly

B.1.5 140-B Cask Railcar

The cask railcar is designed according to American Association of Railroad (AAR) requirements to transport the cask with a gross weight on the rails of less than 263,000 pounds. It provides support and attachment points for the cask cradle during shipment, a platform for removal of the impact limiters, and a stable base for uprighting and downending of the cask.

B.1.5.1 System Description

B.1.5.1.1 General Description

The cask railcar is an all welded, 100 ton, 47'-6-1/2" special purpose flatcar depicted in Figures B.1.6-1. The railcar weighs approximately 39,500 pounds and complies with AAR and FRA Specifications. The loaded deck height is 3'-3" and the maximum width is 10 feet. The railcar has a 150-foot uncoupled turning radius and a 186-foot turning radius when coupled with an AAR base car. The underframe and car body are sand blasted and painted for corrosion protection. All welding is performed by welders certified to AWS D-15.1.

B.1.5.1.2 Component Descriptions

Underframe and body construction: The center sill between body bolsters is constructed of built up box sections of HSLA steel. The top cover plate is locally reinforced for attachment to the cask and cradle. The center sill outboard of the body bolster is constructed from two HSLA AAR CZ-13 @41.2 lb/ft welded together according to AAR Plate 525. A fabricated striker and draft pocket suitable for a SBE67CE coupler and a 15-inch end-of-car cushion unit are provided. A cast steel low profile center plate is attached. The fabricated bolster consists of the following major components:

Top Cover Plate	5/8" x 24"
Bolster Webs	1/2" plate
Bottom Cover Plate	5/8" x 24"
Sole Plate	9/16" x 32"

The top cover plate extends the full width of the car. The bottom cover plates and web plates extend from the center sill to their extremities. They are connected to the sole plate across the bottom center sill. The side bearing reinforcement is a 3/8-inch formed "U" plate. Jacking pads of 1/2-inch structural steel plate are applied to the bottom cover at the ends of the bolsters. Lifting provision holes are provided in the body bolster bottom cover plate to fit the AAR specified gage. Four (4) roping staples are provided on the ends of the body bolsters. End sills are constructed as built-up box sections of 1/4-inch HSLA steel with 12" x 12" cross section. The top surface serves as the cross-over platform. Provisions are made for attachment of auxiliary walkways, platform and the like at loading and unloading sites. These include sprockets and pads to accept mounting struts and studs for the auxiliary equipment as finally designed.

Body Specialties: The body consists of AAR No. SBE67CE, Grade "E" couplers, a fabricated HSLA steel striker designed for a type E coupler and end-of-car cushion unit. The draft Stops are a fabricated HSLA steel design as prescribed for the end-of-car cushion unit which is a 15-inch travel E-O-C unit with gas return for E type coupler application. The coupler release is an AAR standard telescoping rotary operating design. The center plates/center fillers are low profile design, 16-inch diameter, Grade "B" cast steel flame hardened to 375 min. B.H.N. The side bearings are a flat design 5/8" x 4" wide. Shimming is applied to the body bolster as required to adjust side bearing clearance. Grab irons and ladder rungs are 3/4-inch diameter material and are applied with two-piece fasteners in accordance with current AAR/FRA requirements. There are two routing card boards and one defect car holder on each railcar.

Trucks: The trucks are 100 ton capacity ASF Ride Control type with 6-1/2" x 12" roller bearing journals and 4-1/4 inch spring travel. The side frames are AAR approved 6-1/2" x 12" cast steel with column guide wear plates. The bolsters are AAR approved cast steel with a 16-inch diameter bowl for 1-3/4 inch center plate engagement with wear liners in the center of the bowl. The trucks include a center pin, ASF Ride Control snubbing, hydraulic snubbers and side bearings, AAR alloy steel springs, N.F.L. type roller bearings with narrow pedestal adapters, AAR No. 18 brake beams, AAR H-4 2-inch composition brake shoes, single leaf brake shoe keys, unit type brake beam wear plates, and forged or flame cut truck levers, bottom rods, and jaws. The wheels are AAR CH-36 class "C" wheels and the axles are raised wheel seat, Grade "F", 6-1/2" x 12" roller bearing type.

Air Brakes: A truck mounted ABDW brake system is designed and applied in accordance with current AAR Specification No. 2518. The air brakes are tested according to current AAR requirements, including the actual brake shoe force readings. The railcar is equipped with an AAR Model 1980 hand brake with 9/16-inch BBB quality straight link chain and lube fittings, and an AAR approved automatic double acting slack adjuster. The brake fittings are schedule 80 with single gasket flange type socket welded fittings. The pipe clamps are split type wedge/base design and the brake pins are case hardened steel.

B.1.5.2 Operational Description

The railcar will be operated and maintained in accordance with the Office and Field Manual of the A.R.A Interchange Rules and any additional DOE requirements.

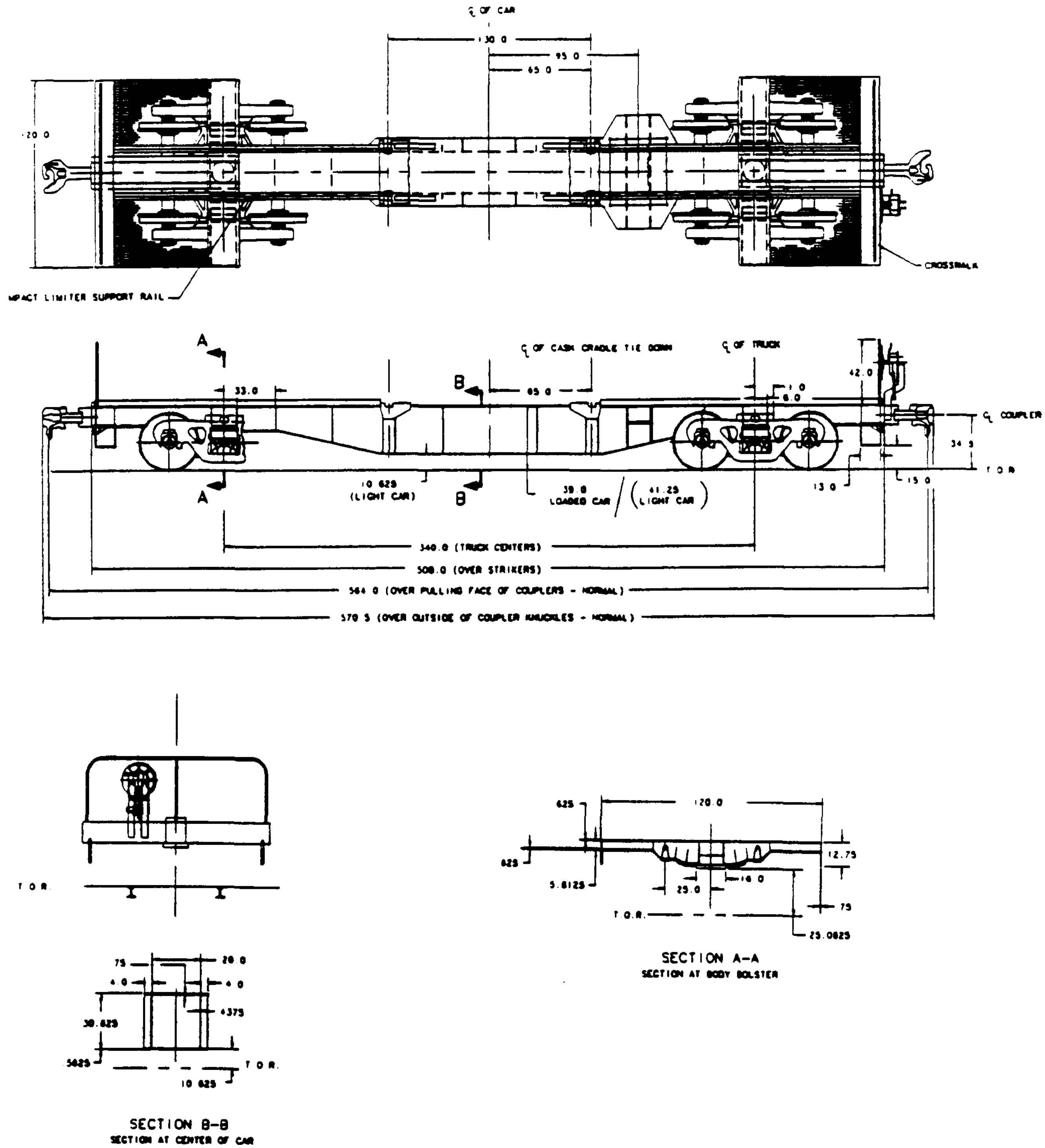


FIGURE B.1.5-1

140B Cask - Railcar Assembly

B.1.6 Other 140-B Auxiliary Equipment

B.1.6.1 Cask Seal Surface Protector Device

This device is installed on the cask prior to loading fuel underwater. This protects the cask seal surface from damage during fuel loading. It will be designed during final design.

B.1.6.2 Cask Leak Detecting Equipment

The cask leak detection equipment for both "Assembly Verification and Annual Test" will be identified during final design.

B.1.6.3 Cask Vacuum Drying Equipment

The cask vacuum drying system will be a single system connected to the vent port and will be designed during final design.

B.1.6.4 Draining and Inert Cask Equipment

This equipment will be identified in detail in the Cask Operating Manual and will be furnished by each loading site.

B.1.6.5 Cask Lid Bolt Torque Wrench System

This system will consist of two air operated Torque Wrenches with a reaction system. This system will be supported by a beam which will be supported by a auxiliary crane. The beam has the air supply for each wrench and can rotate about the crane hook. The wrenches are hung at each end of the beam. A load equalizer is used to support the weight of the wrenches. A flexible hose (Nycoil) is used between each wrench and beam. This type of wrench system has been used on our IF-300 for 12 years. This system will be designed in the final design phase.

B.1.6.6 Other Special Cask Handling Equipment

This equipment will be identified during final design phase and will be included in the Cask Operating Manual.

Appendix B.1.7

Structural Verification Calculations for the 140-B Cask Critical Lift Fixture

B.1.7.1 Description

This section covers the structural analysis of a single load path critical lift fixture made of ASTM-A538 maraging steel per the requirements of ANSI N14.6 (Reference 1). This is the lightest type of critical lift fixture for the cask. It is designed to meet the hook weight and hook height limitations of the OCRWM requirements.

There is no standard crane hook used in all the power plants where the 140-B cask might be operated. Therefore, the fixture configuration presented herein is intended only to show the feasibility of building a satisfactory lifting device and to allow the estimation of its weight. Each power plant may require some amount of customizing of the hook attachment area depending on the crane hook in use at the particular plant. Such modifications can easily be done for either a single or duplex hook.

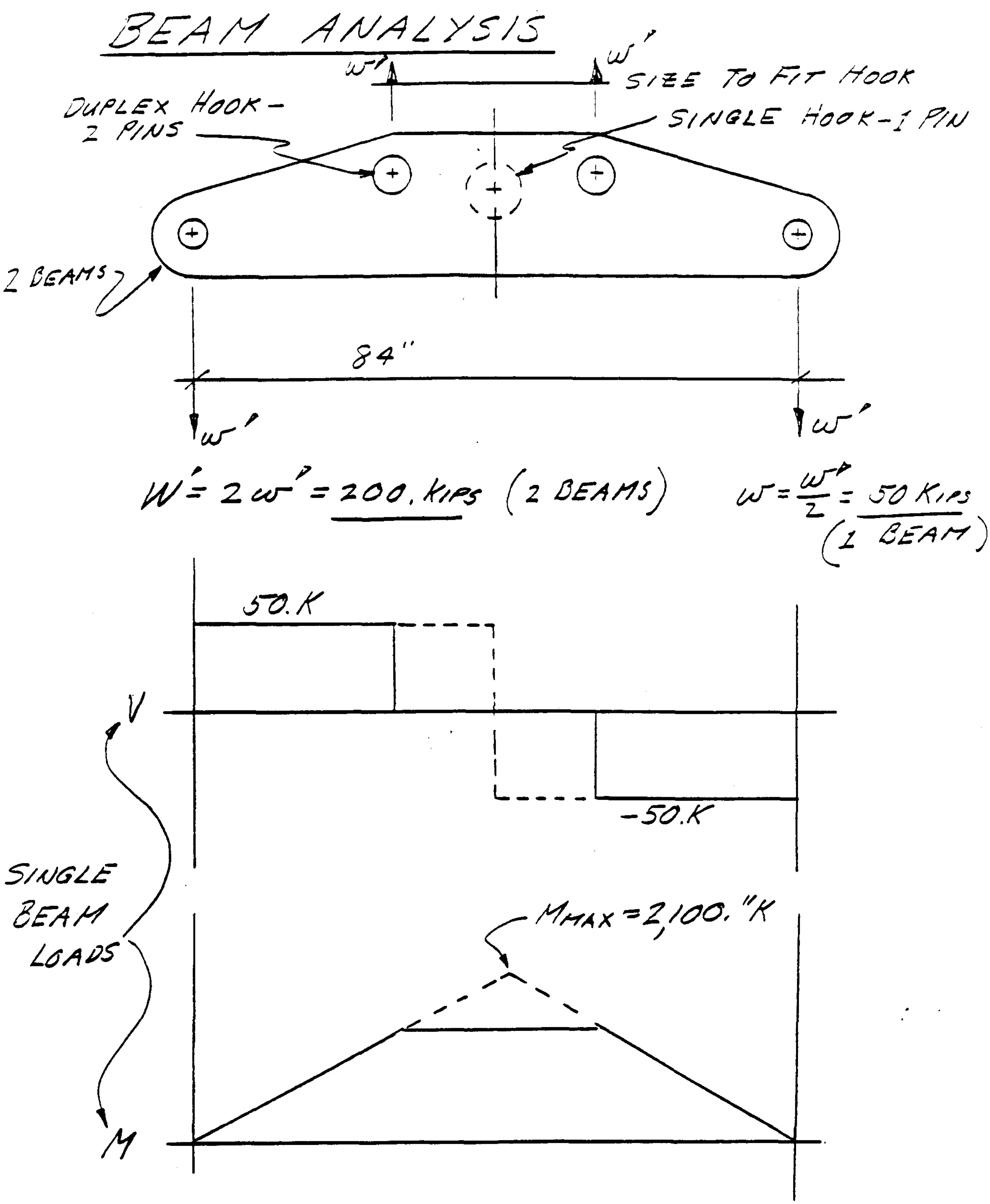
The fixture consists of a single pair of parallel beams (1) (see Figure B.1.1-1, Section B.1.1) and stirrups (2) for connecting to the cask trunnions. The stirrups are pneumatically actuated for remote operation. The fixture also includes equipment (5,6,7) for removing and replacing the cask lid in the fuel pool. Alignment fixtures will have to be attached to the cask prior to the removal/replacement operations.

Other configurations and materials were considered for the lifting fixture. A dual load path system was designed which consisted of two pairs of some what lighter parallel beams. The result was heavier than the single load path version. The use of ASTM A-537 steel was also considered for both the single and double load path configurations. Since the ASTM A-537 steel has a significantly lower strength than the ASTM A-538 the fixtures built with the ASTM A-537 will be heavier than the those built with ASTM A-538 (see Table B.1.1-1, Section B.1.1.4.1).

B.1.7.2 Geometry

See Figure B.1.1-1, Section B.1.1

B.1.7.3 Main Beam Bending



B.1.7.3 Main Beam Bending (continued)

A538 MARAGING STEEL DESIGN

MAIN BEAM CENTER SECTION

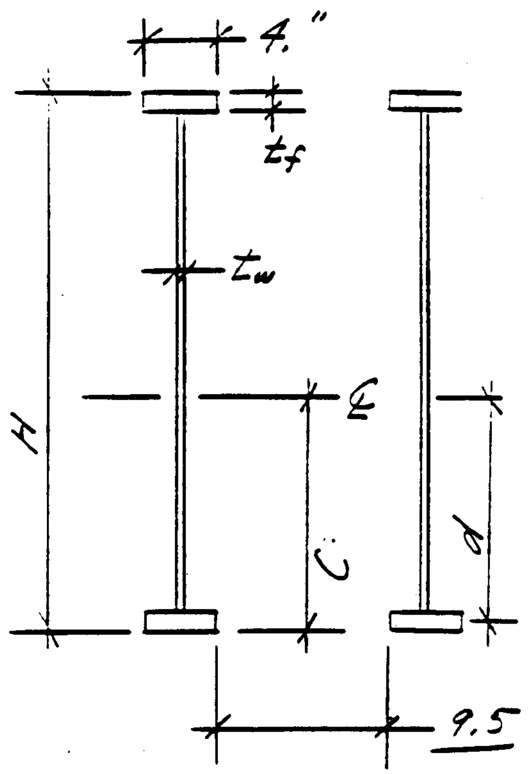
BASE THE SECTION PROPERTIES ON A SINGLE CENTER PIN LIFT AS THE WORST CASE.

MINIMUM SECTION MODULUS:

$$S_{MIN} = \frac{SF \times M_{MAX}}{F_{tu}} = \frac{10(2100K)}{260.K} = \underline{\underline{80.8}}\ IN^3$$

ASSUME A MAX. SECTION DEPTH OF H = 25."

USE A MAXIMUM FLANGE WIDTH OF 4."



ASSUME:

H = 25."

t_f = 1.0

t_w = .625

c = 12.5"

d = 12."

B.1.7.3 Main Beam Bending (continued)

SECTION MODULUS:

$$I = I_f + I_w = A_f d^2 + \frac{t_w(H-2t_f)^3}{12}$$

$$= 8 \times 12^2 + \frac{(.625)(25-2)^3}{12}$$

$$= 1{,}152. + 634 = \underline{1{,}786.}\ \text{IN}^4$$

$$S = \frac{I}{C} = \frac{1786.}{12.5} = \underline{\underline{142.8}}\ \text{IN}^3$$

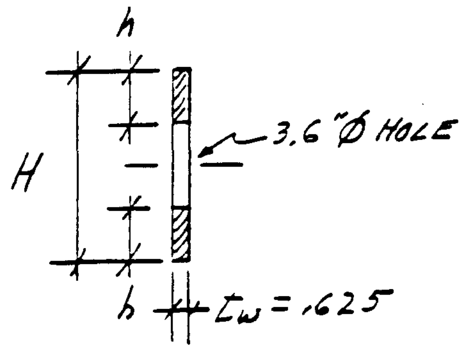
$$MS = \frac{142.8}{80.8} - 1 = \underline{\underline{.77}}$$

MAIN BEAM END SECTION

SHEAR AREA:

$$A_v = \frac{SF \times V}{.6\,F_{tu}} = \frac{10(50K)}{.6(210)} = \underline{3.97}\ \text{IN}^2$$

SECTION DEPTH:



B.1.7.3 Main Beam Bending (continued)

$$(2h)t_w = A_v$$

$$(2h)(.625) = 3.97$$

$$h = \underline{\underline{3.176}}$$

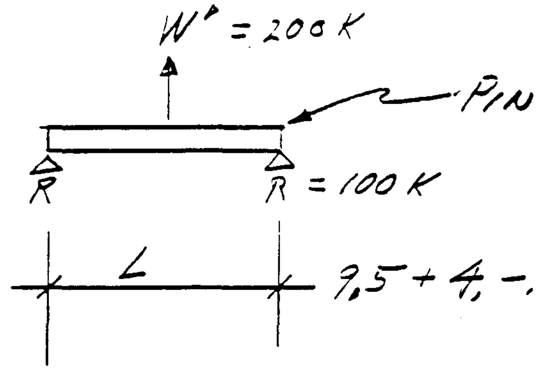
$$H = 3.6 + 2h = 3.6 + 2(3.176) = \underline{\underline{9.95''}}$$

USE H = 10.0"

NOTE - SEE SECT. A1.5 FOR ADDED MARGIN DUE TO PIN HOLE DOUBLERS.

B.1.7.4 Pin Sizes

SINGLE HOOK PIN: A538, T-200



$L = 9.5 + 4 - .625 = 12.875''$

$$M = SF\,\frac{W'L}{4} = (10)\,\frac{200K \times 12.875}{4} = 6{,}437.5\ ''K$$

$$S_{MIN} = \frac{M}{F_{tu}} = \frac{6437.5\ ''K}{210.K} = 30.65\ IN^3$$

$$D_{MIN} = \sqrt[3]{\frac{32S}{\pi}} = \sqrt[3]{\frac{32 \times 30.65}{\pi}} = 6.78''$$

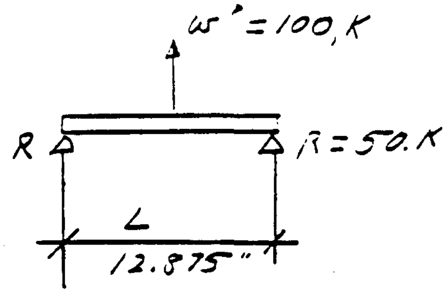
B.1.7.4 Pin Sizes (continued)

USE A 7.0" ϕ SINGLE HOOK PIN

$$S_7 = \frac{\pi}{32} 7^3 = \underline{33.67}$$

$$M.S. = \frac{33.67}{30.65} - 1 = \underline{\underline{.10}}$$

DUPLEX HOOK PINS (2): A538, T-200



$$M = SF \frac{w' L}{4} = 10 \frac{100K \times 12.875}{4} = \underline{3219.}\ ^{"K}$$

$$S_{MIN} = \frac{M}{F_{tu}} = \frac{3219.^{"K}}{210.^{K}} = \underline{15.33}\ \text{IN}^3$$

$$D_{MIN} = \sqrt[3]{\frac{32 S}{\pi}} = \sqrt[3]{\frac{32 \times 15.33}{\pi}} = \underline{5.38}$$

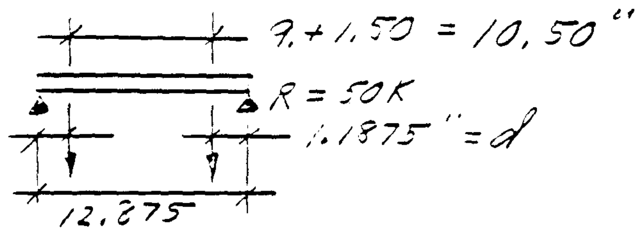
USE 5.6" ϕ DUPLEX HOOK PINS

$$S = \frac{\pi}{32} D^3 = \frac{\pi}{32} 5.6^3 = \underline{17.24}\ \text{IN.}^3$$

$$M.S. = \frac{17.24}{15.33} - 1 = \underline{\underline{.12}}$$

B.1.7.4 Pin Sizes (continued)

STIRRUP PINS: A538, T-200



SHEAR:

$$A_V = \frac{SF \times V}{.6 F_{tu}} = \frac{10(50K)}{.6(210K)} = \underline{3.97}\ IN^2$$

$$D_{MIN} = \sqrt{\frac{4A_V}{\pi}} = \sqrt{\frac{4(3.97)}{\pi}} = \underline{\underline{2.25}}"$$

BENDING:

$$M = SF \times R \times d = 10(50K)(1.1875) = \underline{594}\ "K$$

$$S_{MIN} = \frac{M}{F_{tu}} = \frac{594.K}{210.K} = \underline{2.83}$$

$$D_{MIN} = \sqrt[3]{\frac{32S}{\pi}} = \sqrt[3]{\frac{32 \times 2.83}{\pi}} = \underline{\underline{3.07}}"$$

USE 3.5" ϕ STIRRUP PINS

$$S = \frac{\pi}{32}D^3 = \frac{\pi}{32}(3.5)^3 = \underline{4.21}$$

$$MS = \frac{4.21}{2.83} - 1 = \underline{.49}$$

B.1.7.5 Pin Hole Doublers

DOUBLERS – CRANE HOOK PINS: A538, T-250 PINS

SINGLE PIN (7.0" ⌀)

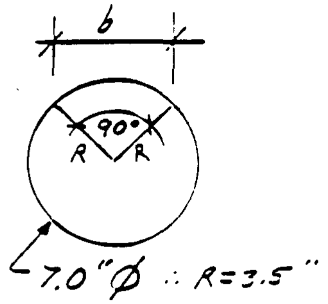
BEARING AREA REQUIRED:

$W = 10(100K) = \underline{1{,}000\,K}$

$F_{bru} = F_{ty} = \underline{205 \text{ ksi}}$ ASSUMED (CONSERVATIVE)

$A_{Br} \approx \frac{1000K}{205K} = \underline{4.88}\ in^2$ EACH END OF PIN

BEARING AREA:



$b = 2\left(R \cos \frac{\theta}{2}\right)$

$= 2(3.5 \cos 45°)$

$= \underline{4.95}"$

$A_B = bt \qquad t_{MIN} = \frac{A_{Br}}{b} = \frac{4.88}{4.95} = \underline{.99}\ IN.$

MINIMUM DOUBLER THICKNESS:

$t_D = (t_{MIN} - t_w)\left(\frac{1}{2}\right) = (.99 - .625)\left(\frac{1}{2}\right) = \underline{.1803}"$

USE ½" THICK DOUBLERS ON EACH SIDE

$M.S. = \frac{1.625"}{.99} - 1 = \underline{.64}$

B.1.7.5 Pin Hole Doublers (continued)

DOUBLE PIN (5.6" Ø), A538, T-200 PINS

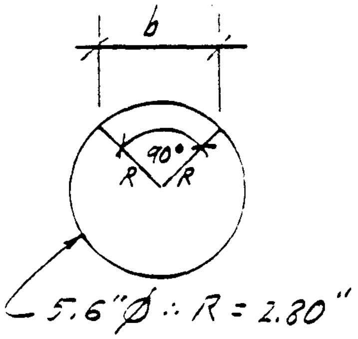
BEARING AREA REQUIRED:

$W = 10(50K) = \underline{500.K}$ EACH END OF PIN

$F_{bru} \approx F_{ty} = 205.KSI$ ASSUMED

$A_{br} \approx \frac{500K}{205K} = \underline{2.44}$ IN^2 EACH END OF PIN INCLUDING THE 5/8" THK. WEB

BEARING AREA:



$b = 2(R \cos \frac{\theta}{2})$

$= 2(2.80 \cos 45°)$

$= \underline{3.89}"$

$A_B = bt$ $t_{MIN} = \frac{A_{Br}}{b} = \frac{2.44}{3.89} = \underline{.616}$ IN.

MINIMUM DOUBLER THICKNESS:

$t_D = (t_{MIN} - t_W)(\frac{1}{2}) = (.616 - .625)(\frac{1}{2}) < \underline{\underline{0.0}}$

DOUBLER NOT REQ'D. FOR BEARING

USE ½" DOUBLERS ON EACH SIDE TO PREVENT POSSIBLE WEB BUCKLING

$M.S. = \frac{1.625}{.616} - 1 = \underline{\underline{1.63}}$

B.1.7.5 Pin Hole Doublers (continued)

STIRRUP PIN DOUBLERS (3.5"Ø) A538, T-300

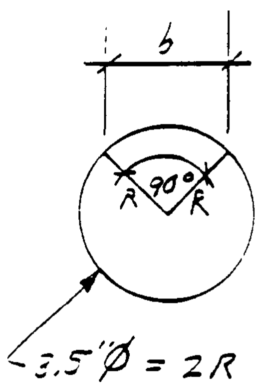
BEARING AREA REQUIRED:

$W = 10(50K) = \underline{500K}$ EACH END OF PIN

$F_{bru} \approx F_{ty} = \underline{205\ ksi}$ ASSUMED

$A_{br} = \frac{500K}{205K} = \underline{2.44\ in^2}$

BEARING AREA:



$b = 2R\cos\frac{\theta}{2}$

$= 3.5\cos 45°$

$= \underline{2.47''}$

$A_B = bt$ $\quad t_{MIN} = \frac{A_{br}}{b} = \frac{2.44}{2.47} = \underline{.986''}$

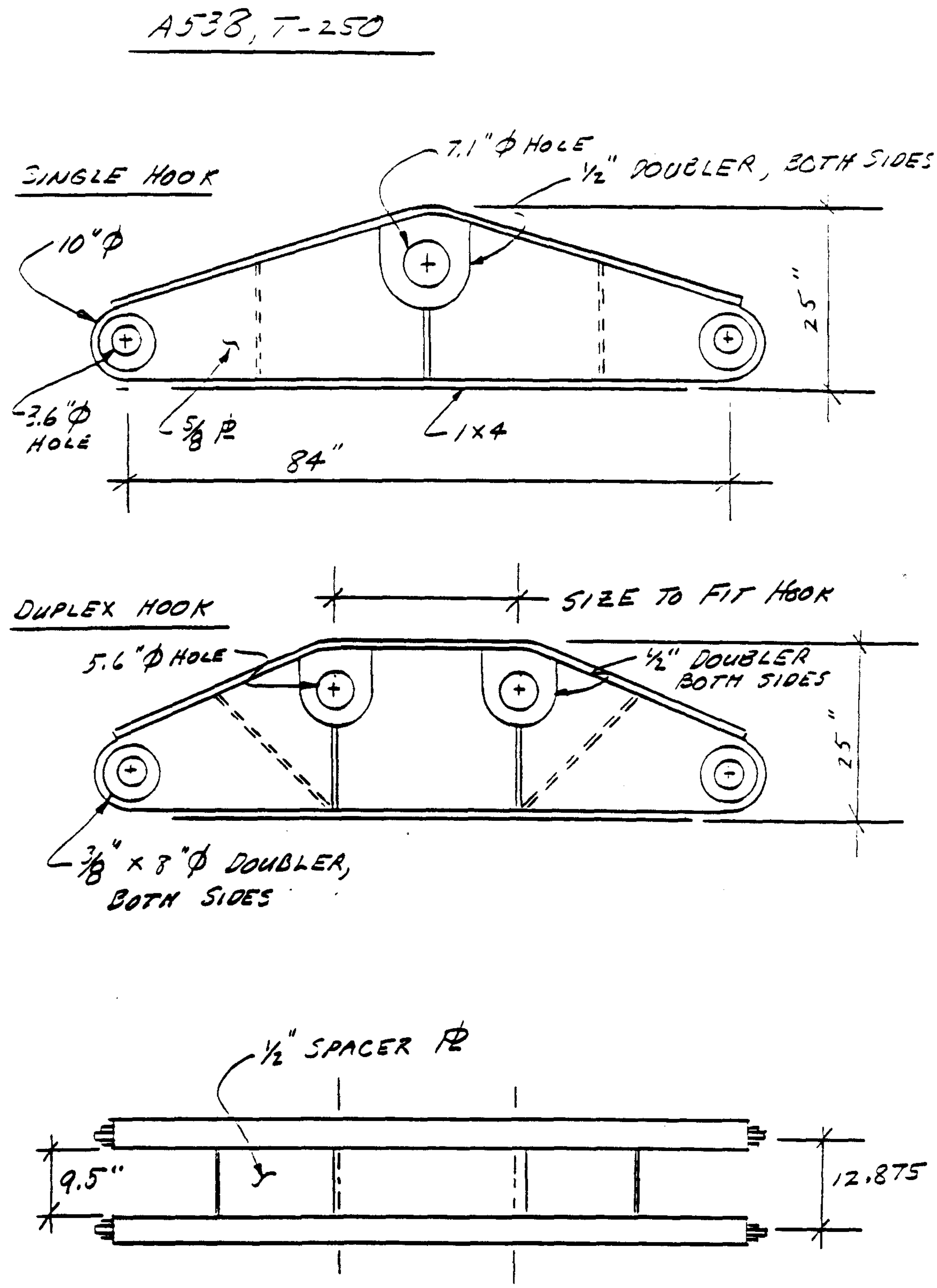
MINIMUM DOUBLER THICKNESS:

$t_D = (t_{MIN} - t_w)(\frac{1}{2}) = (.986 - .625)(\frac{1}{2}) = \underline{.1803\ in}$

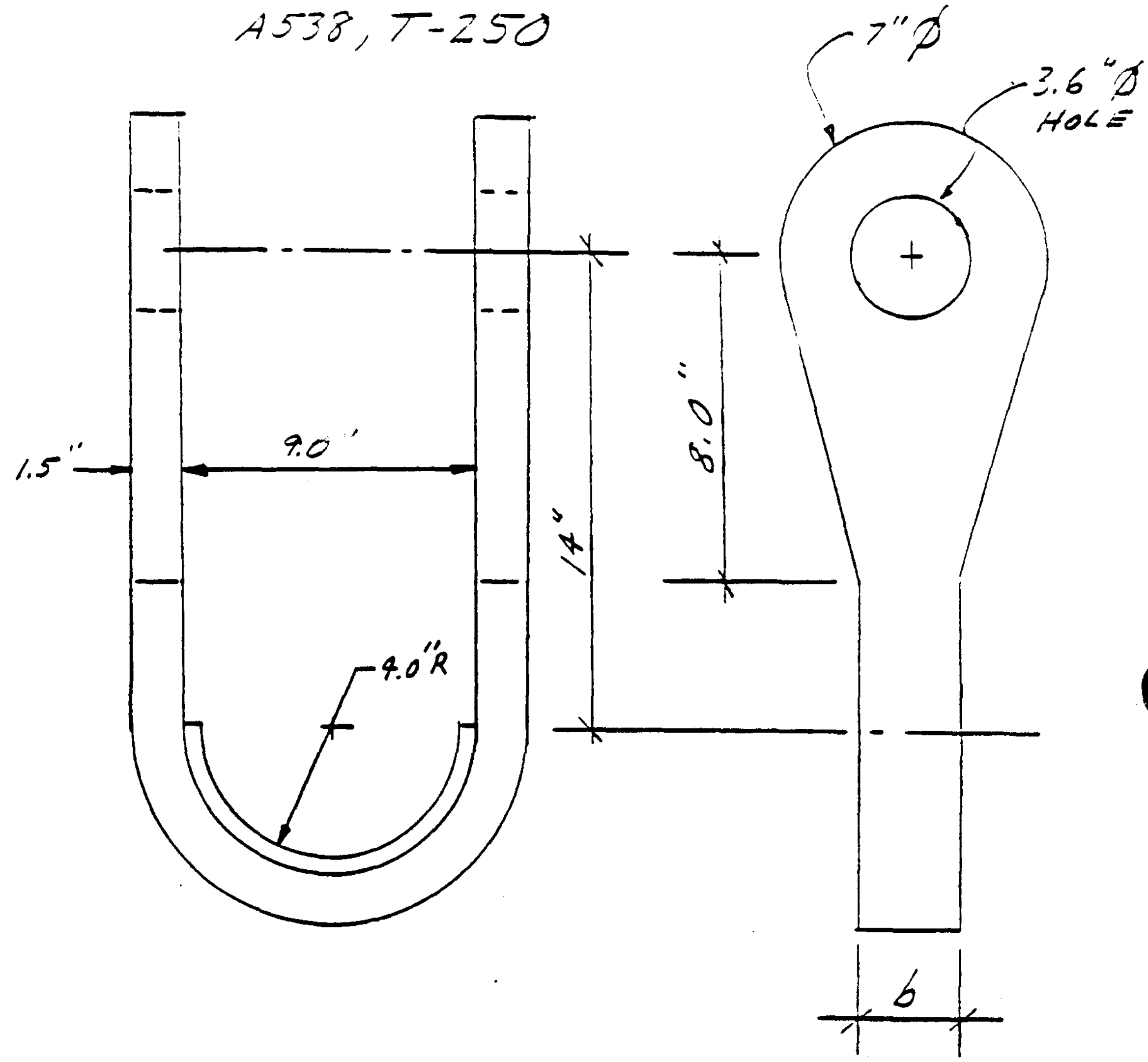
USE 3/8" DOUBLER EACH SIDE

$MS = \frac{.625 + .75}{.986} - 1 = \underline{\underline{.39}}$

B.1.7.6 Main Beam Minimum Geometry



B.1.7.7 Trunnion Stirrups



LEG TENSILE AREA:

$$A_T = \frac{10W}{F_{tu}} = \frac{10(50K)}{260.K} = \underline{1.923} \; IN^2$$

$$b_{MIN} = \frac{A_T}{1.5"} = \frac{1.923}{1.5} = \underline{1.28}"$$

USE 1½" × 3.0" LEG STRAPS

$$M.S. = \frac{1.5 \times 3.}{1.923} - 1 = \underline{\underline{1.34}}$$

B.1.7.7 Trunnion Stirrups (continued)

EYE SIZE:

ALLOWABLE STRESS – PER AISC [REF 10.7]
THE ALLOWABLE STRESS AT AN EYE IS .45 Fty. USE .45 Ftu WITH A SAFETY FACTOR OF 5.0.

$W = 50.K$

$$A_e = \frac{SF \times W}{\sigma} = \frac{5(50K)}{.45 \times 260.K} = \underline{2.137} \text{ IN}^2 \text{ NET}$$

EYE IS 1.50" THICK

WIDTH AROUND EYE:

$$b_e = \frac{A_e}{2\,t_e} = \frac{2.137}{2(1.5)} = \underline{.712}\,''$$

$$D_{MIN} = 3.6 + 2(.712) = \underline{5.02}\,''$$

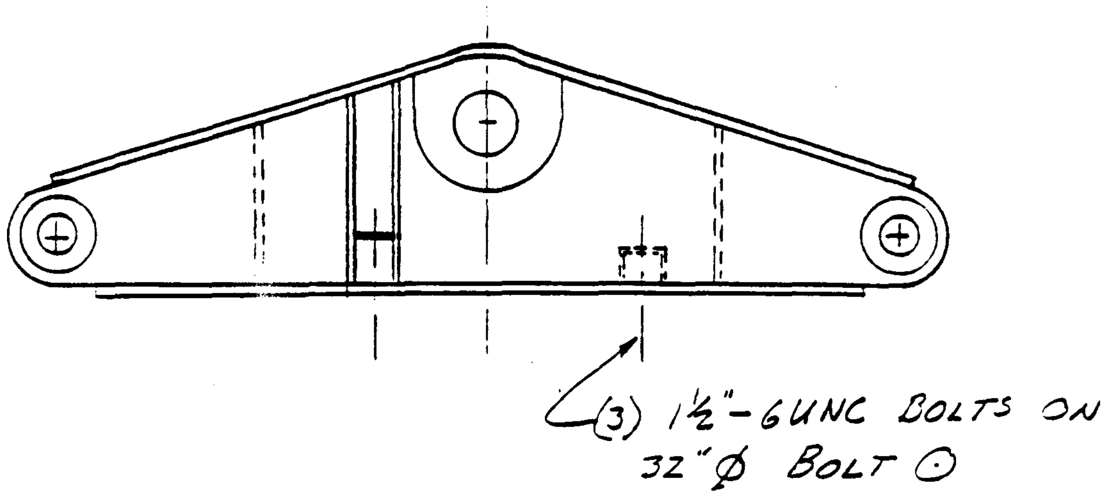
USE D_{eye} = 7.0"

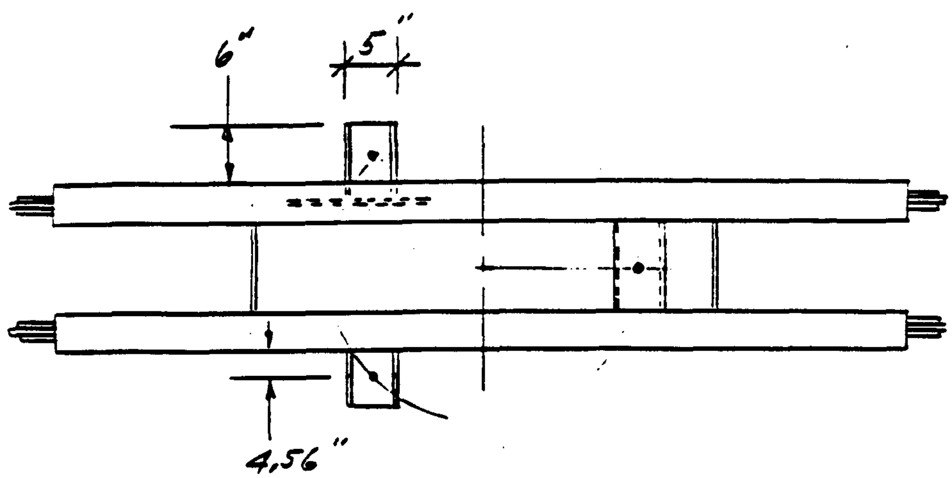
$$M.S. = \frac{(7.-3.6)(1.5)}{2.137} - 1 = \underline{\underline{1.39}}$$

B.1.7.8 Lid Lifting System

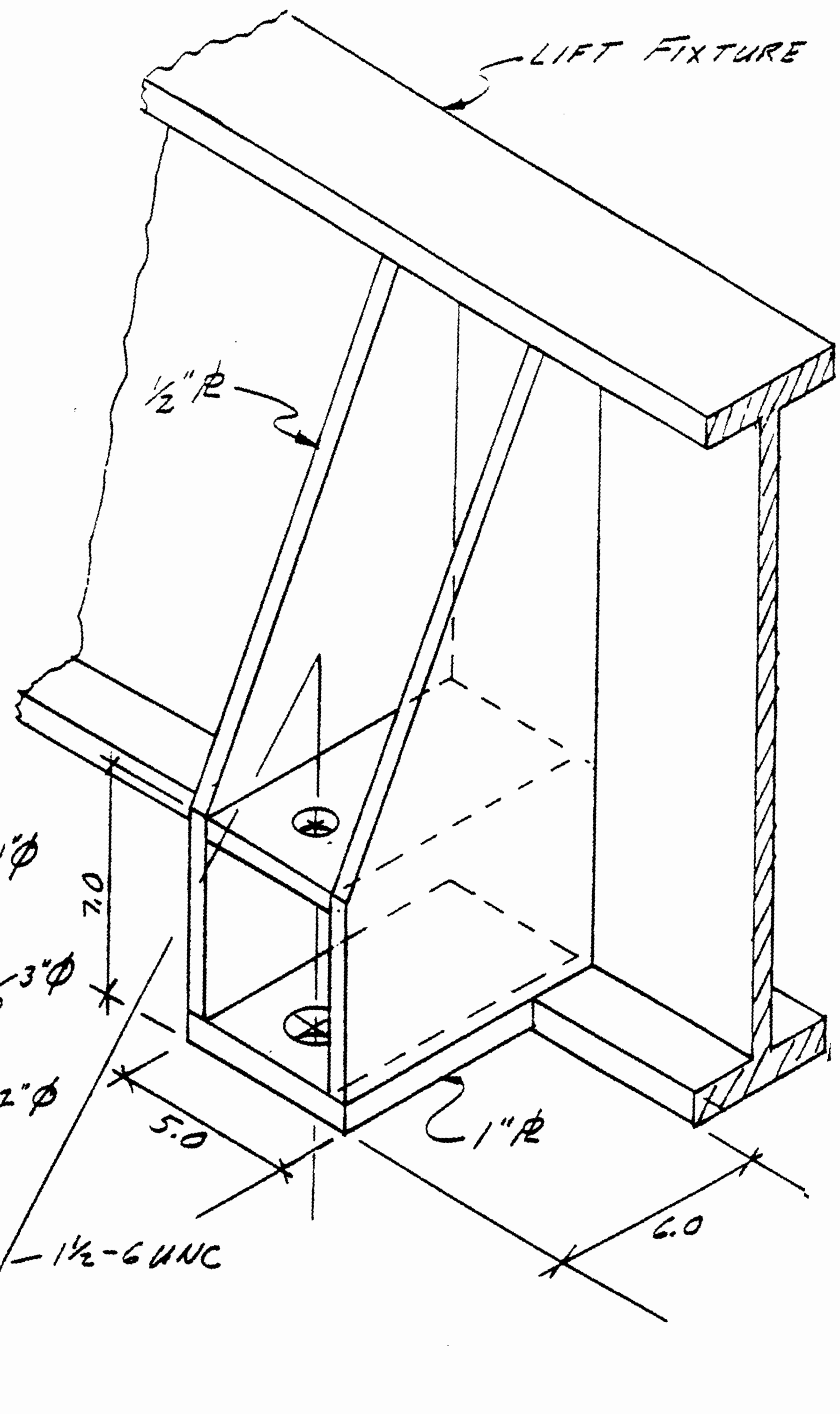
The lid lifting system (parts 5,6,7 - Figure B.1.1.1) provides a means of attaching the cask lid to the critical cask lifting fixture. This is accomplished by running 3 bolts (7) down through the bracket depicted below on the lift fixture and into threaded hole in the lid. The lid is unbolted from the cask but still in place and sealing the cask. The cask is then lifted into the fuel pool and the lifting fixture is released from the cask trunnions. When the lifting fixture is withdrawn from the cask, the lid is also withdrawn. The cask is then open to receive fuel rods.

The lid lift system is an integral part of the cask lifting fixture and must be coordinated with the cask lid design to assure the proper bolt hole alignment.





B.1.7.8 Lid Lifting System (continued)



B.1.7.8 Lid Lifting System (continued)

LID WT

LID DIA ≤ 67.″ LID THK ≤ 11.

$W_L = \left(\frac{\pi}{4} 67^2\right) 11 \times .283 \,\#/in^3 \approx \underline{11{,}000\,\#}$

LOAD PER BOLT

$w = SF\frac{W_L}{N} = 10\frac{11{,}000}{3} = \underline{\underline{36{,}667.\,\#}}$

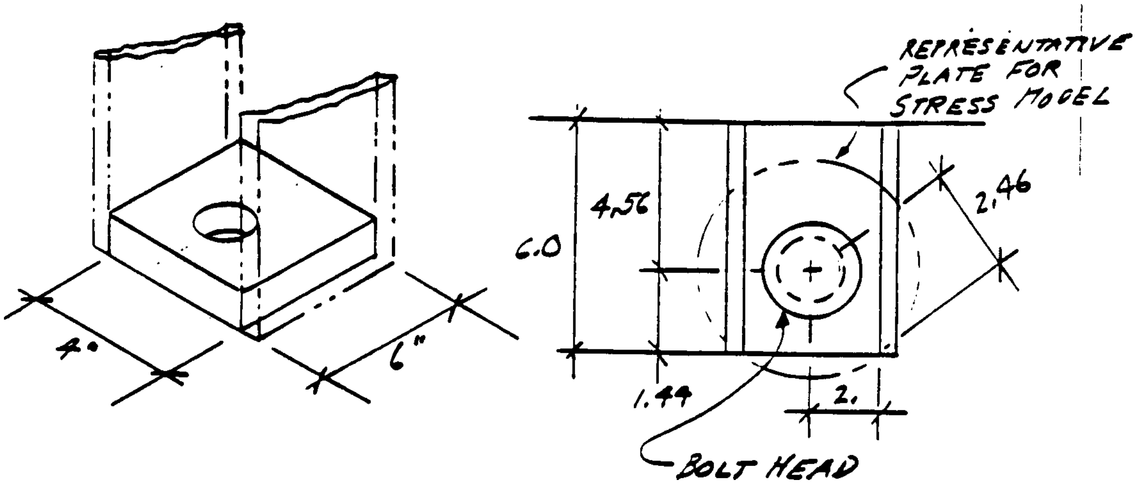
BOLT STRESS

THD = 1½-6 UNC $A_S = \underline{1.4041}\ in^2/BOLT$

$\sigma = \frac{w}{A_S} = \frac{36{,}667.}{1.4041} = \underline{\underline{26{,}114.}}\ PSI$

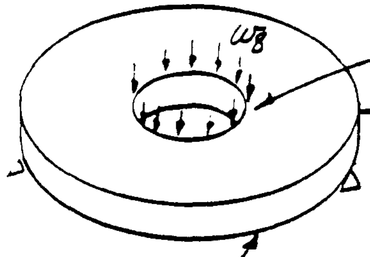
USE BOLT MATERIAL WITH AN ULTIMATE STRENGTH OF GREATER THAN 1.1(26114) = <u>28,725 PSI</u> (10% ADDED TO COVER HIGH TEMPERATURE EFFECT ON STRENGTH)

BRACKET FLOOR PLATE



B.1.7.8 Lid Lifting System (continued)

CONSIDER THE FLOOR PLATE TO BE SIMPLY SUPPORTER CIRCULAR PLATE WITH A HOLE IN THE MIDDLE. [REF: ROARK, 4TH ED p. 220 CASE 14]



$$\sigma_{MX} = \frac{3 W_B}{2\pi m t^2}\left[\frac{2a^2(m+1)}{a^2-b^2}\ln\left(\frac{a}{b}\right)+(m-1)\right]$$

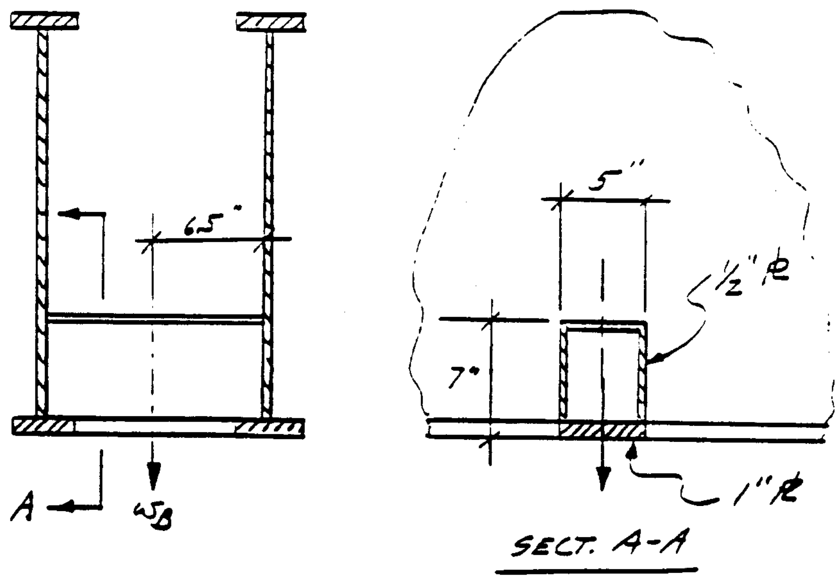
$$= \frac{3(3667)}{2\pi\, 3.448(1^2)}\left[\frac{2(2.5^2)4.448}{2.5^2-1.05^2}\ln\left(\frac{2.5}{1.05}\right)+(2.448)\right]$$

$$= 6,001.\ \text{psi}$$

USE BRACKET MATERIAL WITH AN ULTIMATE STRENGTH OF GREATER THAN 10×1.1(6001.) = 66,013. PSI (NOTE: 10.% ADDED TO COVER HIGH TEMPEATURE DEGRADATION OF MATERIAL STRENGTH)

B.1.7.8 Lid Lifting System (continued)

CENTERLINE BRACKET



$$\bar{Y} = \frac{\Sigma A \bar{y}}{\Sigma A} = \frac{(\frac{1}{2} \times 5)(6.75) + (5.5 \times 1)(3.75) + (5 \times 1)(.5)}{2.5 + 5.5 + 5}$$

$$= \frac{40.}{13.} = \underline{3.077''}$$

$$I = \frac{5(.5^3)}{12} + 2.5(6.75 - 3.077)^2 = 33.78$$

$$+ \frac{1(5.5^3)}{12} + 5.5(3.75 - 3.077)^2 = 16.36$$

$$+ \frac{5(1^3)}{12} + 5(3.077 - .5)^2 = \underline{33.62}$$

$$\underline{\underline{83.76}} \text{ in}^4$$

$$S = \frac{I}{C} = \frac{83.76}{7 - 3.077} = \underline{\underline{21.35}} \text{ in}^3$$

B.1.7.8 Lid Lifting System (continued)

$$\sigma_{MX} = \frac{M}{S} = \frac{\frac{wL}{4}}{S} = \frac{3{,}667 \times 13}{4(21.35)} = \underline{\underline{558.\ psi}}$$

THE SIDE BRACKET MATERIAL REQUIREMENTS GOVERN.

B.1.7.9 Fixture Weight Estimates

WEIGHT OF A538 FIXTURE

(2) WEB ℘	$= [(30 \times 25 \times \frac{5}{8}) + (94-30)(\frac{25+10}{2})(\frac{5}{8})](.286)(2)$	= 668. LBS
(2) TOP FLG	$= [1 \times 4 \times 88](.286 \times 2)$	= 201.
(2) BTM FLG	$= [1 \times 4 \times 72](.286 \times 2)$	= 165.
(2) 5.6" HOLES	$= -[\frac{\pi}{4} 5.6^2 \times 1.625](.286 \times 2)$	= − 23.
(2) 3.6" HOLES	$= -[\frac{\pi}{4} 3.6^2 (.75 + .625)](.286 \times 2)$	= − 8.
(8) ½ × ½ STIFFENERS	$= [.5^2 \times 13](.286 \times 8)$	= 7.
(2) 13 × 20 × ½ SPACER	$= [13 \times 20 \times \frac{1}{2}](.286 \times 2)$	= 74.
(8) ½ × 10 × 10 DBLR	$= [10^2 \times .5](.286 \times 8)$	= 114.
(8) ⅜" × 8 ⌀ DBLR	$= [\frac{\pi}{4} 8^2 \times .375](.286 \times 8)$	= 43.
(4) STIRRUP EYES	$= [\frac{\pi}{4}(\frac{7^2}{2} - 3.6^2) + (\frac{7+3}{2})8](1.5 \times .286 \times 4)$	= 84.
(4) STIRRUP LEGS	$= [1.5 \times 3 \times 6](.286 \times 4)$	= 31
(2) STIRRUP ENDS	$= [\frac{\pi}{4}(\frac{12^2 - 8^2}{2}) 1.5](.283 \times 2)$	= 27.
(2) 5.5" PINS	$= [\frac{\pi}{4} 5.5^2 \times 18](.286 \times 2)$	= 245.
(2) 3.5" PINS	$= [\frac{\pi}{4} 3.5^2 \times 18](.286 \times 2)$	= 99
		1,727.
	ADD 10.% FOR WELDS, ETC	1,900.
	ACTUATORS	~ 200.
	TOTAL	= 2,100.

B.1.7.9 Fixture Weight Estimates (continued)

LID LIFT SYSTEM WEIGHT

SIDE BRACKETS (2)

(2) BTM ℞	$= (5 \times 6 \times 1)(.286)(2)$	17.
(2) UPPER ℞	$= (4 \times 8 \times \frac{1}{2})(.286)(2)$	9.
(4) LOWER SIDES	$= (6 \times 8 \times \frac{1}{2})(.286)(4)$	28.
(4) UPPER SIDES	$= (\frac{2+8}{2})(13 \times \frac{1}{2})(.286)(4)$	59.
		113.

CENTER BRACKET (1)

(1) TUBE BEAM $= [(5 \times 7 - 5.5 \times 4)13 - 5 \times 4 \times 1](.286)(1) = 43.$

BOLTS (3)

$\frac{\pi}{4}(1^2 \times 12.5 + 3^2 \times 1.5 + 2^2 \times 6 + 1.5^2 \times 3)(.286)(3) = 49.$

Σ 205.

ADD 10% FOR CONTINGENCIES 225. #

TOTAL FIXTURE WEIGHT

CASK LIFT SYSTEM	2,100
LID LIFT SYSTEM	225
	2,325. #

Appendix B.1.8

Structural Verification Calculations for the 140-B Cask Transport Tiedown System

B.1.8.1 Description

T cradle is a welded steel beam and plate space frame that is bolted to the railcar or barge deck. It provides support and restraint for the cask/impact limiter assembly during transport and functions as a lift fixture during the intermodal transfer process. It is also designed to facilitate the cask breakaway from the railcar during an accident.

The cradle is made of welded ASTM A-538, T-250 maraging steel plate (Ref. #7, Section B.1.1.4.5).

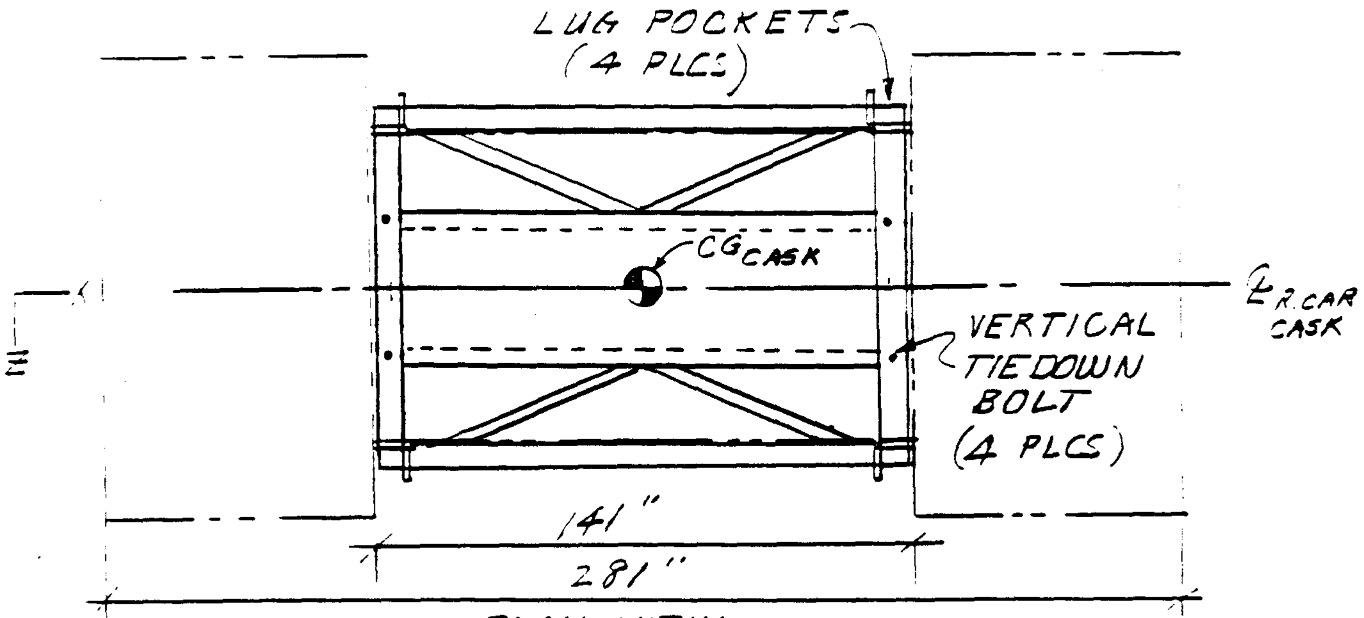
Four cradle lug pockets in the upper corners of the frame support the cask. these pockets grip the cask lugs so as to provide radial tensile capabilities as well as vertical and longitudinal restraints. Clamps are used to hold the lugs in the pockets during transport.

The cradle is bolted to the car deck. two longitudinal bolts restrain the cradle in each longitudinal direction. These bolts are attached to blocks which bear on the inside corners of the cradle base beams. These blocks do not exert any lateral of vertical restraint.

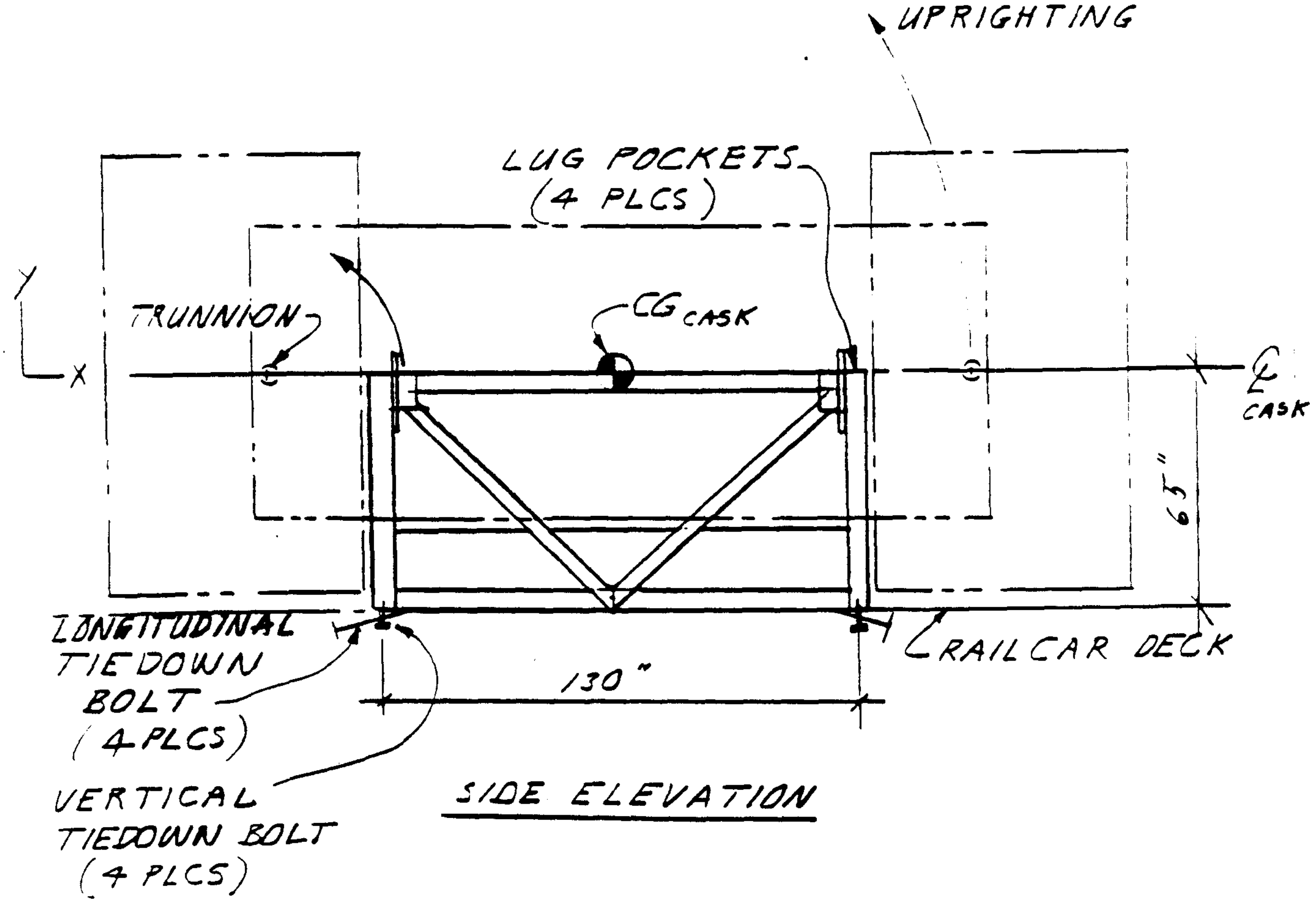
Lateral restraint comes from a lip on the edge of the car deck, which bears on the side of the cradle base and prevents it from sliding laterally.

Vertical restraint is provided by four bolts in the corners of the cradle base. These resist all vertical forces which are created by vertical up loads on the cask and lateral or longitudinal loads due to overturning.

B.1.8.2 Geometry

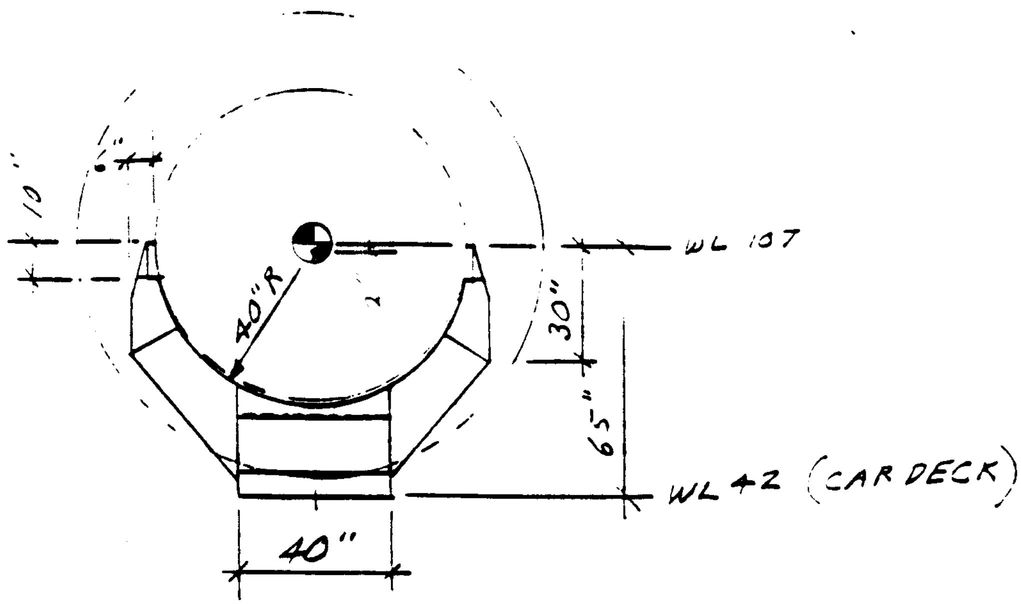


PLAN VIEW



SIDE ELEVATION

B.1.8.2 Geometry (continued)

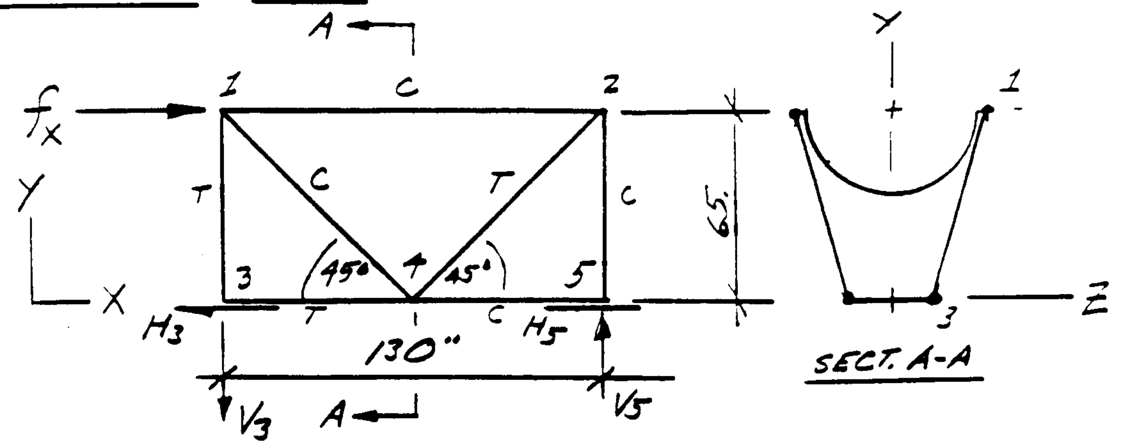


BULKHEAD END VIEW

B.1.8.3 Longitudinal Cradle Analysis

This section covers the column buckling and axial stress in the beams. The members are assumed to have pinned ends.

GEOMETRY - FBD



$$f_x = \frac{SFx\,FX}{2} = \frac{1.1(1859)}{2} = 1{,}022.5K$$

LOAD ON ONE POCKET AT "1"

ΣF_y: $-f_{1,4} \cos 45° = f_{2,4} \cos 45°$

AND: $-f_{1,4} = f_{2,4}$

ΣF_x: $f_{1,2} = -f_{2,4} \cos 45° = f_{1,4} \cos 45°$

AND: $f_{1,2} + f_{1,4} \cos 45° = f_x$

$2\, f_{1,2} = f_x$

B.1.8.3 Longitudinal Cradle Analysis (continued)

$$f_{1,2} = \frac{1022.5K}{2} = \underline{-511.25K} \quad (COMP.)$$

$$f_{1,4} \cos 45° = f_{1,2}$$

$$f_{1,4} = \frac{f_{1,2}}{\cos 45°} = \underline{-723.} K \quad (COMP.)$$

$$f_{2,4} = f_{1,4} = \underline{723. K} \quad (TENS.)$$

SINCE: $H_3 = -1022.5$ (COMP.)

$$f_{3,4} = \frac{F_x}{2} = \frac{1022.5K}{2} = \underline{511.25K} \quad (TENS.)$$

$$f_{4,5} = -f_{3,4} = \underline{-511.25 K} \quad (COMP.)$$

USE A SAFETY FACTOR OF 1.2 ON BUCKLING AT MAXIMUM BREAKAWAY LOADS AND 1.1 ON AXIAL LOADS.

THE MEMBERS ARE CONSIDERED TO BE PINNED END COLUMNS. $(K=1)$

CRITICAL BUCKLING LOAD:

$$P_{cr} = K \frac{\pi^2 E I_i}{L_i^2}$$

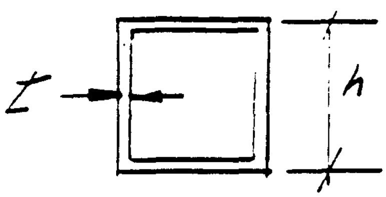
B.1.8.3 Longitudinal Cradle Analysis (continued)

MEMBER	F_i	L	X-SECT.	I	P_{cr}	MARGIN
-2	-511.25K	130."	6×6×3/8	44.692	691.7K	.3
1-4	∓723. K	92.	6×6×1/4	31.745	980.9K	.13
2-4	±723. K	92.	6×6×1/4	31.745	980.9K	.13
				A	P_{YIELD}	
3-4	+1022.5K	65.	6×6×1/4	5.75	1,466.	.30
4-5	+1022.5K	65.	6×6×1/4	5.75	1,466.	.30

* USE A SAFETY FACTOR OF 1.2 ON BUCKLING LOADS AND 1.1 ON AXIAL LOADS.

SECTION PROPERTIES

SQUARE TUBES



$$I = \frac{h^4 - (h-2t)^4}{12}$$

$$P_{cr} = \frac{K \pi^2 E I}{L^2}$$

B.1.8.3 Longitudinal Cradle Analysis (continued)

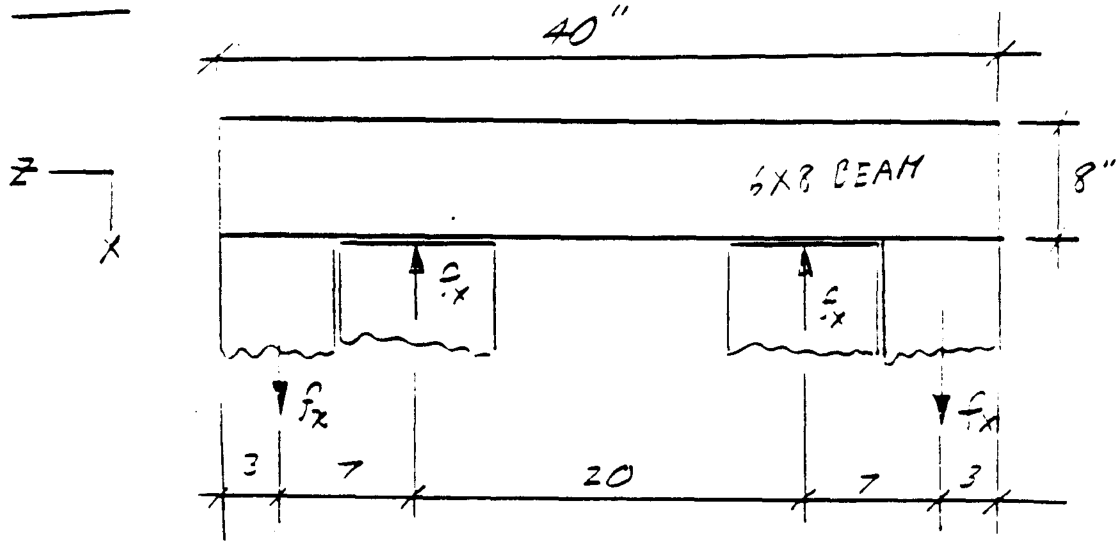
CRADLE END CROSS BEAM

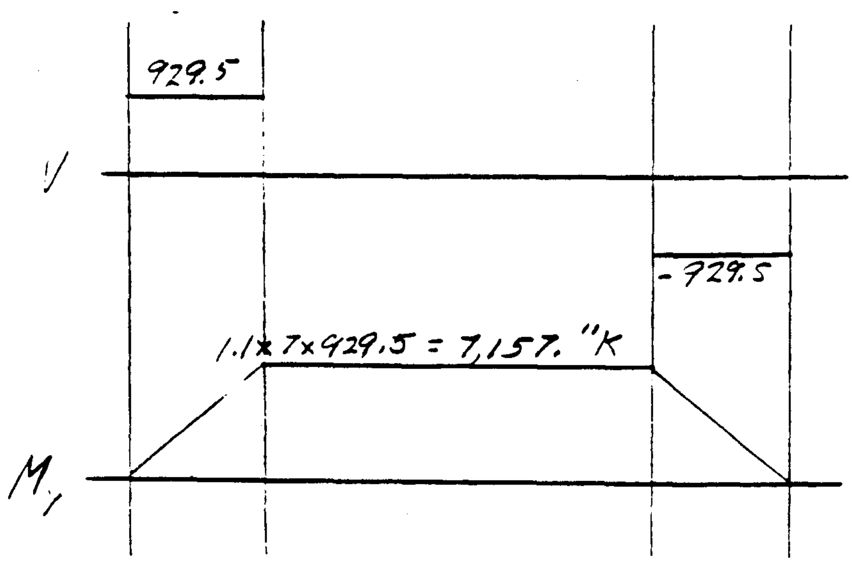
LOADS

$F_{x\,MAX} = \underline{1859.K}$ (MAX. BREAKAWAY) $\qquad f_x = \frac{F_x}{2} = \underline{929.5K}$

USE S.F.=1.1

FBD

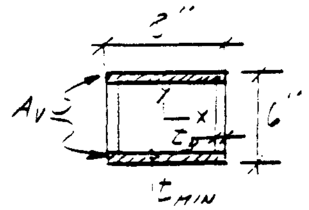




B.1.8.3 Longitudinal Cradle Analysis (continued)

MINIMUM SHEAR AREA:

$$A_V = \frac{1.1 \times 929.5K}{.6(255.K)} = \underline{6.6827} \text{ IN}^2$$



$$t_{MIN} = \frac{A_V}{2 \times 8} = \frac{6.6827}{16.} = \underline{.4177}$$

USE $t = .50$" $MS = \frac{.50}{.4177} - 1 = \underline{.20}$

BENDING:

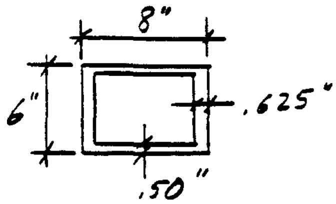
$$S_{MIN_Y} = \frac{M_Y}{F_{TY}} = \frac{7157.^{"K}}{255.K} = \underline{28.0667} \text{ IN}^3$$

$$I_{MIN_Y} = SC = 28.0667 \times 4 = \underline{112.2667} \text{ IN}^4$$

$$I_Y = \frac{6(8)^3}{12} - \frac{5(8 - 2t_B)^3}{12} \qquad t_B = \underline{.4933}"$$

LET $t_B = \underline{.6250}$" $I = \underline{127.86}$ $MS = \frac{127.86}{112.27} - 1 = \underline{.13}$

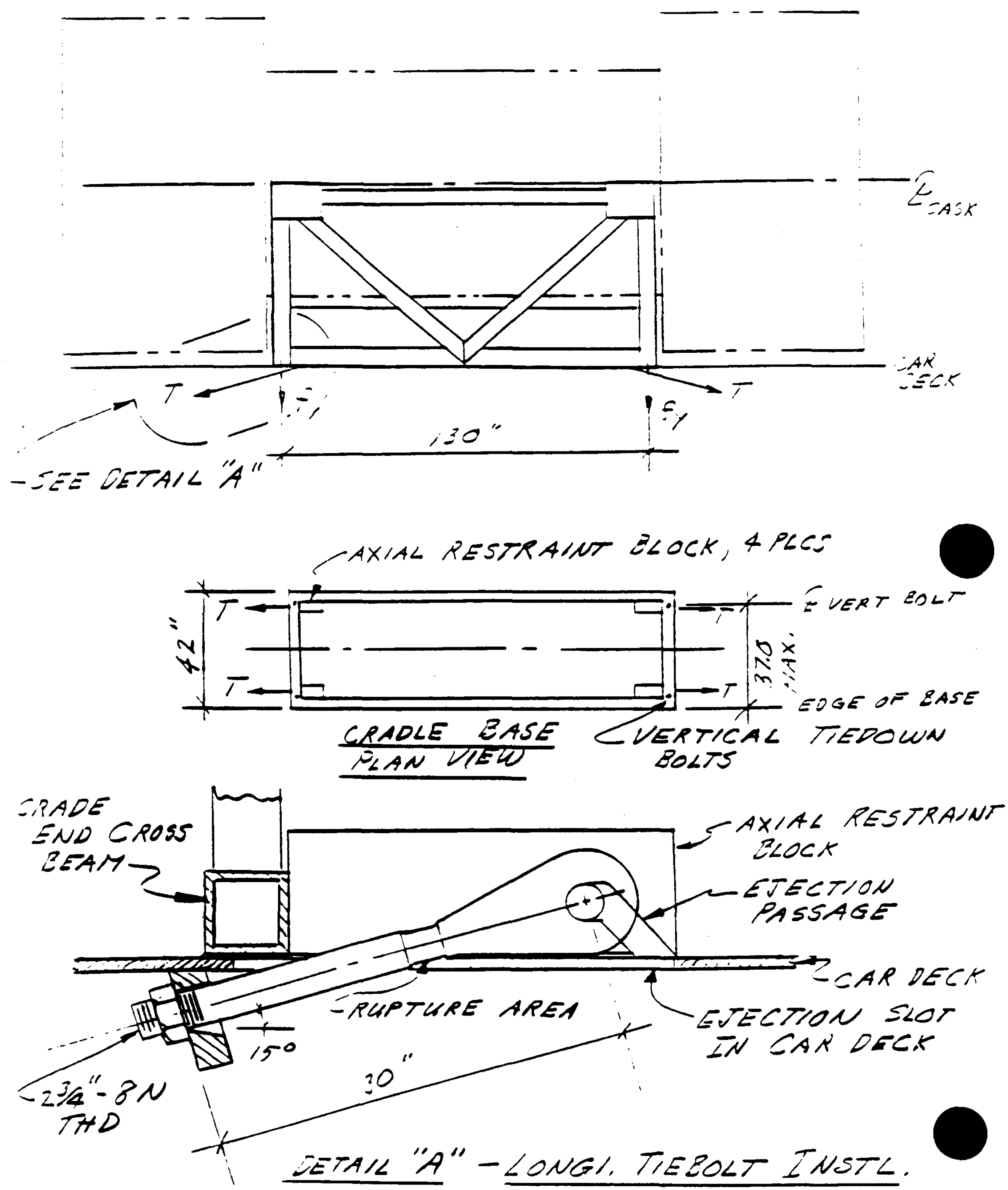
CROSS BEAM SECTION:



WEIGHT:

$$(6 \times 8 - 6.75 \times 5.)(.286)(40.") = \underline{163.02}^{\#} \text{ EACH}$$

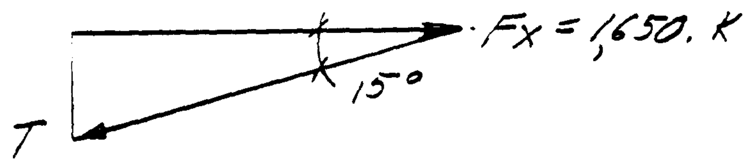
B.1.8.4 Longitudinal Attachment to Rail Car



B.1.8.4 Longitudinal Attachment to Rail Car (continued)

BOLT MATL: A-538, T-200

MINIMUM SIZE OF TIEBOLT – USE AAR LOADS



$$T = \frac{F_x}{\cos 15^\circ} = \frac{1650K}{\cos 15^\circ} = \underline{1,708.\ K} \text{ ON 2 BOLTS}$$

$$A_{MIN.} = \frac{T}{F_{ty}} = \frac{1,708.K}{205.K} = \underline{8.3327} \text{ IN}^2 \text{ FOR 2 BOLTS}$$

2 BOLTS HOLD THE LOAD IN EACH DIRECTION

$$A = \frac{A_{MIN.}}{2} = \underline{4.1664} \text{ IN}^2 \text{ PER BOLT}$$

$$D_{MIN.} = \sqrt{\tfrac{4}{\pi} 4.1664} = \underline{\underline{2.3032}} \text{ IN} \quad (\text{RUPTURE AREA})$$

THE MINOR DIAMETER OF THE BOLT THREADS SHOULD BE LARGER THAN DMIN.

USE 2¾"-8N THDS

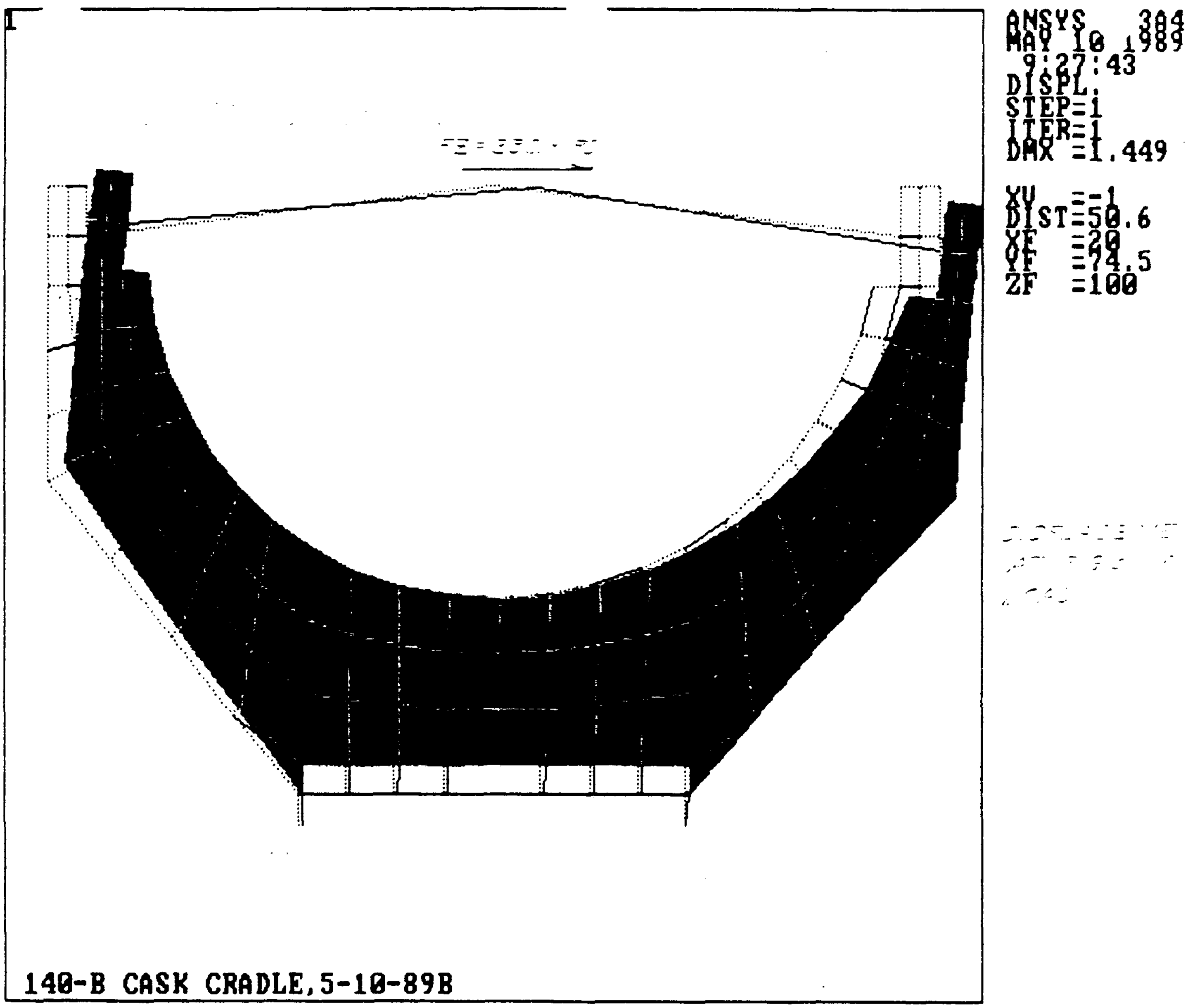
B.1.8.5 Lateral Cradle Analysis

This analysis was done using the ANSYS model CRDL0510. The basic frame of the bulkhead is modeled per the preliminary design. The pocket and tiedown bolt attachment areas will be defined and modeled in final design.

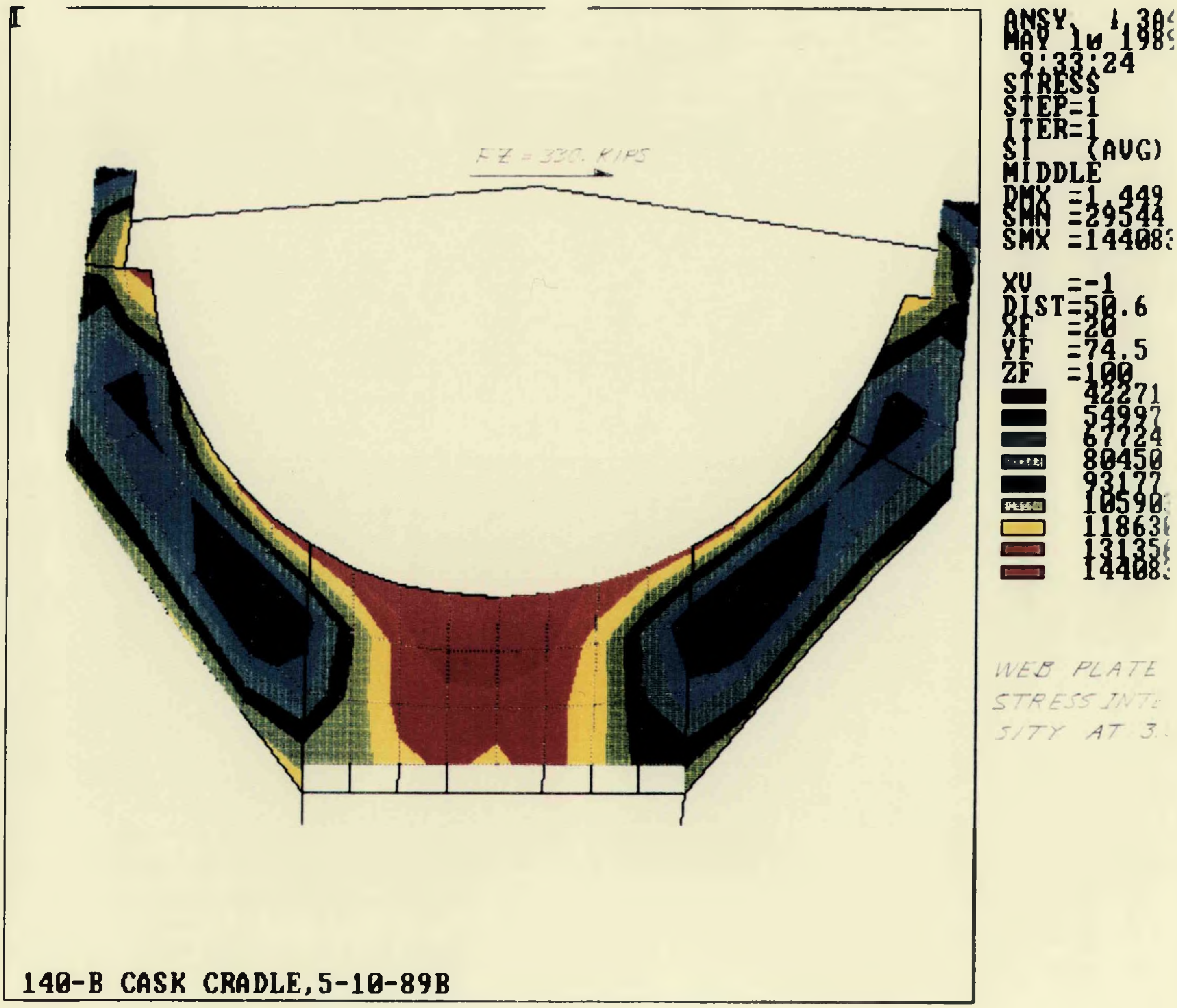
The resulting displacements and web plate stresses are shown in the following computers plots. A listing of the input file and plots of the nodes and elements are included.

The maximum stress intensity of the web is 144.0 ksi. The maximum principal stress in the flanges is 131.4 ksi. These maximums exclude the pocket and tiedown bolt areas.

B.1.8.5 Lateral Cradle Analysis (continued)



B.1.8.5 Lateral Cradle Analysis (continued)



B.1.8.5 Lateral Cradle Analysis (continued)

CRDL0510, 5-10-89B

ANSYS INPUT FILE

```
/TITLE, 140-B CASK CRADLE,5-10-89B
C*** 4 POINT ATTACH - 4 POINT CASK SUPPORT
C*** FN = CRDL0510
C*** TIEDOWN CLAMP VERSION-FZ SHARED EQUAL ON 2 SIDES
C*** 3.0 G'S LATERAL LOAD
C*** UNIFORM 3/8 THK WEB PLATES
C*** 1/2 X 5 FLANGES

C*** ELEMENT TYPES

ET,1,4,,,,,,0                        * 3-D BEAM
ET,2,63                              * 3-D PLATE
ET,3,21,,,2                          * 3-D MASS

C*** MATERIAL PROPERTIES

EX,1,26.5E6                          * A538 STEEL
NUXY,1,.3
DENS,1,7.332E-4
EX,2,26.5E6                          * WEIGHTLESS STEEL
NUXY,2,.3
DENS,2,0.0

C*** REAL CONSTANTS

C*** PLATES
R,1,.125              * 1/8"
R,2,.25               * 1/4
R,3,.3125
R,4,.375
R,5,.4375
R,6,.50
R,7,.625
R,8,.75
R,9,.875
R,10,1.

C*** SQUARE TUBES
R,14,5.75,31.745,31.745,6,6,,        * 6X6X1/4
RMORE,,47.52,3,3
R,15,7.109,38.444,38.444,6,6,        * 6X6X5/16
RMORE,,57.493,3.75,3.75
R,16,8.4375,44.692,44.692,6,6        * 6X6X3/8
RMORE,,66.762,4.5,4.5
R,17,9.7344,50.5097,50.5097,6,6      * 6X6X7/16
ROMRE,,,75.2988,5.25,5.25
R,18,11.,55.9137,55.9167,6,6         * 6X6X1/2
RMORE,,93.1875,6,6

C*** RECTANGULAR BARS
R,19,60,500,180,6,10,,               * 6X10 BEAM
RMORE,,,60,60
R,20,100,838.333,833.333,10,10,,     * 10X10 BEAM
RMORE,,,100,100
R,21,14.25,127.855,73.687,6,8,       * 6 X 8 CROSS BEAM

C*** FLANGES

R,24,1.25,2.6042,.0065,.25,5.        * 1/4X5
RMORE,,,1.25,0
R,25,1.5625,3.2552,.0127,.3125,5     * 5/16X5
RMORE,,,1.5625,0
R,26,1.875,3.9063,.0220,.375,5       * 3/8X5
RMORE,,,1.875,0
R,27,2.1875,4.5573,.0349,.4375,5     * 7/16X5
RMORE,,,2.1875,0
R,28,2.5,26.0417,.0521,.0521,.5,5    * 1/2X5
RMORE,,,2.5,0
R,29,3.75,39.0625,.1758,.75,5        * 3/4X5
RMORE,,,3.75,0
R,30,5.,52.0833,.4167,1.0,5          * 1X5
RMORE,,,5.,0

C*** MASS

R,35,285.                            * 1/2 CASK MASS

C*** CASK (STIFF) BEAMS

R,36,100,10000,10000,100,100
```

B.1.8.5 Lateral Cradle Analysis (continued)

```
RMORE,,,100,100

C*** NODES

N,1,20,107,54
N,3,20,97,54
FILL
N,6,20,77,54
FILL
N,120,20,45,80
FILL,6,120,3,7,1
N,128,20,45,120
FILL
N,130,20,42,100          * TIEDOWN BOLT
N,134,20,42,120          * CRADLE CORNER
N,135,20,42,80
NGEN,2,-110,120,128,1,,3
N,22,20,77,146
FILL,128,22,3,19,1
N,25,20,97,146
FILL
N,27,20,107,146
FILL

LOCAL,11,1,0,105,100,0,-90

N,93,40,-11.537,20
N,96,40,-33.1113,20
FILL
N,100,40,-60,20
FILL
N,108,40,-120,20
FILL
N,112,40,-146.887,20
FILL
N,115,40,-168.463,20
FILL

CSYS                               * REACTIVATES GLOBAL SYSTEM

N,61,20,107,58
N,63,20,97,58
FILL
FILL,1,61,1,31,,3,1
FILL,4,94,2,34,30,21,1
N,85,20,97,142
N,87,20,107,142
FILL
FILL,25,85,1,55,1,3,1
N,131,20,105,100
N,132,20,107,100
N,133,20,147,100
NROTAT,ALL                         * ROTATES ALL NODES TO GLOBAL SYSTEM
NLIST,ALL

C*** ELEMENTS

TYPE,1                   * BEAMS
MAT,1                    * A536 STL
REAL,28                  * 1/2X5 FLG
E,1,31
E,31,61
E,1,2
EGEN,8,1,-1
E,6,36
EGEN,3,30,-1
TYPE,2                   * PLATES
REAL,6                   * 3/8
E,1,2,32,31
EGEN,2,30,-1
EGEN,2,1,-2
E,3,4,34,33
EGEN,3,30,-1
EGEN,11,1,-3
E,9,120,10             * WEB TO CENTERLINE
TYPE,1                   * BEAMS
REAL,30                  * 1" FLG
E,61,62,132
E,62,63,132
E,63,93,132
```

B.1.8.5 Lateral Cradle Analysis (continued)

```
REAL,28               * 1/2X5 FLG
E,3,33
E,33,63
E,93,94
EGEN,7,1,-1
E,100,101
EGEN,8,1,-1
E,9,120
E,10,40
EGEN,3,30,-1
REAL,21               * 6X8 CROSS BEAM
E,120,121
EGEN,8,1,-1
REAL,20               * 10X10 BEAM
MAT,2           * WEIGHTLESS STEEL
E,120,135             * CRADLE BASE CORNER
E,120,10
E,121,11
E,122,12
E,123,13
E,125,15
E,126,16
E,127,17
E,128,18
E,62,132              * CASK SIMULATION BEAMS
E,132,86
E,128,134             * CRADLE BASE CORNER
MAT,1           * A538 STEEL
TYPE,2                * PLATE
REAL,4                * 3/8
E,14,15,45,44
EGEN,3,30,-1
EGEN,11,1,-3
E,128,19,18           * TRI
TYPE,1                * BEAM
REAL,28               * 1/2X5 FLG
E,108,109
EGEN,7,1,-1
E,18,48
EGEN,3,30,-1
E,128,19
E,19,20
EGEN,8,1,-1
E,22,52
EGEN,3,30,-1
E,25,55
E,55,85
E,27,57
E,57,87
REAL,30               * 1X5 FLG
E,85,115
E,85,86
E,86,87
TYPE,2                * PLATE
REAL,4                * 3/8 PLATE
E,25,26,56,55
E,55,56,86,85
EGEN,2,1,-2
ELIST,ALL

ITER,1,1,1

C*** SUPPORTS

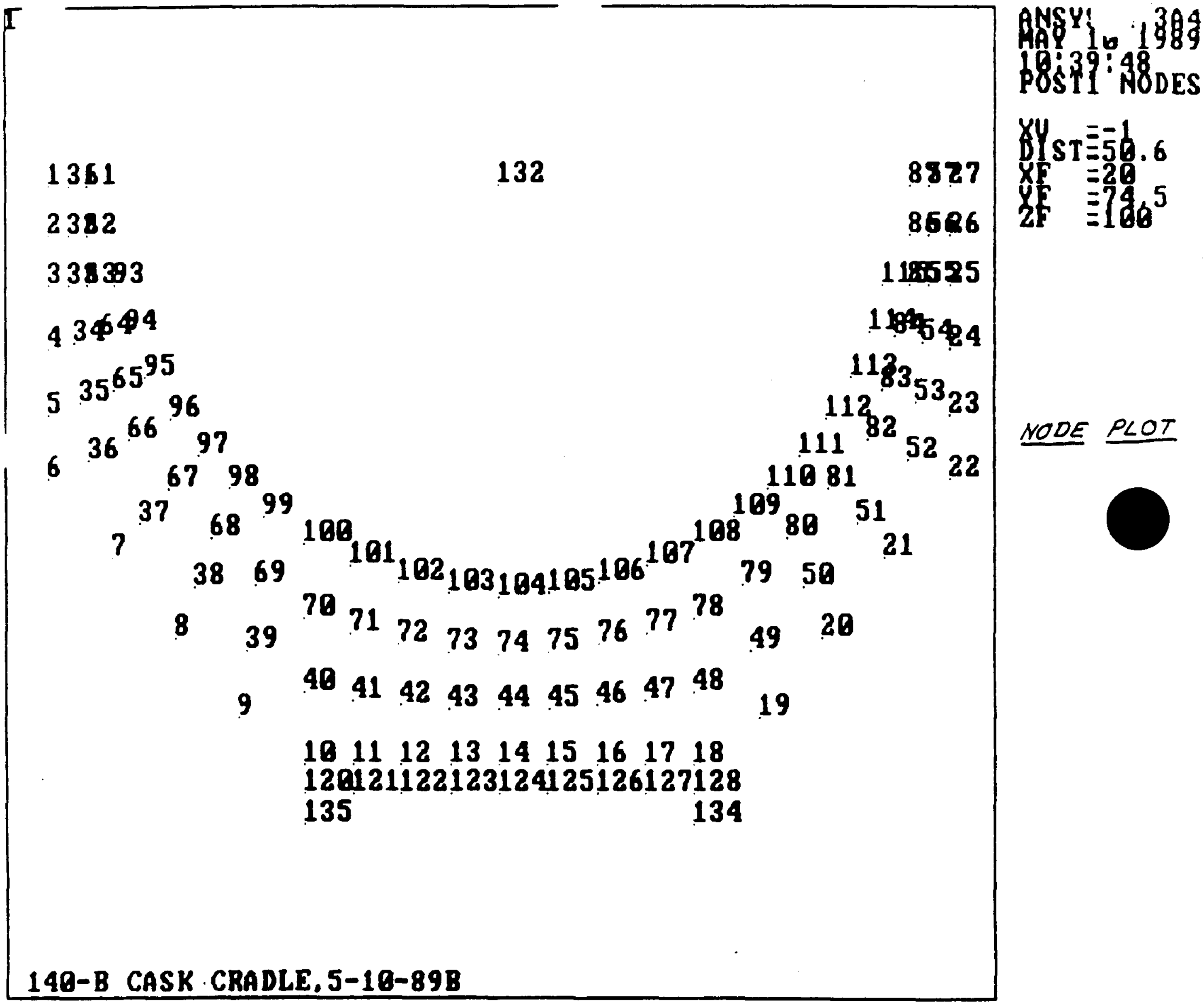
D,62,UX                        * FIXES MODEL IN Y-Z PLANE
D,86,UX
D,134,UX,,,,,UY,UZ               * VERT/LATERAL CORNER SUPPORT
D,135,UX,,,,,UY                  * VERT CORNER SUPPORT
DLIST,ALL

C*** APPLIED LOADS

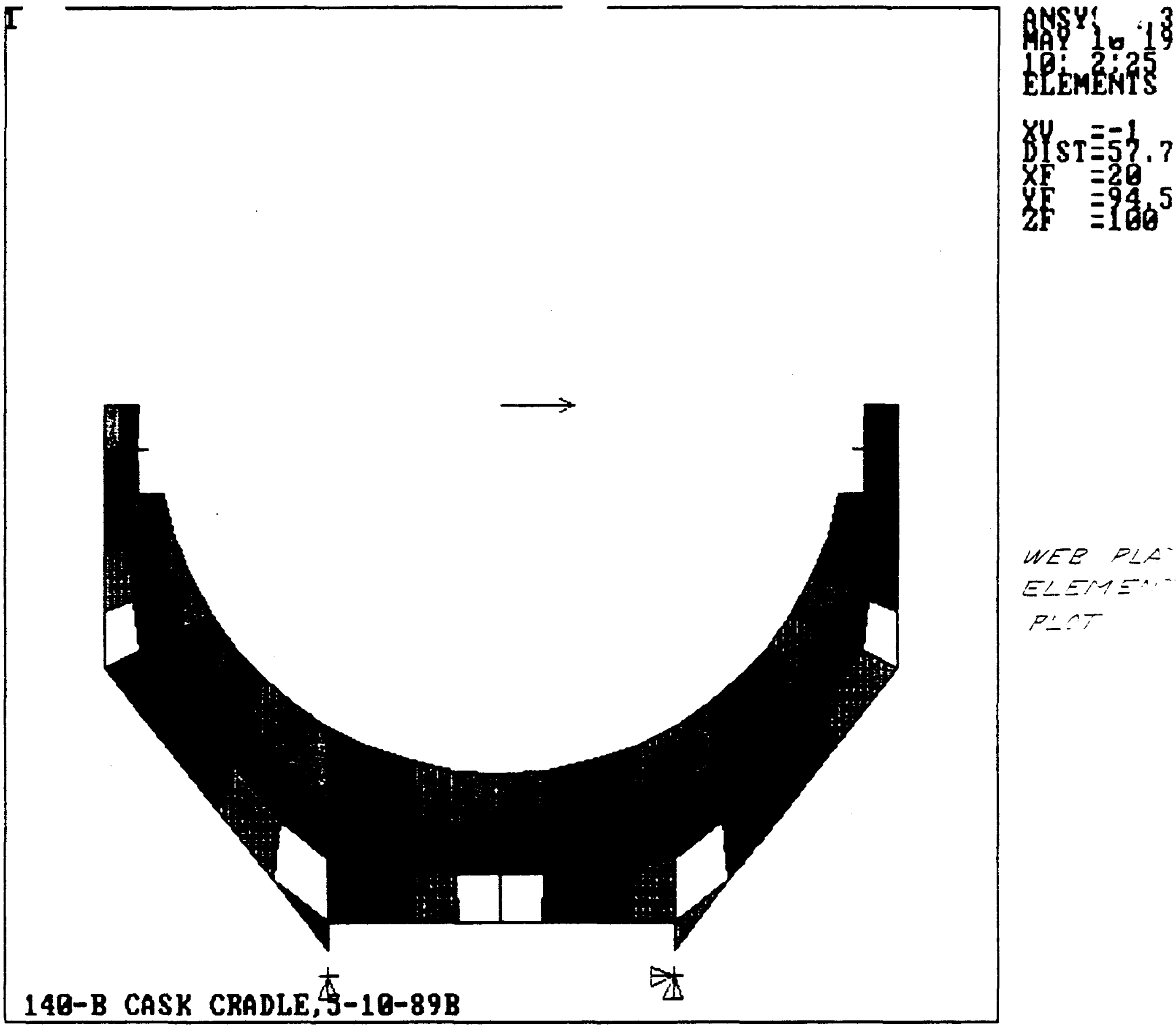
C*** 3.0 G'S LATERAL SHARED EQUAL ON TWO SIDES
F,132,FZ,330000
FLIST,ALL

AFWRIT
FINISH
```

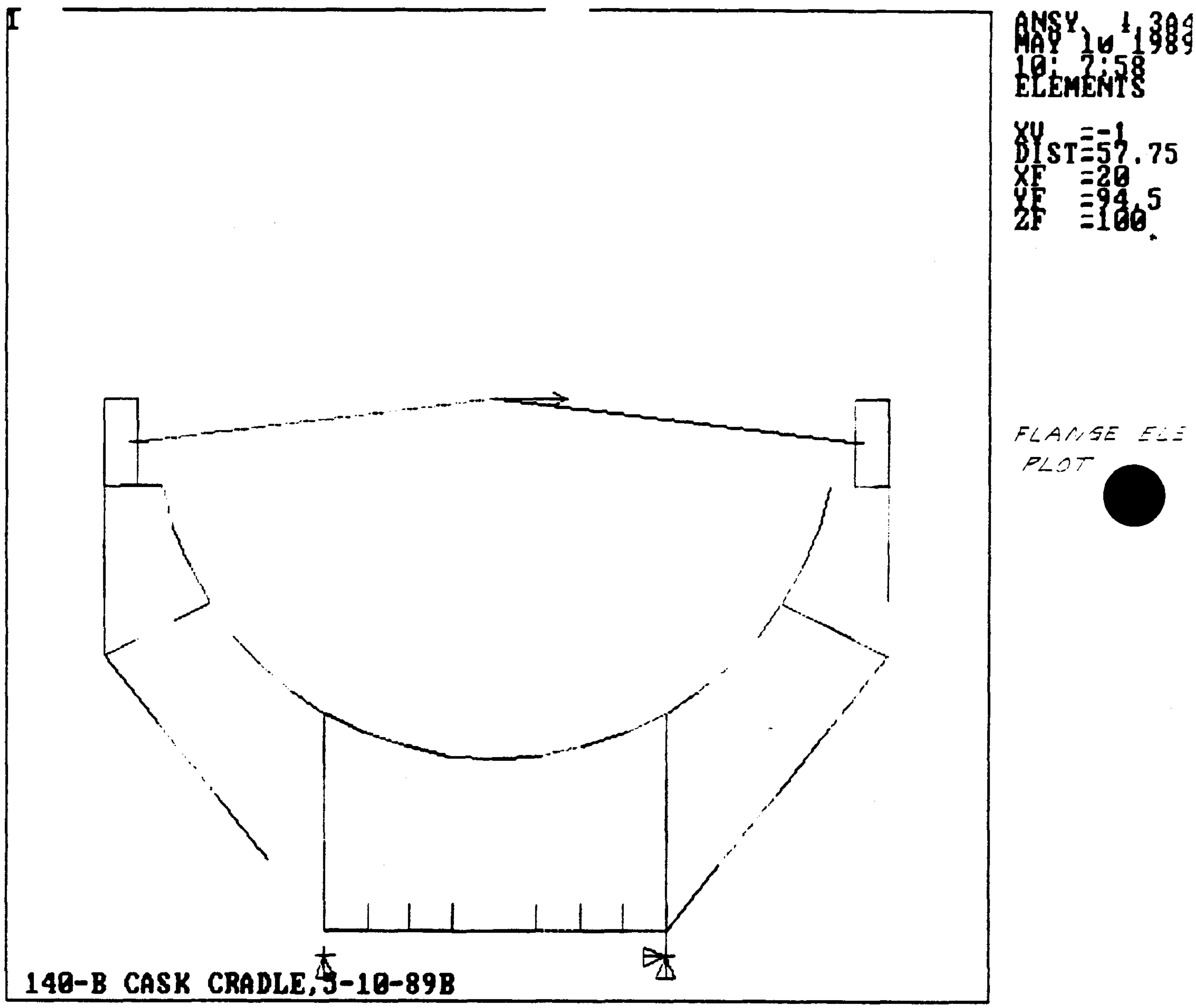
B.1.8.5 Lateral Cradle Analysis (continued)



B.1.8.5 Lateral Cradle Analysis (continued)



B.1.8.6 Lateral Attachment to Rail Car



B.1.8.6 Lateral Attachment to Rail Car (continued)

THE MINIMUM SIZE OF THE VERTICAL TIEDOWN BOLTS IS SET BY THE REQUIREMENT TO PREVENT OVERTURNING DURING A LONGITUDINAL BREAKAWAY.

VERTICAL LOAD FROM LONGITUDINAL BREAKAWAY:

2 BOLTS HOLD THE LOAD

$$f_y = \frac{1859.K \times 65.''}{2 \times 130''} = \underline{465.K} \text{ PER BOLT}$$

MINIMUM THREAD SIZE:

THE BOLT SIZE IS BASED ON NOT YIELDING THE STRESS AREA OF THE THREADS.

$$A_{S\,MIN} = \frac{1.1 \times 465.K}{205.K} = \underline{2.4951} \text{ IN}^2$$

USE 2"-8N THDS.

MAXIMUM TENSILE RUPTURE STRENGTH:

$A_s = 2.4951 \text{ IN}^2$

$P_{MAX.} = 2.4951 \times 210.K \times 1.1 = \underline{\underline{576.K}}$ PER BOLT

$P_{MIN.} = 2.4951 \times 210.K = \underline{\underline{524.K}}$ PER BOLT

B.1.8.6 Lateral Attachment to Rail Car (continued)

THE MAXIMUM SPACING LATERALLY, B, OF THE VERTICAL TIEDOWN BOLTS FROM THE FAR EDGE OF THE CRADLE BASE IS A FUNCTION OF THE LATERAL G LOADING, THE CASK WEIGHT, THE HEIGHT OF THE CASK C.G. AND THE STRENGTH OF THE BOLTS. 2 BOLTS CARRY THE LOAD

LET $G = 1.8 \times \frac{210}{205} = 1.844$ g's (MIN. LATERAL BREAKAWAY)

$$B_{MIN} = \frac{WH}{2 P_{MIN}} G = \frac{220.K \times 65''}{2 \times 524.K} (1.844) = 13.6450 (1.844)$$

$= 25.2''$ (FAR BOLT ℄ TO EDGE OF CRADLE)

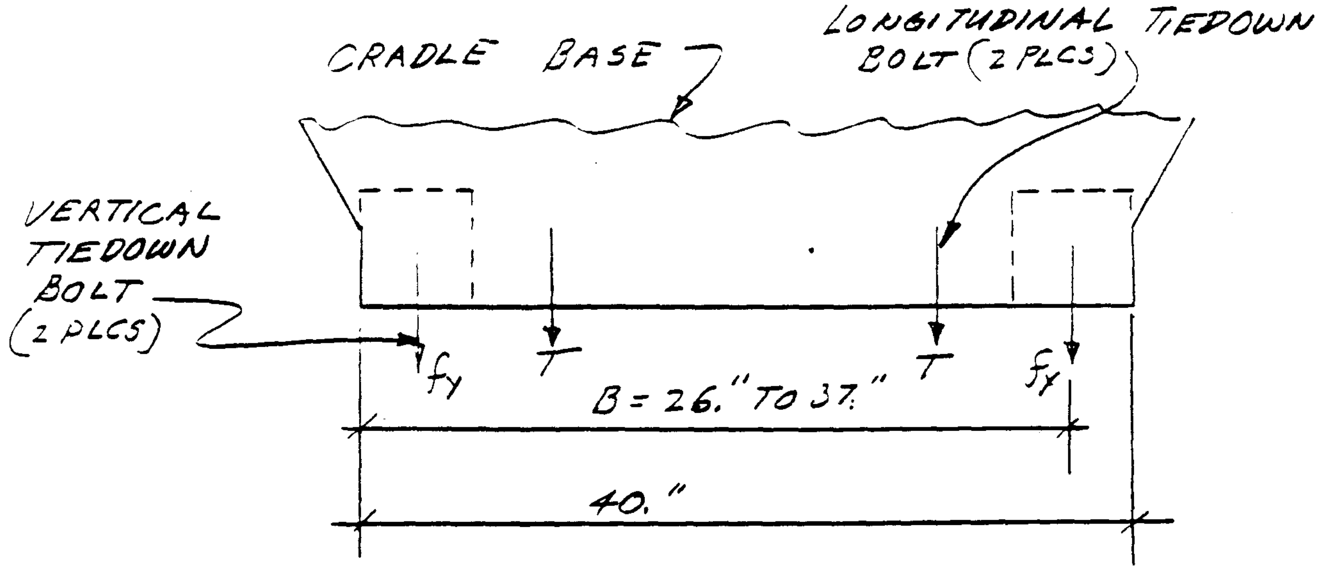
THIS IS JUDGED TO BE TOO NARROW TO PROVIDE A STABLE BASE FOR THE CASK ON THE CAR.

LET $G = 3.0$ g's (MAX. ACCEPTABLE FOR CASK)

$$B_{MAX} = \frac{220.K \times 65'' \times 3}{2 \times 576.K} = 37.2''$$

USE A 40" WIDE CRADLE BASE WITH THE BOLTS SET IN 3." FROM EACH SIDE.

B.1.8.6 Lateral Attachment to Rail Car (continued)



MAXIMUM BREAKAWAY G LOAD:

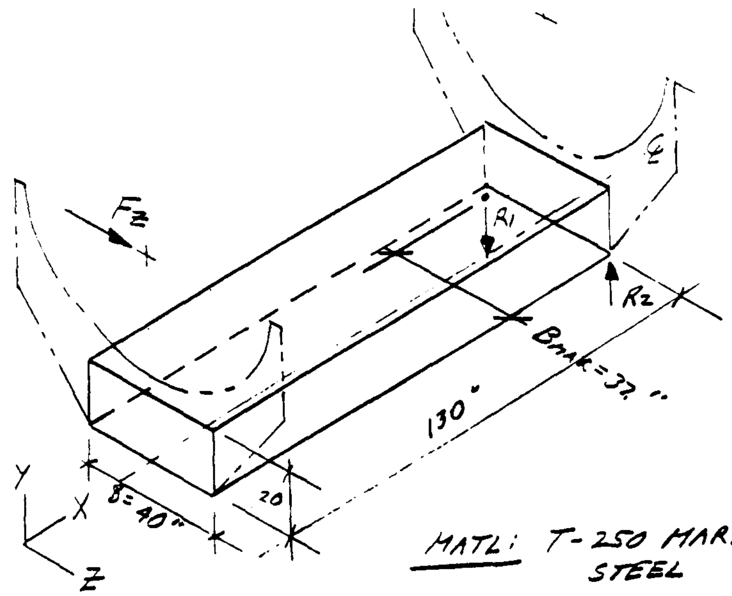
$$G_{MAX} = \frac{2 P_{MX}^{P} B}{W H} = \frac{2 (576 K) 37.''}{220 K \times 65''} = \underline{\underline{2.98}} \text{ g's}$$

B.1.8.7 Lateral Torque Box Analysis

Scope - The real lateral breakaway will be a sequential failure of the bolt at one end and then the second bolt at the other end. The cradle must have sufficient torsional stiffness to prevent the cradle from twisting after the first bolt breaks and damaging the cask before the second bolt breaks. This is done by connection the 2 end bulkheads with a torque box. The box must be strong enough to transmit sufficient torque to break the second bolt without having the box yield.

B.1.8.7 Lateral Torque Box Analysis (continued)

FBD



MATL: T-250 MARAGING STEEL

$\tau_{MAX} = .6\ F_{TY}$
$= 153.$ KSI

LOADS

R_1 = MAXIMUM TENSILE STRENGTH OF A TIEDOWN BOLT = 576. K

CALCULATIONS

TORQUE TO BREAK THE SECOND BOLT:

$T = R_1 B_{MX} = 576.K(37.") = 21,312.$ "K

FOR A BOX SECTION:

$t_{MIN.} = \frac{T}{2A_0 \tau}(SF)$ [REF 9.5, P. 89, 4.16]

$t_{MIN} = \frac{21,312. \times 1.2}{2(20 \times 40) 153.K} = .1045$

USE .1046 SHEET WITH STIFFENERS (12 GA)

B.1.8.8 Lateral Natural Frequency of Cask/Cradle

Scope - The section estimates the natural roll frequency of the cask/cradle system. The mounting base of the cradle is assumed to be rigid. The rotational moment of interim is neglected. This analysis is based on the lateral displacement of the cask C.G. for the ANSYS run of CRDL0719, 7-26-89A.*

$$UZ_{132}\ (\text{CASK C.G.}) = \underline{.4227}\ \text{AT}\ 1.g = \delta_{st}$$

$$f_n = \frac{1}{2\pi}\sqrt{\frac{g}{\delta_{st}}} = \frac{1}{2\pi}\sqrt{\frac{386.}{.4227}} = \underline{\underline{4.8}}\ Hz$$

* CRDL0719 is the same model as CRDL0510 except for the acceleration loading vs. the force load.

B.1.8.9 Vertical Cradle Analysis

Scope - Neither the vertical up or vertical down load provide a governing case for the cradle. The cross sectional area is much larger than what is required for vertical support. However, the final design should be checked for buckling during the vertical down load case.

B.1.8.10 Vertical Attachment to Rail Car

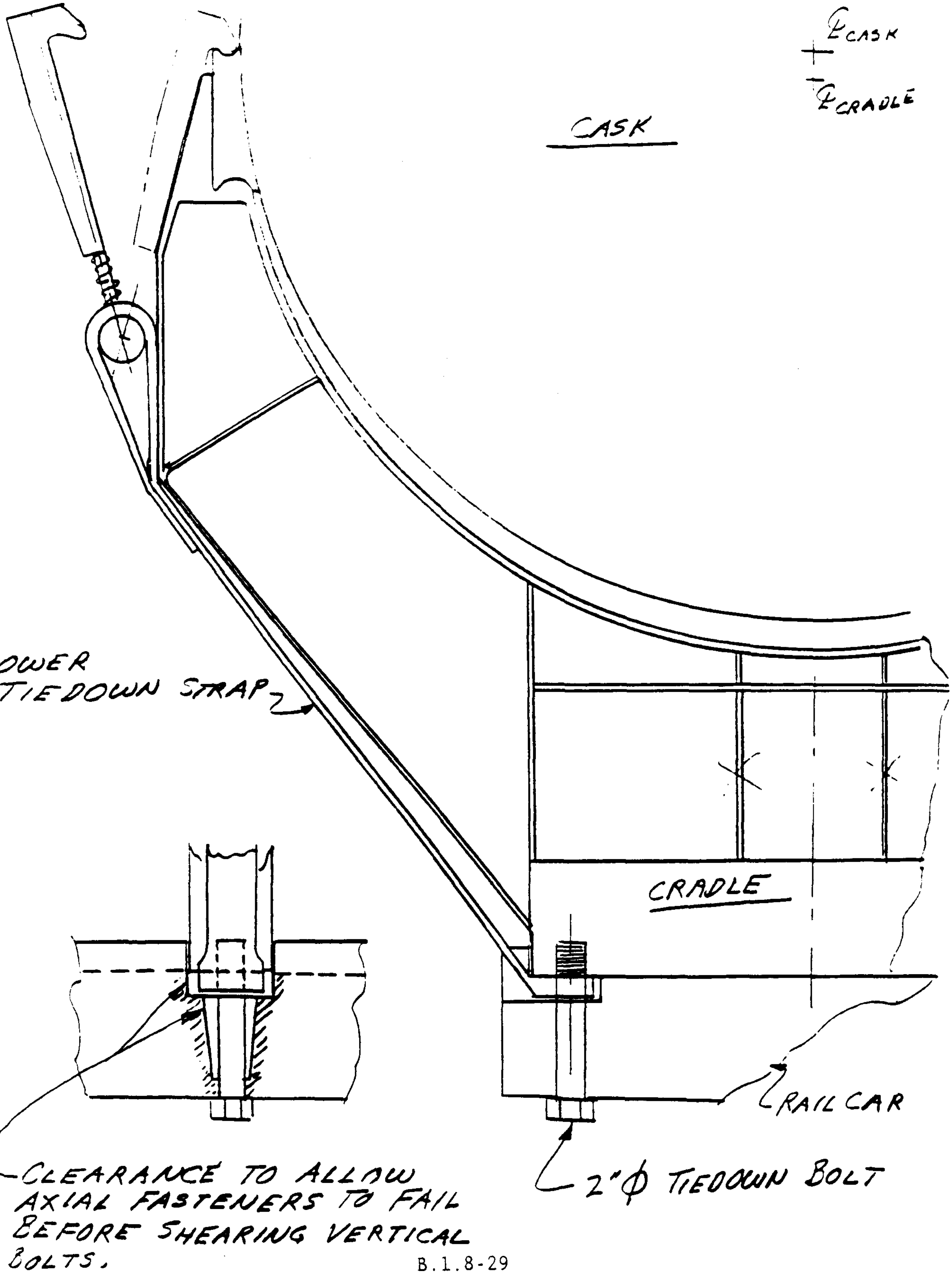
Scope - This section covers the clamps which hold the cask lugs in the cradle pockets. The clamp blocks are bolted down against the lugs to provide a vertical down preload. This retains the lug in the pocket during vertical up and radial inward loads.

After loosening the bolts the clamps can be swung outboard out of the way during the cask operations.

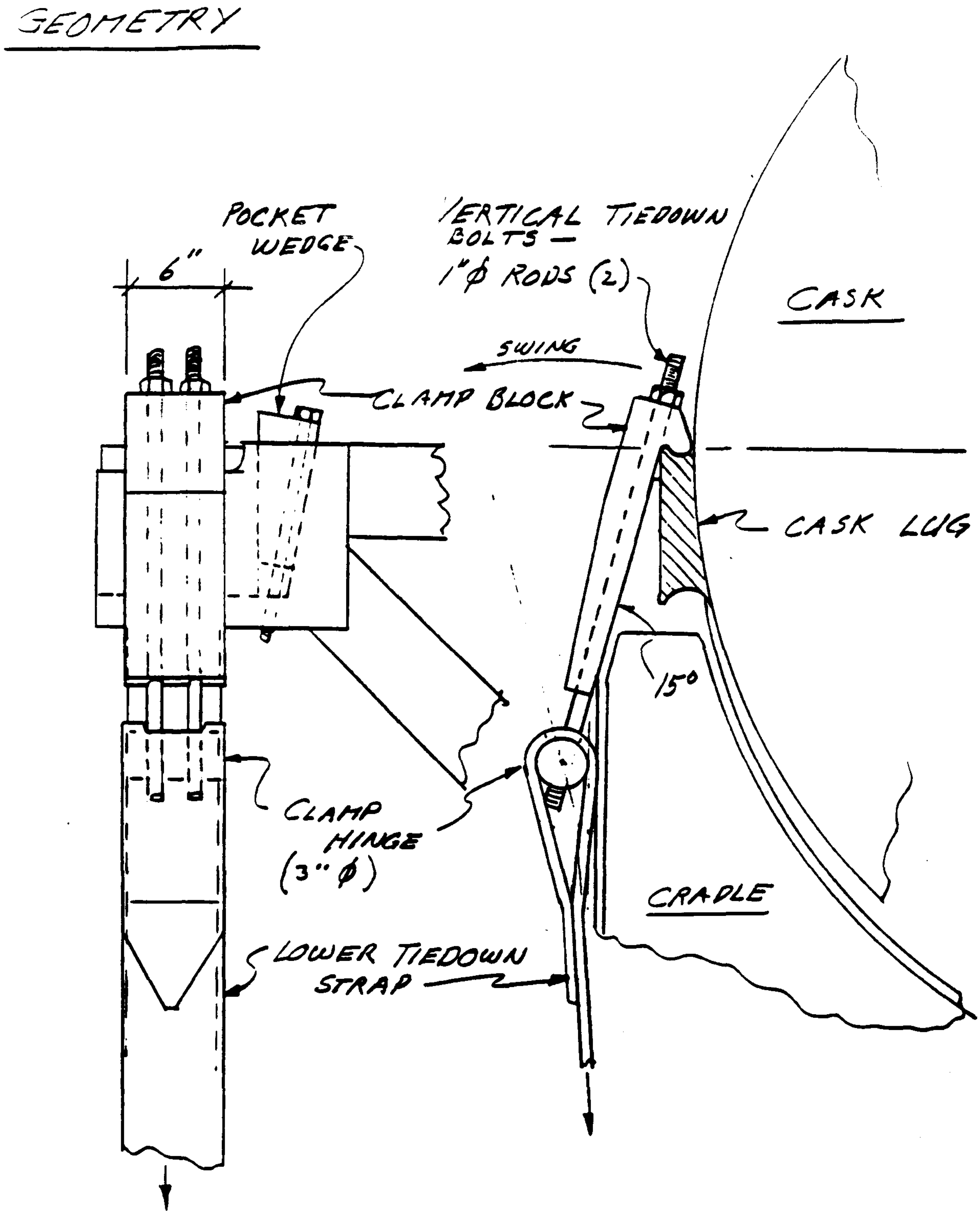
The clamp blocks are attached to the lower tiedown straps. The straps are pinned between the cradle and the car deck such that they are released during a breakaway. Thus the clamp blocks are released and the cask is free of the cradle assembly.

The upper and lower surfaces of the lugs are longitudinal cylindrical curves. This is to create a surface such that the pocket/clamp block can pull radially outward on the lug. It also provides a centering effect to diminish to dubbing between mating surfaces during transport. The curves eliminate sharp corners which might cause fatigue problems.

B.1.8.10 Vertical Attachment to Rail Car (continued)

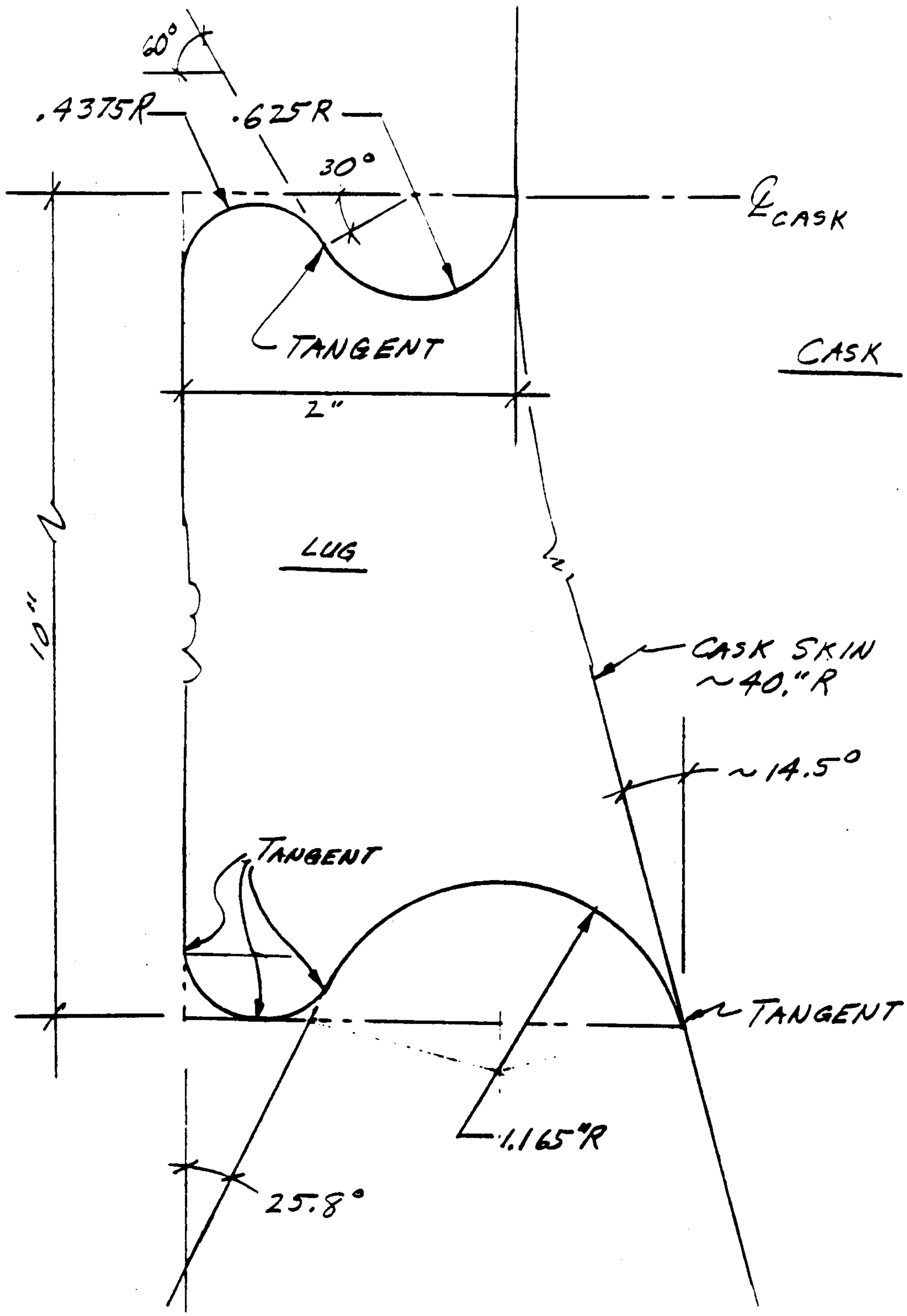


B.1.8.10 Vertical Attachment to Rail Car (continued)



B.1.8.10 Vertical Attachment to Rail Car (continued)

LUG SURFACE CONFIGURATION



B.1.8.10 Vertical Attachment to Rail Car (continued)

Loads

Longitudinal and vertical down loads will be carried by the cradle pocket and will not affect the lug clamp assembly. The maximum lateral load is assumed to the 1/4 Fz on each pocket. The picket will carry the leading lug in bearing while the clamp and pocket will resist the trailing lug's tendency to pull out of the pocket. The assumed maximum lateral load is 3.0 g's.

$$f_z = \frac{3(220)}{4} = \underline{165.K} \text{ PER POCKET}$$

Vertical up loads will be carried by the clamp assembly.

$$f_y = \frac{4(220.K)\left(\frac{212}{208}\right)(1.1)}{4} = \underline{247.} \text{ KIPS PER POCKET}$$

B.1.8.10 Vertical Attachment to Rail Car (continued)

VERTICAL LOADS:

VERTICAL TIEDOWN BOLTS:

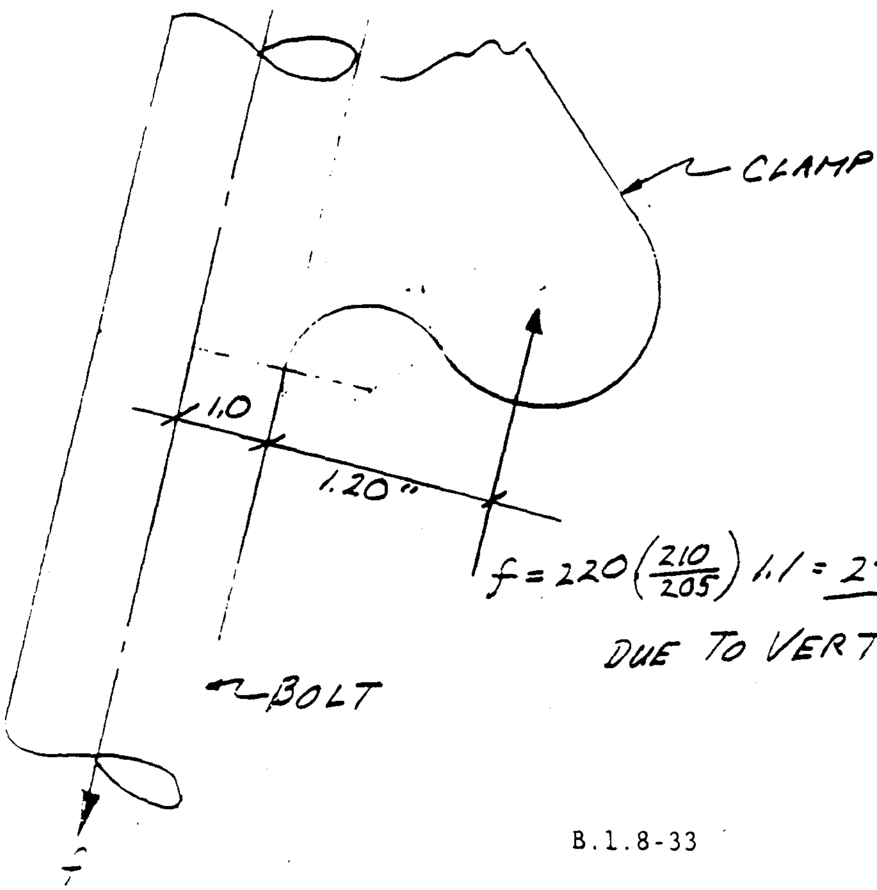
THE NO YIELD LOAD FOR THE BOLTS IS 220.K PER PAIR OF BOLTS AT EACH POCKET

USE T-200 MATERIAL — $F_{ty} = 205.$ KSI

$$A_{MIN.} = \frac{1.1 \times 220\,K}{2(205\,K)} = \underline{.5902}\ IN^2/BOLT \qquad D = \underline{.8669''}$$

USE 1"-8 UNC BOLTS WITH A PORTION OF THE SHANK TURNED DOWN TO .8669"Ø.

CLAMP BLOCKS: T-200 MARAGING STEEL



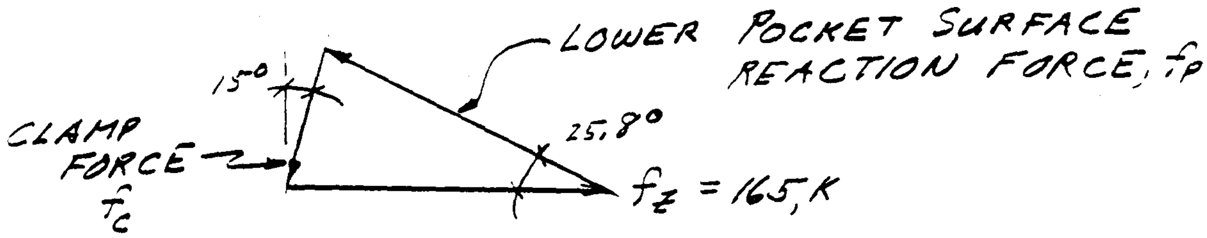
$$f = 220\left(\frac{210}{205}\right)1.1 = \underline{248.\,K}/CLAMP$$

DUE TO VERTICAL BREAKAWAY

B.1.8.10 Vertical Attachment to Rail Car (continued)

CALCULATIONS

LATERAL LOADS:



$$\Sigma F_Z: \quad f_c \sin 15^\circ + f_p \cos 25.8^\circ = f_z$$

$$\Sigma F_y: \quad f_c \cos 15^\circ - f_p \sin 25.8^\circ = 0$$

$$f_p = f_c \frac{\cos 15^\circ}{\sin 15^\circ} = 3.7321 \; f_c$$

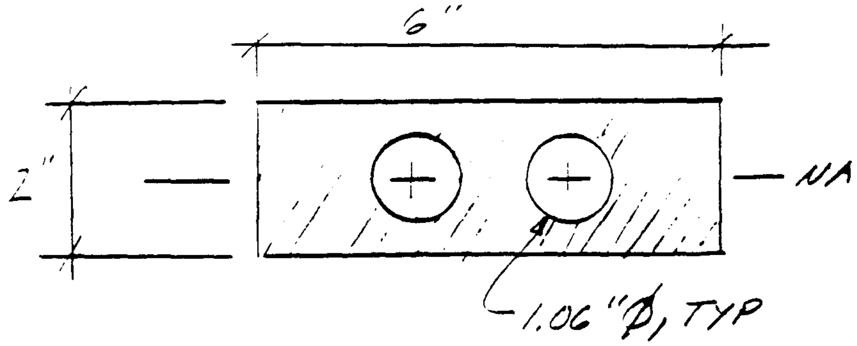
$$f_c \left(\sin 15^\circ + 3.7321 \cos 25.8^\circ \right) = 165 \text{ K}$$

$$f_c = \underline{\underline{45.6 \text{ K}}}$$

THE CLAMP SHOULD BE PRELOADED TO 45.6 KIPS TO PREVENT THE LUG FROM MOVING IN THE POCKET DURING A LATERAL BREAKAWAY(22.8K PER BO

B.1.8.10 Vertical Attachment to Rail Car (continued)

CLAMP BODY SECTION PROPERTIES



$$I = \frac{6(2^3)}{12} - 2\left[\frac{\pi}{64} 1.06^4\right] = \underline{3.8761}$$

$$S = \underline{3.8761}$$

$$M = (1.20 + 1)\,248.\,K = \underline{545.6\ ''K}$$

$$\sigma_B = \frac{M}{S} = \frac{545.6\,K}{3.8761} = \underline{\underline{140{,}762\ psi}}$$

$$MS = \frac{205.}{140.7} - 1 = \underline{\underline{.45}}$$

B..8.10 Vertical Attachment to Rail Car (continued)

LOWER TIEDOWN STRAP: T-250

$$A_{MIN.} = \frac{247.K}{255.K} = \underline{.9686}\ IN^2$$

REQ'D: ELONGATION $\leq$ .10", LATERAL LOAD = 45.6 K

$$e = \frac{\sigma}{E} \qquad \text{WHERE } L \approx 55."$$

$$= \frac{\frac{45.6\ K}{.9686}(55.)}{26.5K^2} = \underline{.0977}"\ \text{TO}$$

USE A ½" x 4¼" STRAP

$$A = \underline{2.125\ IN^2}$$

$$\sigma = \frac{45.6K}{2.125} = \underline{21.46\ KSI}$$

$$e = \frac{21,460.(55")}{26.5E6} = \underline{.0445}"$$

USE ½ x 4 ¼ STRAP

BOLT ELONGATION: [(2) 1" BOLTS x 24" LONG]

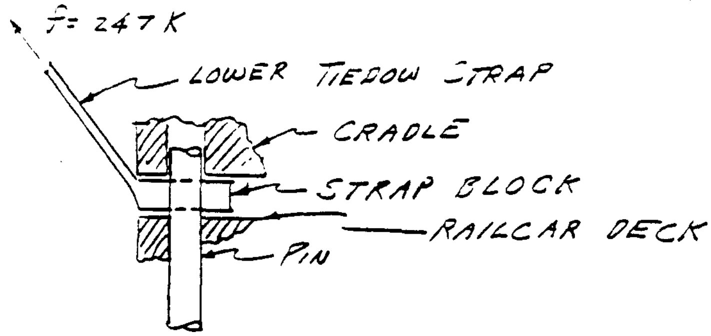
$$e = \frac{\sigma L}{E} = \frac{45.6K \times 24}{2(\frac{\pi}{4})\ 26.5E6} = \underline{.0263}"$$

TOTAL ELONGATION:

$$.0445 + .0263 = \underline{.0708}" \leq .10"$$

B.1.8.10 Vertical Attachment to Rail Car (continued)

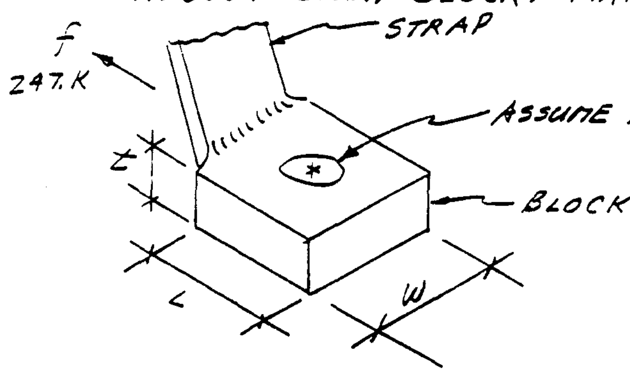
TIEDOWN PIN: MATL = T-250

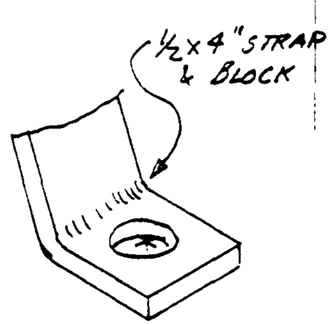


THE 248.K LOAD IS CARRIED BY THE PIN IN DOUBLE SHEAR.

$$A_{MIN.} = \frac{248.K}{2(.6 \times 255K)} = \underline{\underline{.8105}}\ in^2 \rightarrow D_{MIN} = \underline{\underline{1.0158''}}$$

TIEDOWN STRAP BLOCK: MATL = T-250





$$A_{MIN} = \frac{248.K}{255K} = \underline{.9725}\ in^2$$

LET $t = .50''$

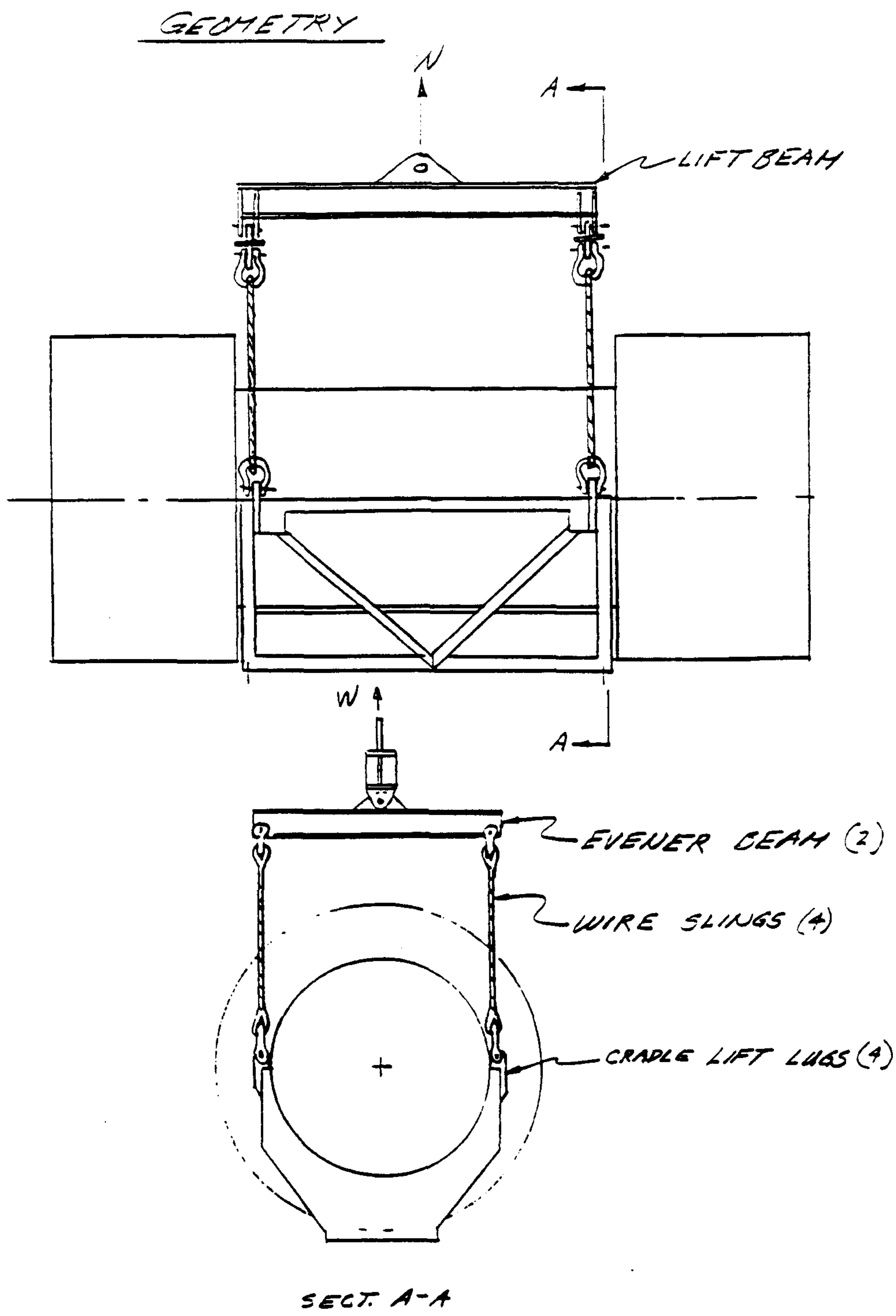
$$W = 2.125 + \frac{.9725}{.50} = \underline{\underline{4.07''}}$$

USE ½ x 4¼" STRAP & BLOCK

B.1.8.11 Intermodal (Horizontal) Lift

Scope - During an Intermodal Transfer the cask with impact limiters is to be picked up in a horizontal attitude from the railcar and set on the barge deck (or vice versa). It is intended to use the cradle as a lifting fixture for this purpose. Lifting lugs are to be added to the corners of the cradle for this purpose. A lifting beam with load eveners on it will be used to provide uniform and vertical loads on each lug during a normal lift. Thus the cradle members involved in the lift must be acceptable for ANSI N14.6.

B.1.8.11 Intermodal (Horizontal) Lift - (continued)



B.1.8.11 Intermodal (Horizontal) Lift - (continued)

Loads - To comply with ANSI N14.6 factors of safety of 3.0 on yield and 5.0 on ultimate must be used.

USE: T-250 MARAGING STEEL FOR CRADLE LUGS.

50. ksi YIELD x 70. ksi ULT. STEEL FOR BEAMS.

SHACKLES = LOAD RATING x $\frac{\text{PROOF TEST}^{*}}{3}$ [9.6] (* 2.2 X, CROSBY)

= .7333 LOAD RATING (FOR CROSBY)

CABLES = 1/5 THE FITTING OR EYE RATING.

Calculations

$W = \underline{220.\ \text{Kips}}$

$w = \frac{W}{4} = \underline{55.\ \text{kips}}$ PER CORNER = $\underline{27.5}$ TONS

SHACKLE SIZE = $\frac{27.5}{.7333}$ = 37.5 TON MIN. RATING.

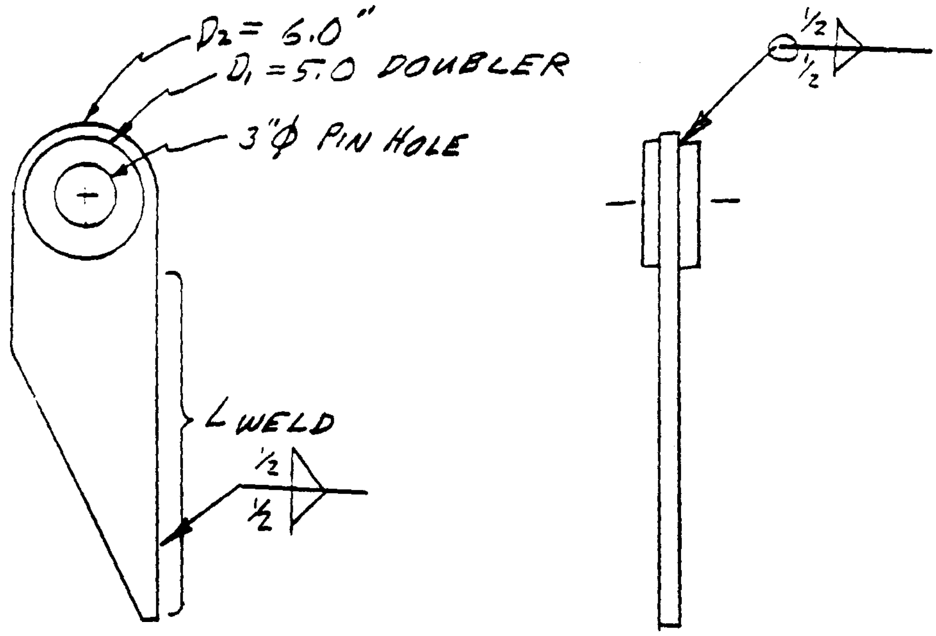
USE 55. TON SHACKLES — PIN ϕ = $\underline{2.75''}$ [9.6]

WIDTH = 4 1/8" AT PIN [9.6]

B.1.8.11 Intermodal (Horizontal) Lift (continued)

LUG SIZE:

USE 1" ℞ LUG WITH 1" ℞ DOUBLER ON EACH SIDE.



MAXIMUM ALLOWABLE STRESS AT THE EYE:

$\sigma_{MAS} = .45\,F_{tu} = .45(260) = \underline{117.}$ ksi [9.7]

$A_{MIN.} = \frac{55.K \times 5.0}{117.K} = \underline{2.35}$ IN²

$A_{ACTUAL} = (6-3) + 2(5-3) = \underline{7.0}$ IN²

$MS = \frac{7.}{2.35} - 1 = \underline{\underline{1.9}}$ WITH DOUBLERS

B.1.8.11 Intermodal (Horizontal) Lift (continued)

LENGTH OF WELD:

ASSUME FULL STRENGTH OF BASE METAL.

$A_W = (.5)(.7071) = \underline{.3536}$ IN.²/IN (½" △ WELD)

$\tau_W = (.6)(255K) = \underline{153.0\ Ksi}$ MAX. ALLOWABLE SHEAR

$L = \frac{W}{\tau_W A_W} = \frac{55.K \times 5.}{(153K)(.3536)} = \underline{\underline{5.08''}}$ EACH LUG

USE 10" MINIMUM WELD ON EACH SIDE

$M.S. \approx \underline{\underline{3.0}}$

NOTE THAT THE WELD SIZE AND LENGTH WILL ALSO DEPEND ON THE PIECE ON THE OTHER SIDE OF THE WELD.

B.1.8.12 Tiedown System Weight

This section contains an estimate of the weight and center of gravity of the tiedown system components. The major components are the cradle, the cask tiedown clamps and the cradle tiedown bolts and blocks.

The weight and location of most of the components are determined by hand calculations. But the end cradle bulkheads were weighed and the CG determined using the ANSYS Model CRDL0510 (which is the same as CRD10510 used for the stress analysis except for the appropriate loading changes).

10% is added to the calculated weights to cover contingencies.

B.1.8.12 Tiedown System Weight (continued)

RESULTS OF THE ANSYS RUN ON CRDL0719, 7-26-89B WITH ACELZ = 386. "/SEC² TO DETERMINE WEIGHT AND C.G. OF BULKHEAD MODEL.

REACTION FORCES

NODE	FY	FZ
135	404.6#	–
134	–404.6	655.# = BLKHD WT.

NODES 134 AND 135 ARE 40." APART

$$\bar{Y} = \frac{404.6^{\#} \times 40''}{655.^{\#}} = \underline{\underline{24.7}}'' \text{ ABOVE CAR DECK}$$

B.1.8.12 Tiedown System Weight (continued)

DATUM FOR CG IS THE CAR DECK

ITEM	N	Ax (IN²)	L (IN.)	N×WT (LB)	$\bar{Y}$ (IN)	M = $\bar{Y}$×WT
CRADLE						
BULKHEAD	2	REF: CRDL 0719, 7-26-89B		1,310.	24.7	32,357.
UPPER LONG. 6×6×3/8	2	8.4375	130.	627.	62.0	38,874.
LOWER LONG. 6×6×1/4	2	5.75	130.	428.	3.0	1,284.
DIAGONALS 6×6×1/4	4	5.75	92.	605.	32.5	19,662.
TORQUE BOX I=.1046	1	12.522	130.	467.	10.0	4,670.
HORIZ. LIFT LUG	4	109. IN³×4		125	65.0	8,125.
POCKETS	4	5×10×10		572	60.0	34,320.

ΣW = 4134. ΣM = 139,292."#

1.1W = 4547.# $\bar{Y} = \frac{139K}{4.1K} = 33.7"$

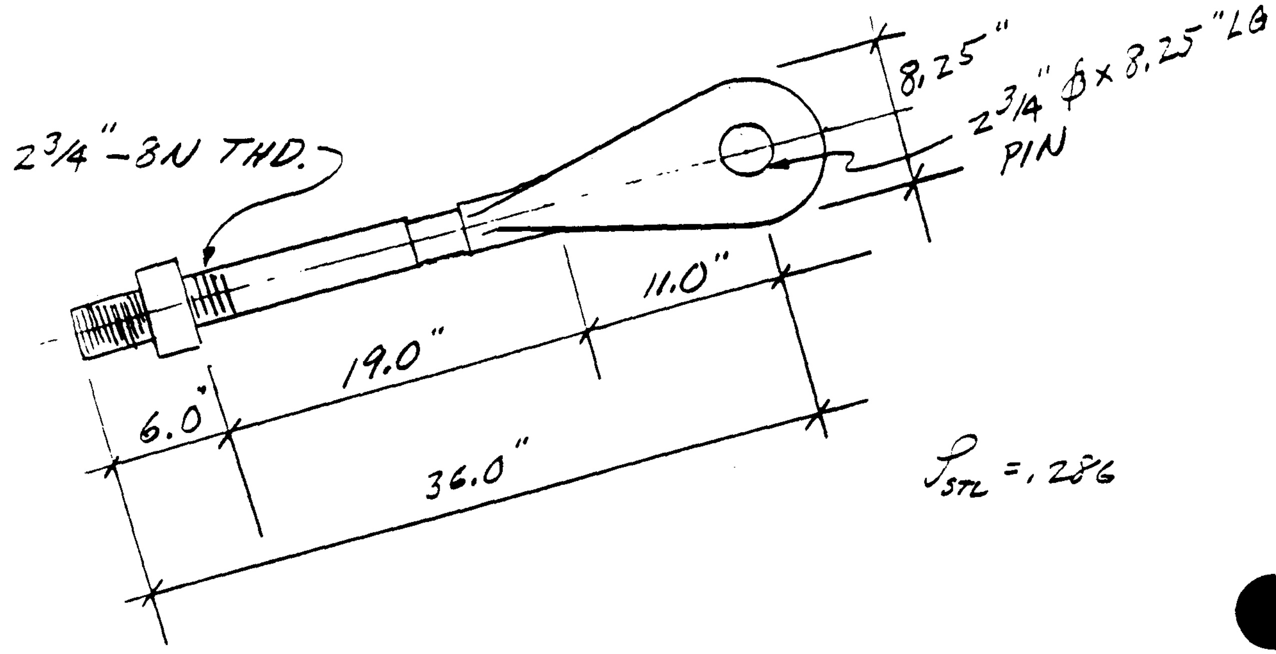
CASK TIEDOWN CLAMPS						
CLAMP BLK.	4	2×6×20	—	275.#	60."	16,500.
VERT. TDN. BOLT	8	1"×30"	—	54.	50.	2,700.
LOWER TDN STRAP	4	½×4¼	73.	177.	30.	5,310.
HINGE PINS	4	3"ϕ	6.	49.	50.	2,450.

ΣW = 555. ΣM = 26,960."#

1.1W = 610# $\bar{Y} = \frac{26.9}{.555} = 48.6"$

B.1.8.12 Tiedown System Weight (continued)

LONGITUDINAL TIEDOWN BOLTS



WEIGHT

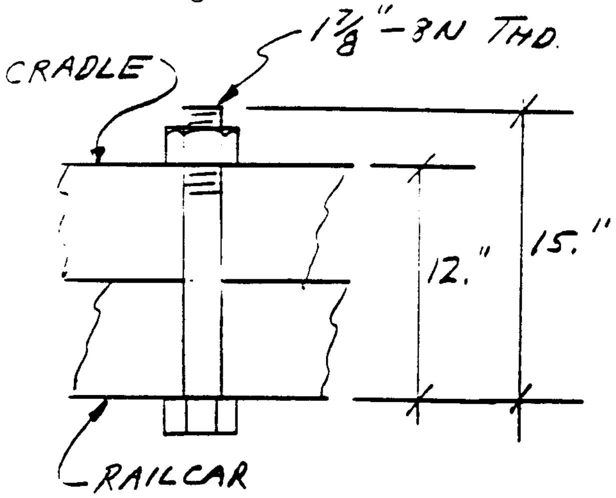
BOLT	=	$(36-11)\left(\frac{\pi}{4}\,.275^2\right)(.286)$	=	42.47
NUT	=	$\left(\frac{\pi}{4}\right)(4.25^2 - 2.75^2)(2.75)(.286)$	=	6.49
TAPER	=	$(2 \times 2.75 \times 11.)(2.75)(.286)$	=	47.58
EYE	=	$\frac{1}{2}\left(\frac{\pi}{4}\,8.25^2\right)(2.75)(.286)$	=	21.02
PIN	=	$(2 \times 2.75)\left(\frac{\pi}{4}\,2.75^2\right)(.286)$	=	9.34
		TOTAL	=	126.90 #/BOLT

1.1 × 126.9 = **140.#** EACH

B.1.8.12 Tiedown System Weight (continued)

Vertical Tiedown Bolt

The total length of these bolts is a function of the rail car design and is, thus not yet defined. So the rail car member height is assumed to be equal to the 6" height of the cradle cross beam.



$$BOLT = \left(\frac{\pi}{4}1.875^2\right)(15.)(.286) = 11.8$$

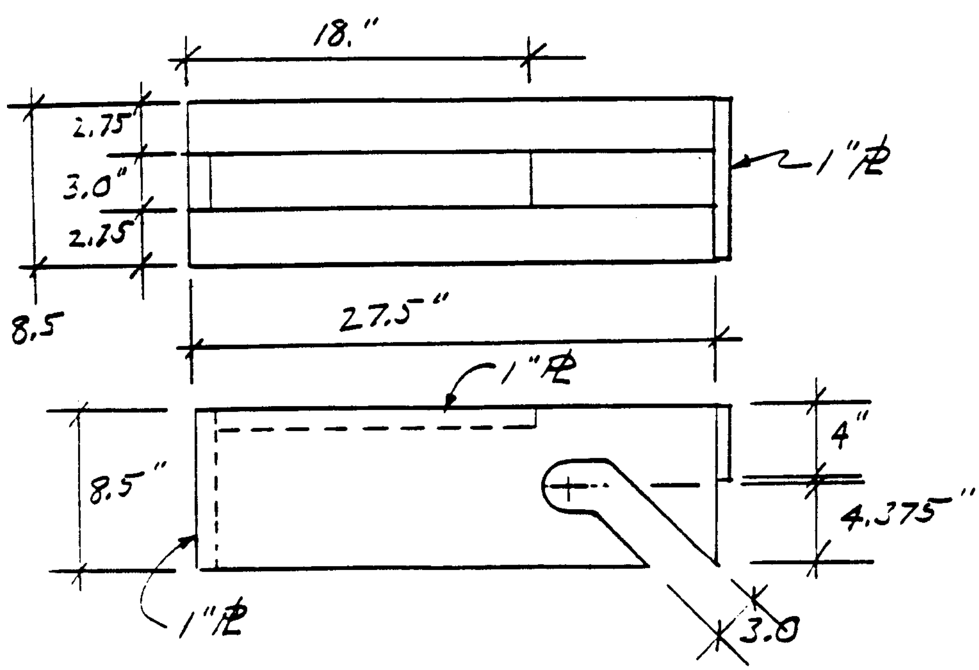
$$NUT = \left(\frac{\pi}{4}(2.9375^2 - 1.875^2)\right)(1.875 \times .286) = 2.2$$

$$HEAD = \left(\frac{\pi}{4}2.9375^2\right)(1.875 \times .286) = 3.6$$

$$TOTAL\ \#/BOLT = 17.6$$

$$1.1 \times 17.6 = \boxed{19.\#}$$

Longitudinal Restraint Blocks



B.1.8.12 Tiedown System Weight (continued)

WEIGHT (BLOCKS)

SIDES	= 2×2.75×8.5×27.5×.286	=	367.7
TOP	= 1×3×17×.286	=	14.6
END	= 1×3×8.5×.286	=	7.3
X-BAR	= 1×4×8.5×.286	=	9.7
SLOTS	= −3×8.5×2×2.75×.286	=	−40.1
	TOTAL #/BLOCK	=	359.2

359.2 × 1.1 = **395.#**

CRADLE TIEDOWN BOLTS/BLOCKS WEIGHT
(INCLUDES 10% CONTINGENCY)

LONGI. BOLTS	= 4(140.)	=	560.#
VERTICAL BOLTS	= 4(19.)	=	76.
LONGI. BLOCKS	= 4(395.)	=	1,580.
CG ~ 3.0"			2,216.#

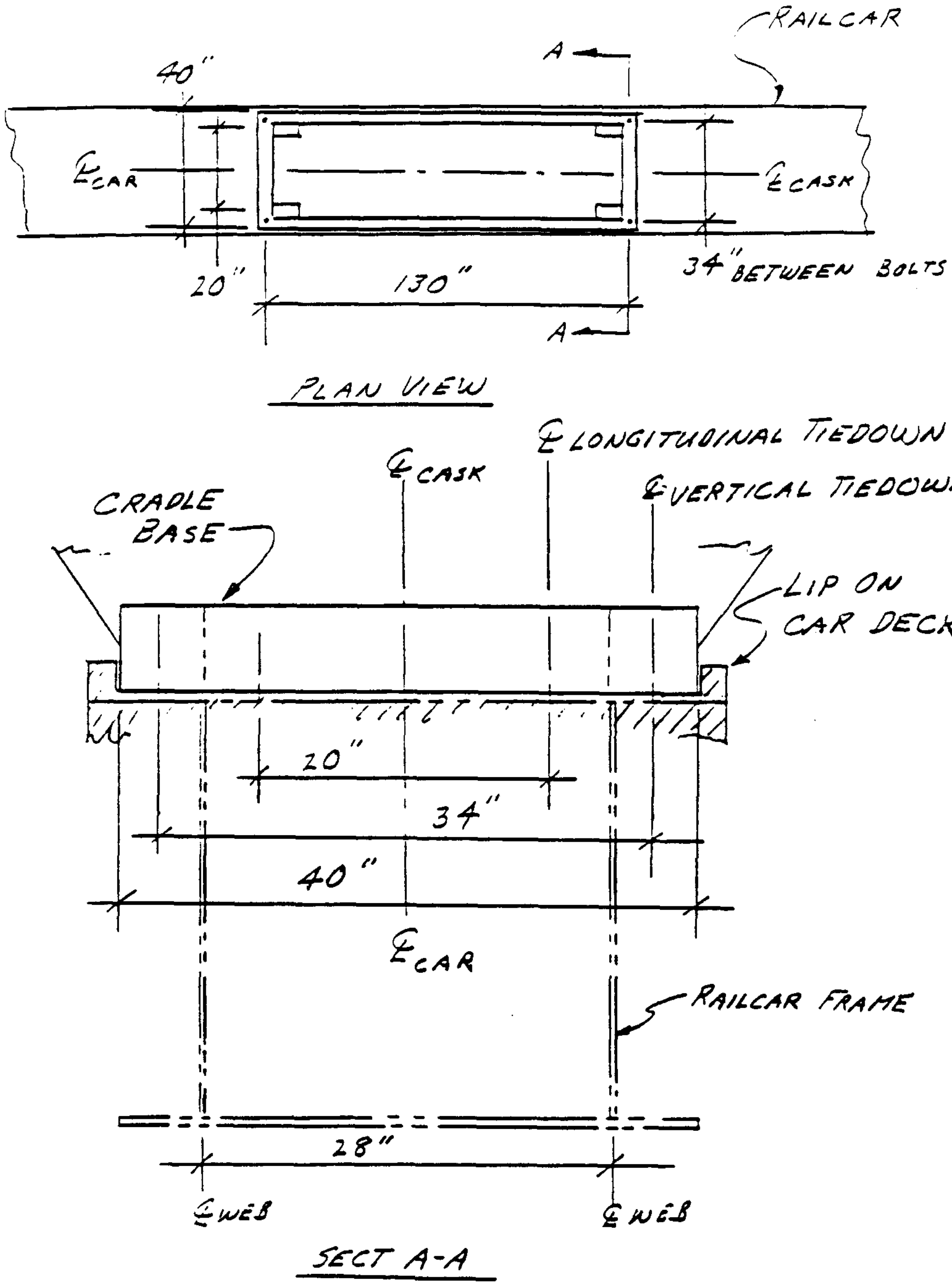
TOTAL TIEDOWN SYSTEM WEIGHT & CG

	W	$\bar{Y}$	M
CRADLE	4,547.#	33.7"	153,234."#
CLAMPS	610.	48.6	29,646.
BOLTS/BLOCKS	2,216	3.0	6,648.
	7,373.#		189,528."#

$$CG = \frac{189,528.}{7373.} = 25.7\text{" ABOVE CAR DECK}$$

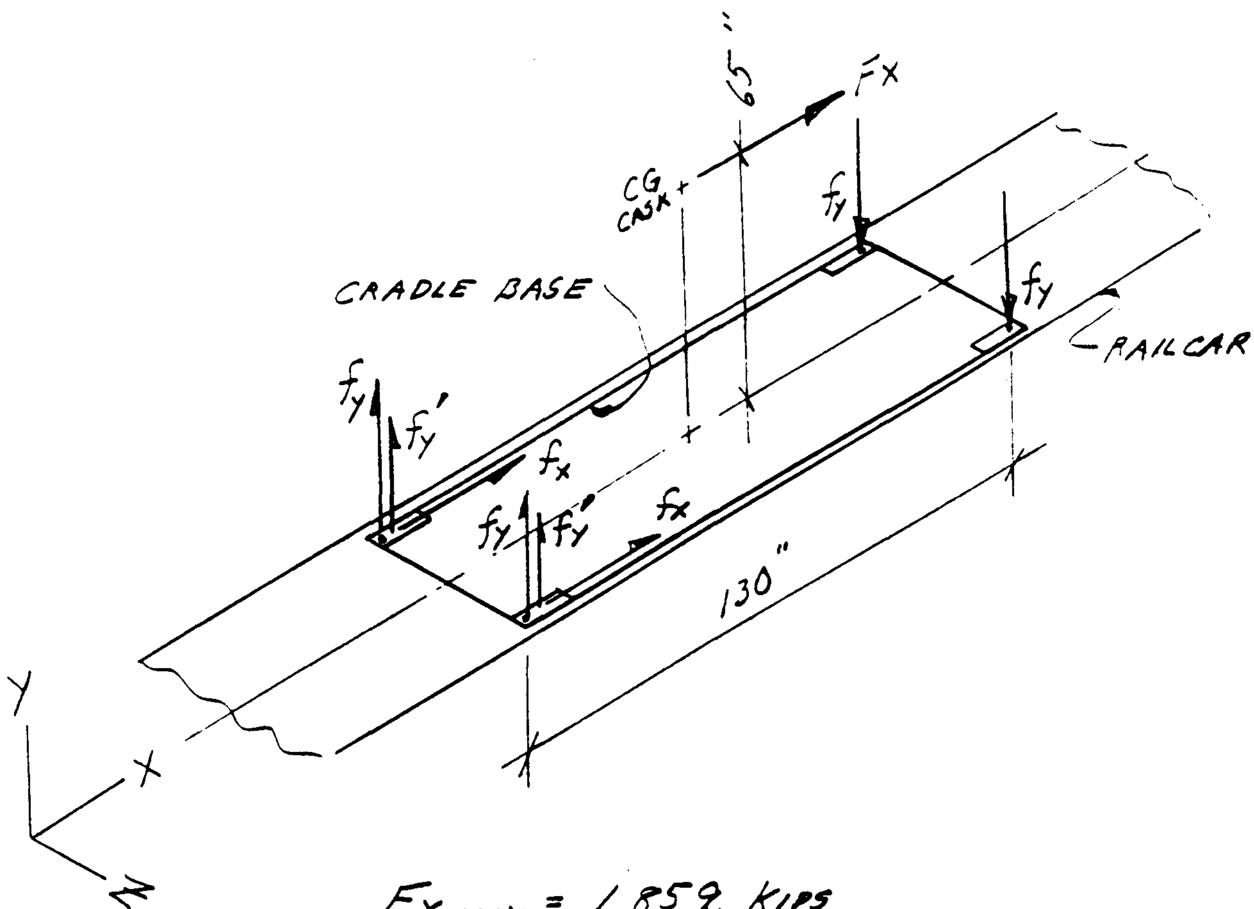
B.1.8.13 Rail Car Interface Loads

- CRADLE BASE GEOMETRY



B.1.8.13 Rail Car Interface Loads (continued)

- LONGITUDINAL LOADS



$$F_{X\,MAX} = 1{,}859.\ \text{KIPS}$$

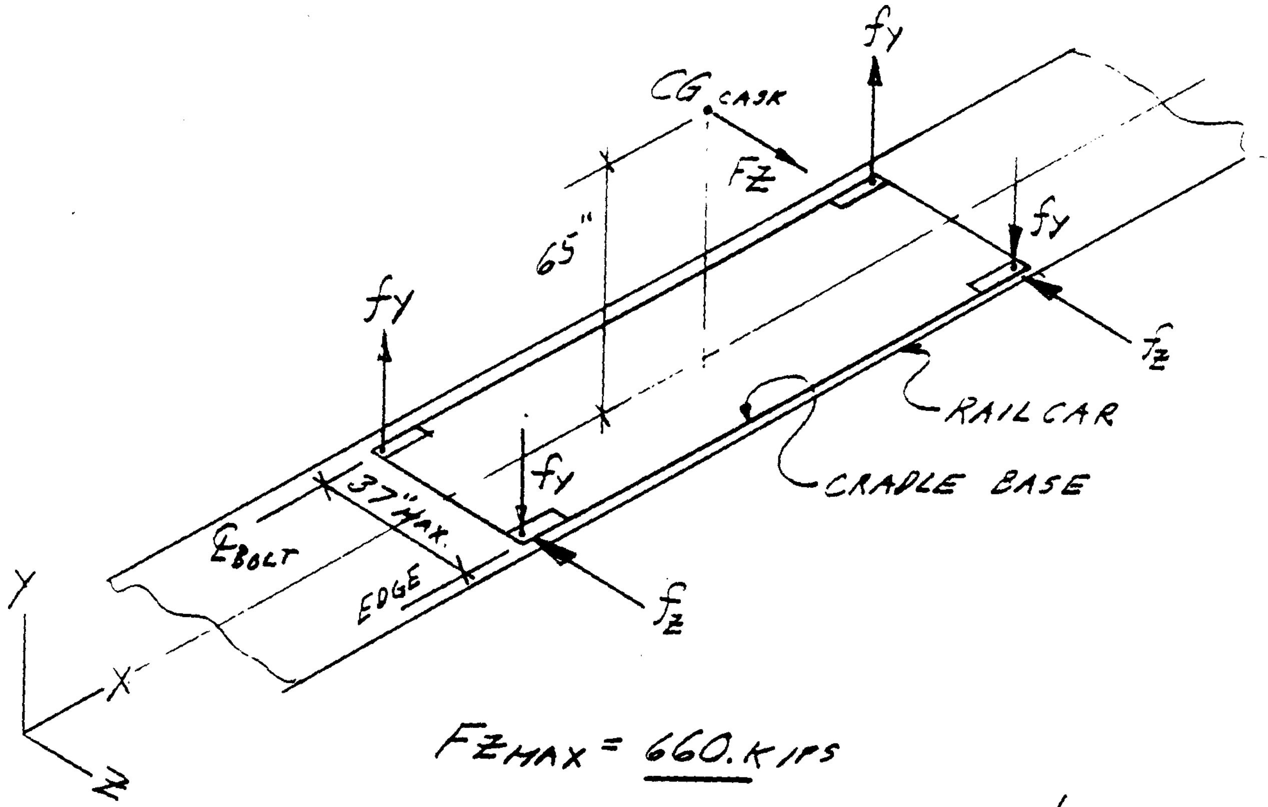
$$f_X = \tfrac{1}{2}F_X = \frac{1859.K}{2} = \underline{930}\ \text{KIPS (LONGITUDINAL BOLT)}$$

$$f_Y' = \tfrac{1}{2}F_X \tan\theta = \frac{1859K}{2}\tan 15^\circ = \underline{249.}\ \text{KIPS (LONGITUDINAL BOLTS)}$$

$$f_Y = \tfrac{1}{2}F_X \frac{65''}{130''} = \frac{1859K}{2}\times\frac{65}{130} = \underline{465.}\ \text{KIPS (VERTICAL BOLTS)}$$

B.1.8.13 Rail Car Interface Loads (continued)

- LATERAL LOADS



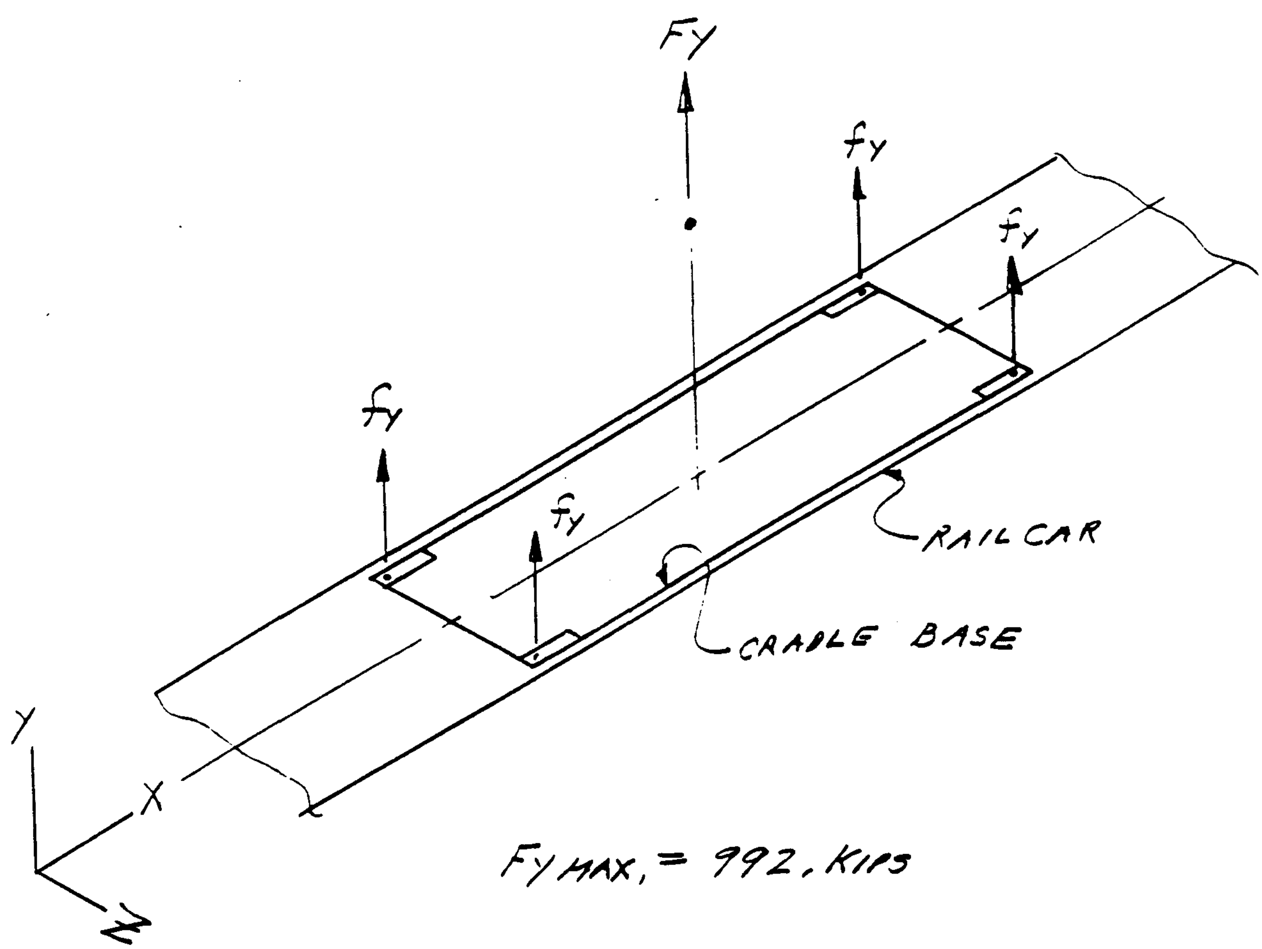
$$F_{Z\,MAX} = \underline{660.\ kips}$$

$$f_Y = \frac{1}{2} F_Z \frac{65''}{130''} = \frac{660K}{2} \times \frac{65''}{37.} = \underline{580.\ kips}$$ (UP ON VERT. BOLTS OR DOWN ON EDGE OF CRADLE BASE.)

$$f_Z = \frac{1}{2} F_Z = \frac{660K}{2} = \underline{330.\ kips}$$ (EDGE OF CRADLE BASE)

B.1.8.13 Rail Car Interface Loads (continued)

- VERTICAL LOADS



$F_{Y\,MAX.} = 992.\ KIPS$

$f_Y = \frac{1}{4} F_Y = \frac{992.\,K}{4} = \underline{248.\ KIPS}$ (UP ON VERT. BOLTS)

IMPACT LIMITER POLYURETHANE FOAM HIGH TEMPERATURE STRUCTURAL PERFORMANCE TEST RESULTS

(FINAL REPORT)

SEPTEMBER 28, 1989

BY

NUCLEAR PACKAGING DIVISION OF
PACIFIC NUCLEAR SYSTEMS, INC.

CONTRACT NO.

DE-AC07-88ID12700

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APPENDIX B, Compressive Stress vs. Strain For Densities From 5 To 25 PCF And Temperatures of 75° F and 220 To 300° F, Perpendicular And Parallel To The Foam Rise

APPENDIX C, Stress vs. Strain Comparisons Of 1985 With 1989 FR-3700 Foam Formulations

APPENDIX D, Compressive Stress vs. Strain Data for a Composite Foam Design At Room Temperature And -20° F

1.0 INTRODUCTION AND SUMMARY

The polyurethane impact limiters planned for the 100 Ton 140-B rail/barge cask being designed by NuPac are similar in form to those on the successfully licensed NuPac 125-B transport cask. The maximum temperatures of the 125-B impact limiters only ranged from 100° F to 135° F through their thickness. The 140-B cask will carry a payload that has to dissipate significantly more heat than the 125-B cask; around 13000 watts versus 700 watts. Thus, as predicted from detailed finite element thermal analyses, the maximum temperatures of the 140-B impact limiters will range, from 130° F on the outside to 270° F on the inside adjacent to the cask body.

In order to determine foam energy absorbing capability and corresponding impact limiter foam thickness and density requirements, accurate details of the foam stress/strain structural characteristics must be known. For the 125-B cask, NuPac had extensive tests performed to characterize the General Plastics FR-3700 formulation of foam. The test temperatures ranged from -20° F to 180° F, and the densities ranged from 5 to 25 lb/cubic ft. The testing described herein represents an extension of 125-B data to temperatures as high as 300° F. The density range remains the same along with the foam formulation; namely, the General Plastics FR- 3700.

The local structural capability of foam on the inside of the impact limiter adjacent to the cask is less than that on the outside because inside temperatures are significantly higher. Thus, a composite foam structure with lower density on the outside and higher on the inside would, in theory, compensate. Composite samples were tested at -20° F. and 75° F.

Finally, thermal conductivity data are presented in order to confirm the above mentioned analytically predicted impact limiter foam temperature distribution. Values of thermal conductivity are presented for 175° F and 275° F mean temperatures, for densities of 15 and 25 lb/cubic ft, and for the FR-3700 formulation.

Sufficient high temperature thermal and structural data have been obtained to properly design the polyurethane foam impact absorbing material planned for the NuPac 140-B cask impact limiters. Further testing is not recommended.

Verification of the structural performance of a composite laminated impact limiter foam design has been obtained. However, more testing would be required to optimize the concept. Such testing is not felt to be necessary because current analyses show that a constant density foam will be satisfactory.

Except for cold -20°F analyses to determine maximum inertia loads, application of the compressive stress vs. strain data presented herein will require interpolation for impact limiter design applications.

2.0 DISCUSSION OF TESTING

The tests described in this report were conducted using, as a guideline, NuPac PQT-0007-NP, Rev. 1, which may be considered an extension of the 1985/1986 test program conducted at temperatures of -20, 75, 100, 140, and 180° F. In the current test series the same five foam densities were tested at 75, 220, 260, and 300° F, the 75° F series acting as a control.

2.1 Overall Methodology

The overall test methodology, parameters for foam density, temperature, strain rate, configuration and number of specimens, were defined in test procedure, NuPac PQT-0007-NP (see APPENDIX A). The significant aspects are given below.

A. Sets of FR-3700 foam samples consisting of five different densities (5,10,15,20, & 25 lb/cubic ft, nominal) were tested in compression to 80 % strain. The specimens were taken from full size production pours, representative of the pour sizes commonly used in impact limiters and overpacks for nuclear materials shipping containers.

B. Each foam density was tested in compression per ASTM D-1621, with exception of specimen size and strain rate. Test were performed at five different temperatures.

C. Three (3) test specimen samples of each foam density were tested at each temperature both perpendicular and parallel to the direction of foam rise.

D. The compressive strain rate for all tests in this series was 0.20 inches per inch (of foam test specimen) per minute. This compared with a 0.10 inches per inch (of foam test specimen) per minute used in the 1985 test series. The higher strain rate was chosen to reduce specimen cool down while testing. The effects of the higher strain-rate were found to be negligible.

E. Specimens size (+/- 0.01 inch)

FR-3700
Foam Density 5.0 lbs/ft^3

3.000 x 3.000 x 1.000

FR-3700
Foam Density 10.0 lbs/ft^3

3.000 x 3.000 x 1.000

FR-3700
Foam Density 15.0 lbs/ft^3

1.500 x 1.500 x 1.000

FR-3700
Foam Density 20.0 lbs/ft^3

1.000 x 1.000 x 1.000

FR-3700
Foam Density 25.0 lbs/ft^3

3.000 x 3.000 x 1.000

The load was applied to the specimens parallel to the one inch dimension.

F. Thickness recovery: After unloading, the specimen thickness was monitored using a dial indicator. Measurements were taken at 5,10,15 and 24 minutes from time of unloading. Typical thickness recovery data are given in the upper left hand section of the composite stress vs. strain plots included in APPENDIX D.

2.2 Test Equipment

The tests were conducted on an Instron Universal testing machine. Stress measurements were made using a 20,000 lb Instron reversible load cell. Strain measurements were made with an L.V.D.T. electronic instrument utilizing AC excitation. Phase shift discriminated input was used with both transducers to eliminate possible DC interference.

Specimen temperature was obtained by heating or cooling the specimen in a steel "thermal box", a thick insulated steel container with a floating steel lid and a large thermal mass. The "thermal box" containing the specimen was placed in an oven maintained at the appropriate test temperature. The specimens were tested while still inside their "thermal boxes", which allowed their temperature to be maintained in the proper range throughout the test. See Table 2.1 below. Chromel/Alumel, type K, thermocouples peened into the "thermal box" bottom surfaces were used to record the "worst case" specimen temperature, which was the temperature of the metal in contact with the specimen surfaces.

All test/measuring equipment used during the performance of these tests were calibrated in accordance with the requirements contained in ASTM E-4 and/or MIL-STD-45662.

2.3 Test Temperatures

Table 2.1 below shows typical specimen "thermal box" temperature measurements which were monitored during the high temperature testing. It should be noted that the internal specimen temperature will change even less than the recorded specimen surface temperature. The temperatures were recorded at 10 % deflection intervals and a test of one specimen typically takes four minutes.

TABLE 2.1 Typical Foam Specimen Surface Temperature at Indicated Strain

Nominal Temp (°F)	10%	20%	30%	40%	50%	60%	70%	80%
75	75	75	75	75	75	75	75	75
220	219	218	218	217	217	216	215	215
260	261	260	259	258	257	256	254	253
300	298	297	296	295	294	293	291	290

2.4 Data Reduction

Compressive strength of rigid urethane foam at a given temperature, direction of foam rise, strain and strain rate is a function of the foam formulation and density. As all tests were conducted on the same formulation and at the same

strain rate, compressive strength may be considered to be a function of density, temperature and direction of foam rise only.

The test data for each temperature condition and direction of foam rise was analyzed by computing a linear regression of stress vs. strain at the following strain intervals:

10% 20% 30% 40% 50% 60% 65% 70% 75% & 80%

As the regression line is a power curve of the form $Y = ax^b$, the **logarithms** of both the densities and the compressive **strengths were taken**, and a "line of best fit" for the **following equality** was computed.

$$\log Y_e = \log a + b \log x$$

where: Y_e = Compressive strength in PSI at strain e

x = foam density in lb/cubic ft (PCF)

a = the Y-intercept of the regression line

b = the slope of the regression line

The antilog of the Y-intercept was then taken and the equation

expressed as: $Y_e = ax^b$

The deviation in PSI and the deviation in percent of the actual test data above or below the regression line was computed for each data point. Using the percent deviations calculated for each data point, the coefficient of variation was calculated for each regression line. These calculations were performed for 100 regression lines using the data from 15 compressive strength tests and their 15 corresponding densities for each line.

The method of fitting yield strength data as a power function of the foam density is commonly used in aerospace foam specifications. Extension of this method to strains beyond the foam yield point has been verified by NuPac on various cask projects including the 125-B. The resulting data were plotted as will be subsequently described in Section 3.1.

3.0 TEST RESULTS

Test results are presented in this section for the following:

- Compressive strength vs. density and temperature for constant density foam samples at high temperature.

- Compressive strength vs. temperature for composite density laminated (adhesively bonded) and non-laminated (no adhesive) foam samples at low temperature.

- Thermal conductivity vs. density and temperature for constant density foam samples at high temperature.

3.1 Basic Compressive Strength

APPENDIX B contains plots and corresponding tabulated data for all high temperature foam compressive strength data obtained in this program. The data consists of ten plots and ten corresponding tables. Each plot and corresponding table gives stress vs. strain data for four temperatures; namely, 75, 220, 260, & 300 °F. The relative high valued 80 % stress/strain data are given only in the tables because their inclusion in the plots would have resulted in readability problems. The first five plots and tables are for test results perpendicular to the foam rise, and the remaining are for results parallel to the rise. To obtain stress data between zero strain and 10 % strain, multiply the stress value at 10 % strain (the yield stress) from the plots or tables by the appropriate factor given in Table 3.1 below.

Table 3.1 Factors To Be Used To Obtain Compressive Stress Values Between Zero And 10 % Strain

	Foam Density (PCF)				
Percent strain	5	10	15	20	25
Zero %	0	0	0	0	0
3 TO 7 %	1.24	1.12	1.00	1.00	1.00
10 %	1.00	1.00	1.00	1.00	1.00

The above factors were derived from the raw test data. They will result in conservative values to be utilized with computer codes that compute quasi-static or dynamic inertia loads transmitted to the cask via the impact limiter shock absorbers.

APPENDIX C contains plots that compare room temperature data from 1985 (the OLD) with 1989 (the NEW). These data were obtained for control purposes, in order to assure that the FR-3700 foam formulation utilized in 1985 and 1989 showed essentially the same stress vs. strain performance. The slight differences shown are to be expected according to the foam manufacturer. Thus, the FR-3700 formulation utilized in the 1989 or current test series gives essentially the same stress vs. strain performance as that utilized in 1985.

3.2 Composite Compressive Strength

APPENDIX D contains stress vs. strain data obtained from composite foam specimens. The composite design consists of three layers of foam; first layer has density equal 15 PCF; middle layer has density equal 20 PCF; and the third layer has density equal 25 PCF. Of the total thickness, 40% consists of 15 PCF, 40 % consists of 20 PCF, and 20 % consists of 25 PCF. In actual application, the 25 PCF layer will be on the impact limiter side adjacent to the cask.

The composite design substantially reduces inertia loads transmitted to the cask (on the order of 35 %) when compared with an equivalent constant density design. Furthermore, the composite design maintains foam strength within the limiter at regions adjacent to the cask equal to or higher than external regions that first get crushed. The constant density design is weaker under nearly all environmental conditions in regions of the impact limiter adjacent to the cask.

Eight characteristic curves of stress vs. strain are presented for the composite design specimens at room temperature or 75°F. The first four represent foam sections taken perpendicular to the rise and the other four parallel to the rise. Two specimens were not laminated or glued together, and show that the effects of lamination are negligible.

Six characteristic curves of stress vs. strain are presented for the composite design specimens at -20°F. Three specimens represent foam sections taken perpendicular to the rise and the other three parallel to the rise. All specimens tested at -20°F were laminated. Actual test data for the above are tabulated at the end of the appendix.

Typical thickness recovery data are given in the upper left hand section of each plot listed in APPENDIX D. These data are included for information only since they are not utilized in design applications.

3.3 Thermal Conductivity

Thermal conductivity testing was conducted for 15 PCF and 25 PCF foam density specimens in accordance with ASTM C-177 at mean temperatures of 175 and 275 °F. The results are presented in Table 3.2 below. The testing was performed by GEOSCIENCE LTD.

Table 3.2 High Temperature Foam Thermal Conductivity Test Results For Formulation FR-3700

Foam Density (lb/cu-ft)	Thermal Conductivity (Btu/ft-hr-°F)	
	175° F (mean)	275° F (mean)
15 PCF	0.0182	0.0270
25 PCF	0.0172	0.0270

4.0 CONCLUDING REMARKS

A. Sufficient high temperature thermal and structural data have been obtained to properly design the polyurethane foam impact absorbing material planned for the NuPac 140-B cask impact limiters. Further testing is not recommended.

B. Verification of the the structural performance of a composite laminated impact limiter foam design has been obtained. However more testing would be required to optimize the different laminated densities and corresponding thicknesses. Initial discussions with the foam manufacturer, General Plastics, have been positive with respect to fabrication feasibility of a composite foam impact limiter.

C. Except for cold -20°F analyses to determine maximum inertia loads, application of the compressive stress vs. strain data presented herein will require interpolation. For hot conditions with large temperature gradients throughout the foam, stress vs. strain characteristics will be determined entirely by interpolation based on the guiding analytically determined temperature profiles.

APPENDIX A

Copy of NUPAC PQT-0007-NP, "Performance Test Procedure For 140-B Impact Limiter Foam High Temperature Structural Performance Test Plan"

PACIFIC NUCLEAR ®

TITLE

PERFORMANCE TEST PROCEDURE FOR 140 - B IMPACT LIMITER FOAM HIGH TEMPERATURE STRUCTURAL PERFORMANCE TEST PLAN

PROCEDURE # PQT-0007-NP

REVISION: 1 DATE: 12-16-88

ESSENTIAL RELATED NUPAC DOCUMENTS

The following related NuPac document(s) contain operations or information essential to performance of instructions herein and must be issued in conjuction with this document:

1. N/A ORC 12/29/88	2.
3.	4.
5.	6.

	DATE		DATE
Chuck Cunningham	11/29/88	NA	11-29-88
PREPARED BY		OTHER	
James R Schumhart	11-29-88		11-29-88
PROGRAM MANAGER		OTHER	
NA	11-29-88	Herbert Wienecke	11/29/88
ENGINEERING (LICENSED PRODUCTS)		PURCHASING	
D L Stuerzmark	11/29/88	H. Lerch	11/29/88
ENGINEERING (DESIGN)		CHECK	
Stan A. Foster	11.29.88	D. E. Hill	11/29/88
ENGINEERING (ANALYSIS)		QA	
W.R. Brown by DLS	11/28/88	Carolyn Carmier	11/30/88
MANUFACTURING		RELEASE (Document Control)	

NPQ089 9-20-88

NA 11-29-88

PROCEDURE REVISION RECORD

Procedure No. PQT-0007-NP **Initial Release Date** November 30, 1988

TITLE: Performance Test Procedure for 140-B Impact Limiter Foam High Temperature Structural Performance Test Plan

REV	DESCRIPTION OF CHANGE	PAGE(S) AFFECTED	DATE	SIGNATURE
0	Initial Release	ALL	11-30-88	C. Carnick
1	Sections 1.0,3.4,3.6,3.10,3.11,4.1, 4.2,4.3.2,4.3.3,4.4	1,2,3,4, 5,6	12-16-88	C Carnick

NPQ072 8/24/88

TABLE OF CONTENTS

1.0 SCOPE

This procedure presents the requirements for compressive strength tests on the polyurethane foam formulation planned for the impact limiters for the 140-B transportation cask. The formulation planned is the General Plastics FR-3700. The testing shall follow the general guidelines specified in ASTM-D-1621. The primary goal of the testing is characterization of the foam stress/strain performance from zero to 80% strain for temperatures from 180°F to 300°F. Foam densities from 5 PCF to 25 PCF shall be tested.

In addition, a few samples may be tested to obtain thermal conductivity values per the general guidelines specified in ASTM-C-177. The corresponding mean temperatures will be chosen between 75°F and 300°F. Additional application and foam improvement compressive strength testing may be performed. All testing in this paragraph shall be optional and performed as deemed appropriate by the cognizant NuPac engineer.

2.0 REFERENCES

2.1 ASTM-D-1621, Compressive Properties Of Rigid Cellular Plastics, 1973 or latter Edition.

2.2 ASTM-C-177, Steady State Heat Flux Measurements And Thermal Transmission Properties By Means Of The Guarded-Hot-Plate Apparatus, 1985 or latter Edition.

3.0 REQUIREMENTS

3.1 A suitable compression testing machine capable of operating at a constant rate of motion of the movable crosshead. The rate of crosshead movement shall be 0.2 +/-0.01 inches per minute per inch of specimen thickness. This increased speed has been found to be negligible and is needed to reduce sample cooling effects.

3.2 A load-indicating mechanism that will permit measurements to a precision of +/-1%.

3.3 A deformation-indicating mechanism that will permit measurements to a precision of +/-0.1%.

3.3 A micrometer dial gage, caliper, or steel rule, suitable for measuring dimensions of the specimens to +/-1%.

3.4 One hundred twenty foam specimens ranging in size nominally 3 inches by 3 inches to 1 inch by 1 inch square and all 1 inch thick. Six specimens for each of five densities, namely 5, 10, 15, 20, & 25 PCF (lbs per cu ft) with a tolerance of +/-20%. Specimens shall be permanently marked or tagged to indicate the foam rise direction and density.

3.5 At each density, three of the six specimens are to be taken perpendicular to the rise, and the other three to be taken parallel to the rise all from typ-full size production pours.

3.6 A thermal conditioning oven and foam fixture of relatively large thermal mass for minimizing specimen cooling during the four minute tests will be utilized. The cooling rate of the foam specimens shall average less than $5^{O}F$ per minute overall for typical four minute compressive tests.

3.7 Temperature monitoring equipment capable of measuring test requirements with a precision of $+/-5^{O}F$ shall be utilized.

3.8 A stress/strain measuring plotter capable of recording the corresponding test data with sufficient resolution to produce meaningful results; namely, repeatable stress values with a precision of +/-1% of indicated stress.

3.9 Guarded-Hot-Plate apparatus shall be required that corresponds with the requirements of ASTM-C-177.

3.10 Four foam specimens will be required for four thermal conductivity tests per ASTM-C-177. Foam densities to be tested shall be 15 and 25 PCF +/-20%. Nominal mean temperatures shall be $275^{O}F$ & $175^{O}F$. The same foam specimens shall be tested at both mean temperature levels. Nominal specimen size shall be 10 inch diameter by 1 inch thick. Specimens shall be permanently marked or tagged to indicate the foam rise direction and density in order to meet requirements of paragraph 4.3.2.

3.11 All test/measuring equipment used for the testing described herein shall be calibrated to National Bureau of Standards (traceable standards per ASTM-4 and/or MIL-STD-45662). The serial numbers and the dates of next and last calibration of all test/measuring equipment shall be recorded, verified and presented with corresponding data results in the final report mentioned in section 4.2.5.

4.0 PROCEDURE

4.1 Testing conducted per this procedure shall follow the general guidelines of ASTM-D-1621 and ASTM-C-177. Deviations from the above two procedures are allowed for practical reasons. The requirements of this procedure take precedence over requirements of the two ASTM test procedures; however, any other significant deviations shall be listed below and approved by the NuPac cognizant engineer before proceeding with the tests. Any deviations from the requirements of this procedure shall be brought to the attention of the cognizant NuPac engineer by listing them in the non-conformance section 4.1.3. Disposition and approval shall be recorded by the cognizant NuPac engineer with QA concurrence.

4.1.1 Significant Deviations From ASTM-D-1621

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Cognizant Engineer Approval________________Date____

4.1.2 Significant Deviations From ASTM-C-177

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Cognizant Engineer Approval________________Date____

4.1.3 Non-conformance Record

NON-CONFORMANCE______________________________

____

____

____

DISPOSITION____________________________________

____

____

Cognizant Engineer Approval________________Date____

4.2 Compressive Stress/Strain Testing

4.2.1 Obtain six samples of FR-3700 foam and test per requirements of section 3.0. Record the following:

	SPL 1	SPL 2	SPL 3	SPL 4	SPL 5	SPL 6
o DENSITY	____	____	____	____	____	____
o START TEMP	____	____	____	____	____	____
o FINISH TEMP	____	____	____	____	____	____

Note: SPLs 1, 2,& 3 perpendicular to rise
SPLs 4, 5,& 6 parallel to rise
SPL (means Sample)

4.2.2 Repeat 4.2.1 for densities of 5, 10, 15, 20, & 25 PCF +/-20%.

4.2.3 Repeat 4.2.1 at each density specified in 4.2.2 for temperatures of 75, 220, 260, & 300 DEG F +5/-10 DEG F.

4.2.4 Produce 120 plots of stress vs strain as shown in Figure 1, attached. Record all data, material, test number, temperature, load, configuration, density, recovery rates, test operator, and date as shown in Figure 1.

4.2.5 Provide preliminary test report including background, overview, test procedure information, test equipment and associated calibration verification dates, data reduction utilizing linear regression methods, stress/strain plots for each test including all data mentioned in 4.2.4 above, test observations, conclusions, any nonconformances per 4.1.3 above, and summary plots for each density of stress vs strain from zero to 80% and at the four test temperature levels of 4.2.3 above.

4.3 Thermal Conductivity Testing

4.3.1 This testing shall be performed if the cognizant NuPac engineer deems it appropriate, as mentioned in section 1.0 above.

4.3.2 Obtain two samples of FR-3700 foam and test per requirements of section 3.0. Record the following:

	TOP SAMPLE	BOTTOM SAMPLE
o DENSITY	________	________
o TOP PLATE TEMP	________	________
o BOTTOM PLATE TEMP	________	________

Note: TOP SAMPLE perpendicular to rise

BOTTOM SAMPLE parallel to rise

4.3.3 Repeat 4.3.2 for densities of 15 & 25 PCF +/- 20%.

4.3.4 Repeat 4.3.2 at each density specified in 4.3.3 for nominal mean temperatures of 175 & 275 DEG F.

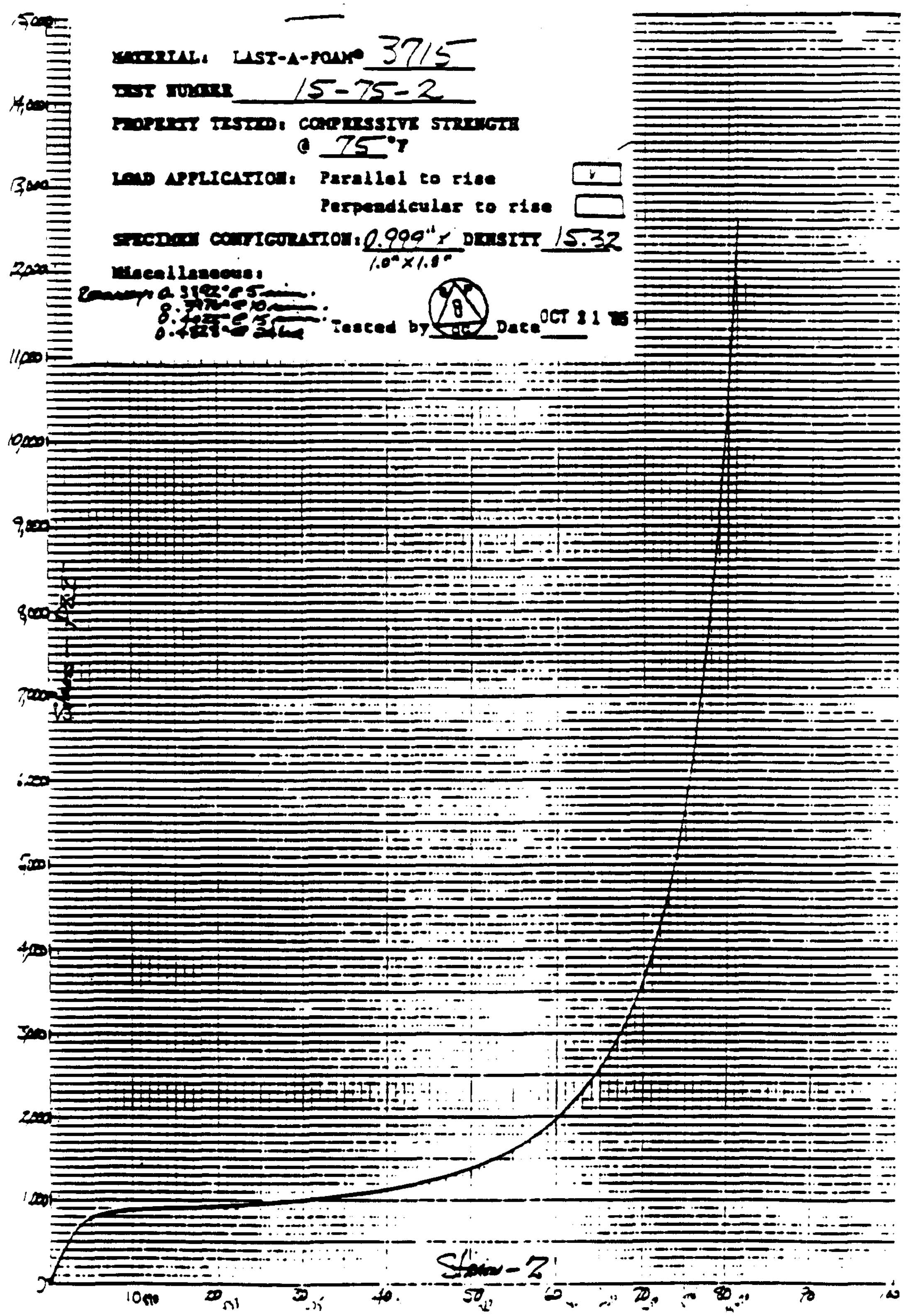
4.3.5 Provide preliminary test report listing the following:

- o Thermal conductivity, k = Btu(in)/(hr)(sqft)(F)
- o Thermal resistance, R = (hr)(sqft)(F)/Btu(in)
- o Thickness of specimen as tested, inches
- o Density of material as tested, lbs/cu ft
- o Temperature gradient across specimen, DEG F
- o Mean temperature of test, DEG F
- o Heat flux through specimen, Btu/(hr)(sqft)
- o Orientation of plane of specimen (rise dir)
- o Air temp around guarded-hot-plate during test
- o Test date

- o Test equipment calibration data
- o NBS standard information and % error

4.4 Optional application and foam improvement testing (details to be formulated at end of the above test program)

Figure 1
Sample Stress/Strain Data



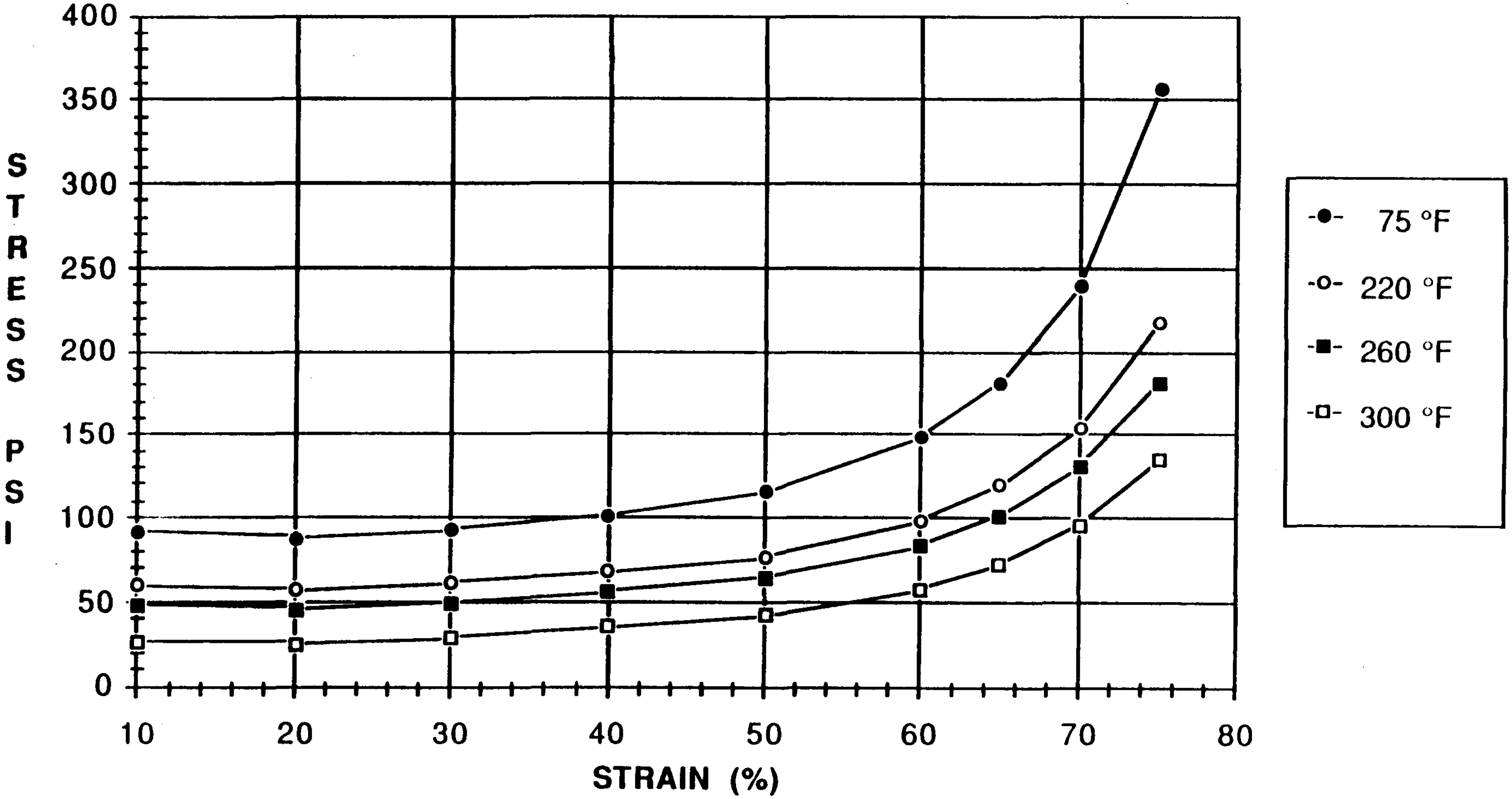
APPENDIX B

Compressive Stress vs. Strain For Densities From 5 To 25 PCF And Temperatures at 75° F and 220 To 300° F, Perpendicular And Parallel To The Foam Rise

GENERAL PLASTICS MANUFACTURING COMPANY PO.BOX 9097 TACOMA WA. 98409

FR-3700 Comp. Strength Perpendicular to rise

Foam Density 5.0 lbs/ft^3



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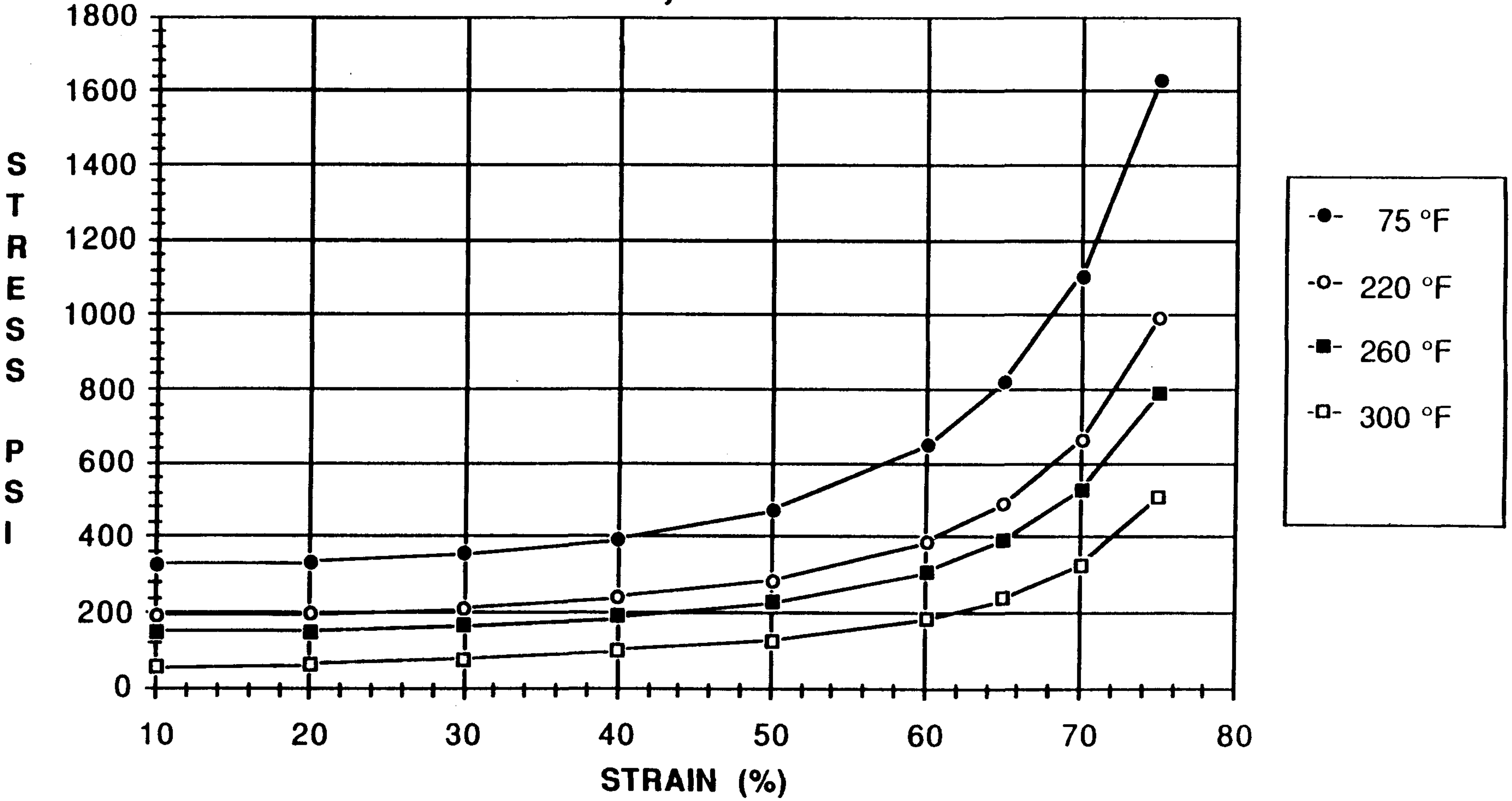
LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PERPENDICULAR TO RISE
Strength in (PSI)

DENSITY= 5.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	92	88	93	102	116	149	182	240	356	588
220 °F	60	57	62	68	77	99	120	154	218	318
260 °F	48	46	50	57	65	84	102	131	182	257
300 °F	26	26	30	36	42	58	73	97	135	217

FR-3700 Comp. Strength Perpendicular to rise

Foam Density 10.0 lbs/ft^3



LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PERPENDICULAR TO RISE
Strength in (PSI)

DENSITY= 10.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	330	333	355	395	474	649	822	1105	1629	2700
220 °F	195	196	213	241	285	389	490	664	994	1810
260 °F	150	150	166	190	227	311	393	531	791	1433
300 °F	56	65	79	100	128	185	239	330	509	898

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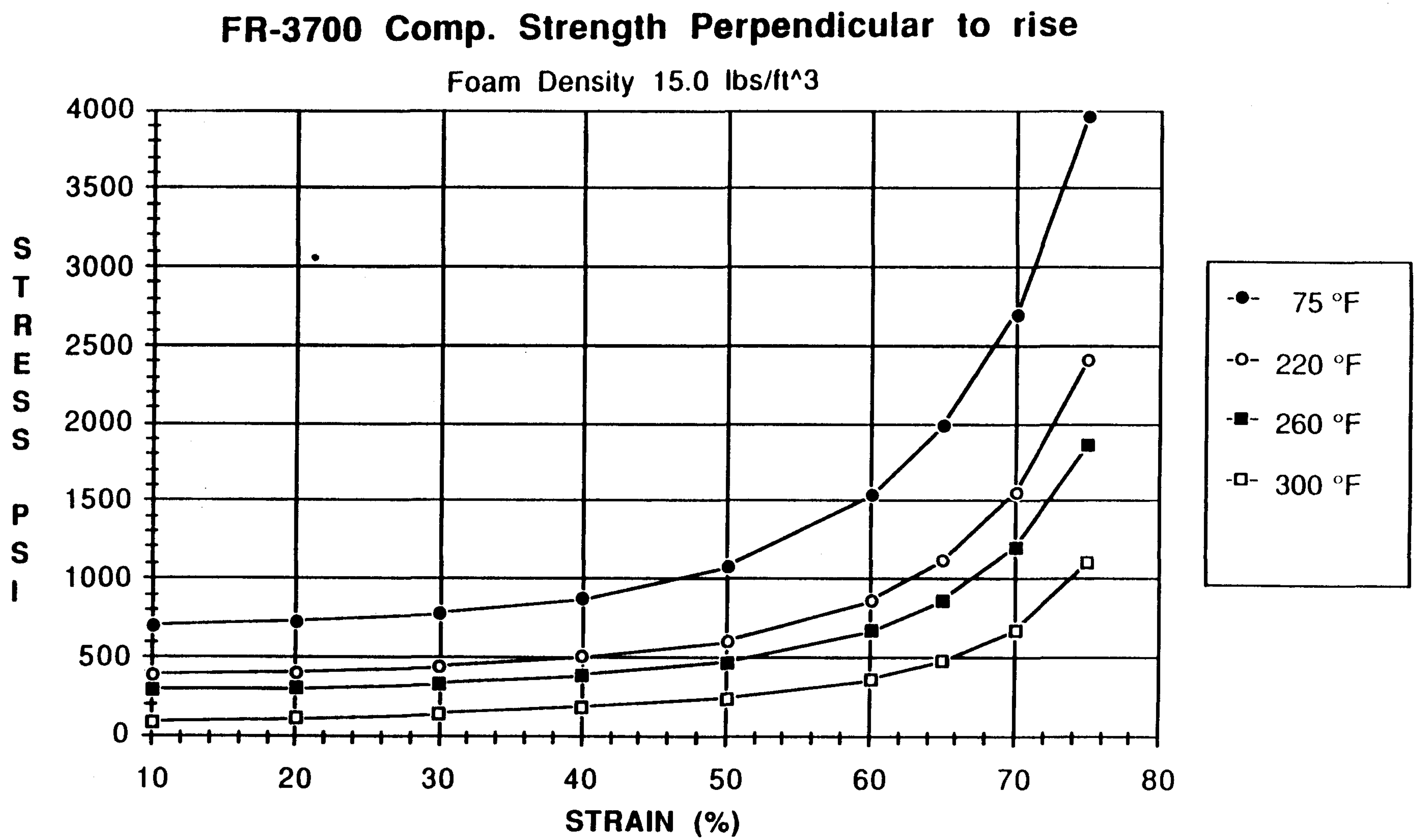

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LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PERPENDICULAR TO RISE

Strength in (PSI)

DENSITY= 15.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	698	726	779	873	1081	1538	1990	2701	3964	6584
220 °F	388	403	439	505	611	865	1119	1559	2414	5002
260 °F	291	302	334	386	473	669	867	1203	1868	3920
300 °F	86	112	142	183	243	365	479	677	1108	2061

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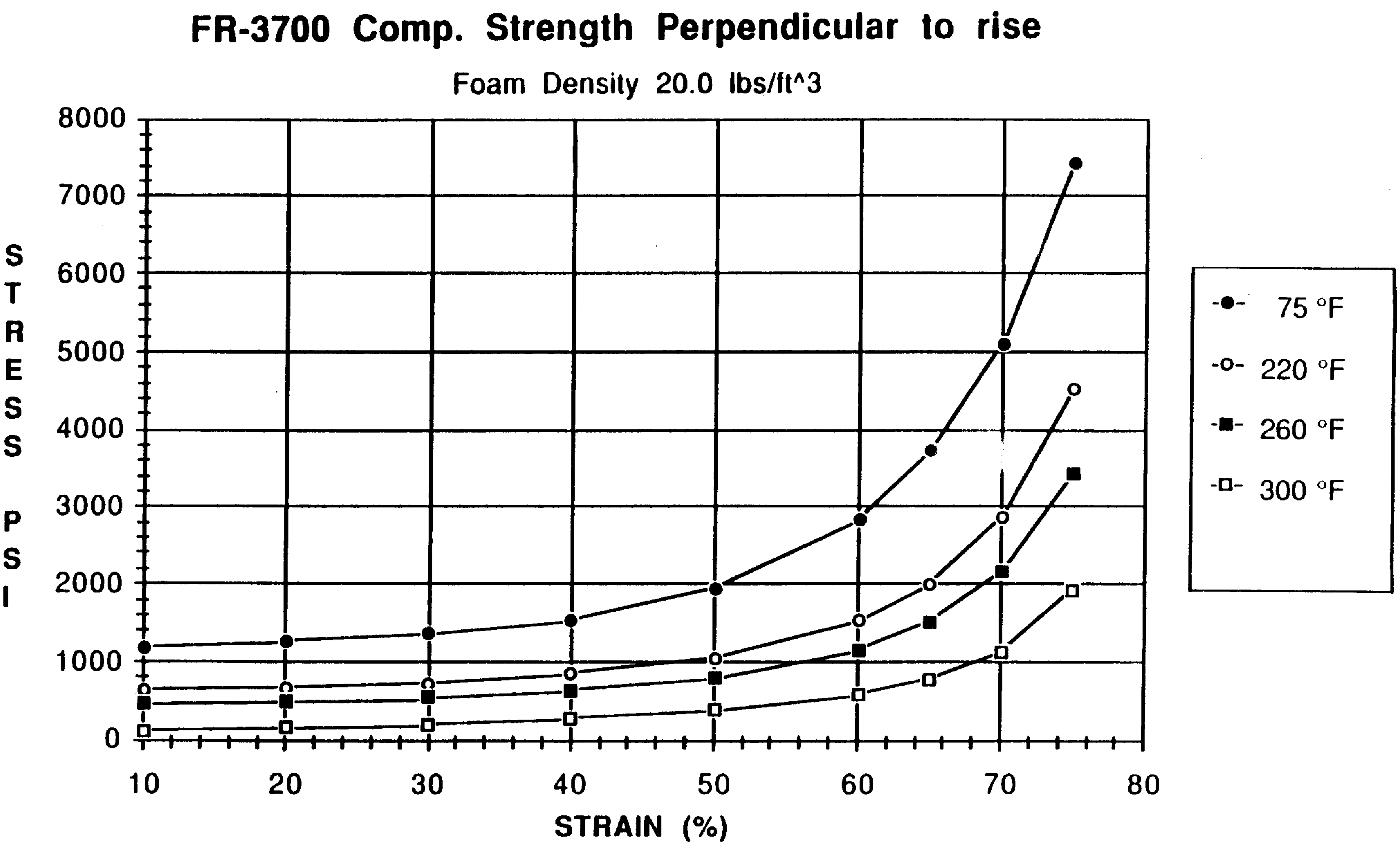

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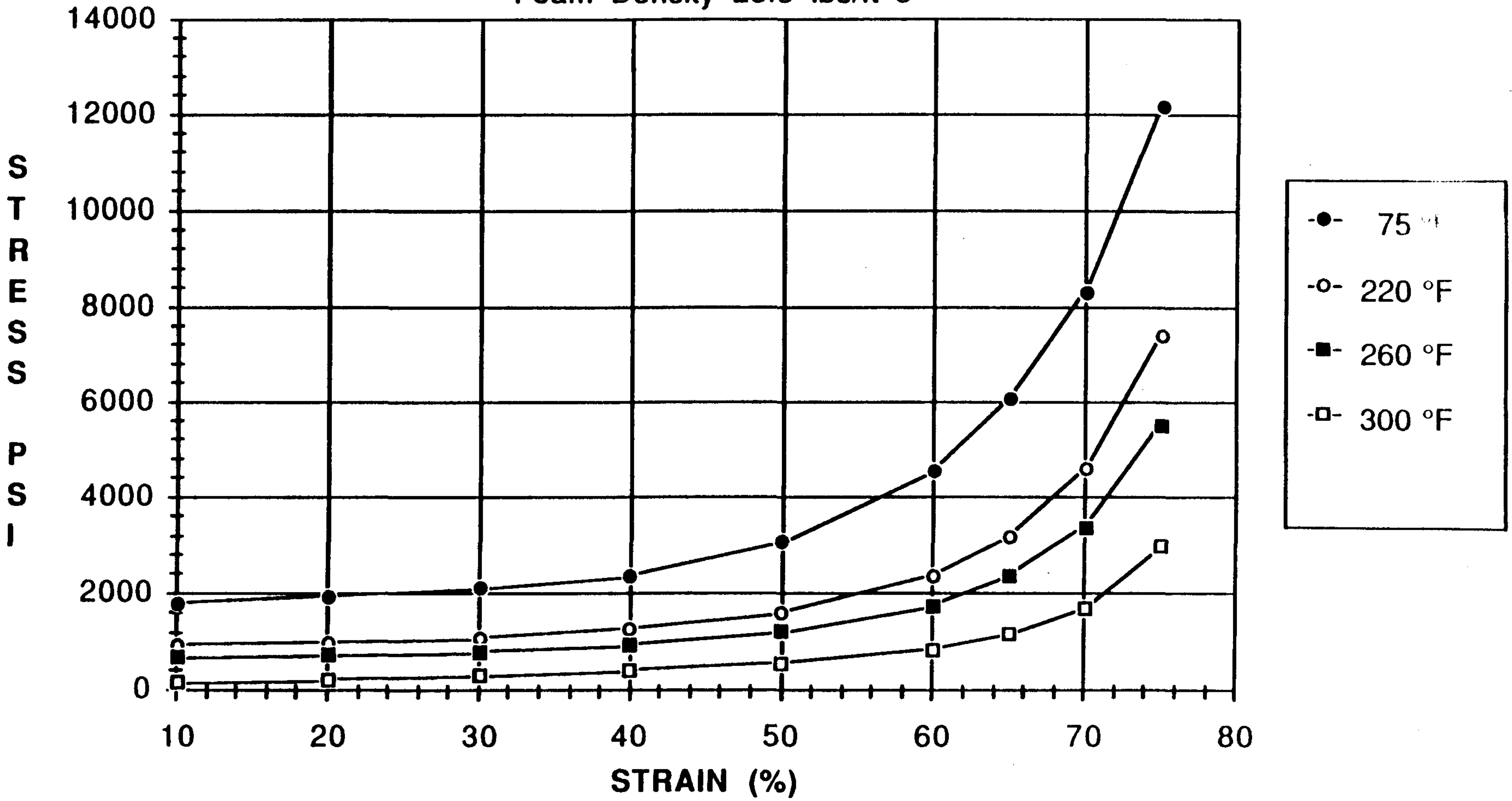
LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PERPENDICULAR TO RISE
Strength in (PSI)

DENSITY= 20.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	1186	1262	1361	1533	1940	2837	3726	5091	7449	12392
220 °F	633	671	733	853	1049	1526	2009	2857	4530	10290
260 °F	465	494	548	637	795	1152	1518	2149	3438	8004
300 °F	117	164	214	281	385	590	783	1128	1923	3716

FR-3700 Comp. Strength Perpendicular to rise

Foam Density 25.0 lbs/ft^3



LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PERPENDICULAR TO RISE
Strength in (PSI)

DENSITY= 25.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	1791	1937	2096	2373	3054	4560	6059	8325	12150	20238
220 °F	924	997	1092	1282	1595	2371	3163	4571	7382	18007
260 °F	670	725	805	941	1191	1757	2346	3371	5517	13925
300 °F	149	222	294	393	549	856	1147	1675	2951	5869

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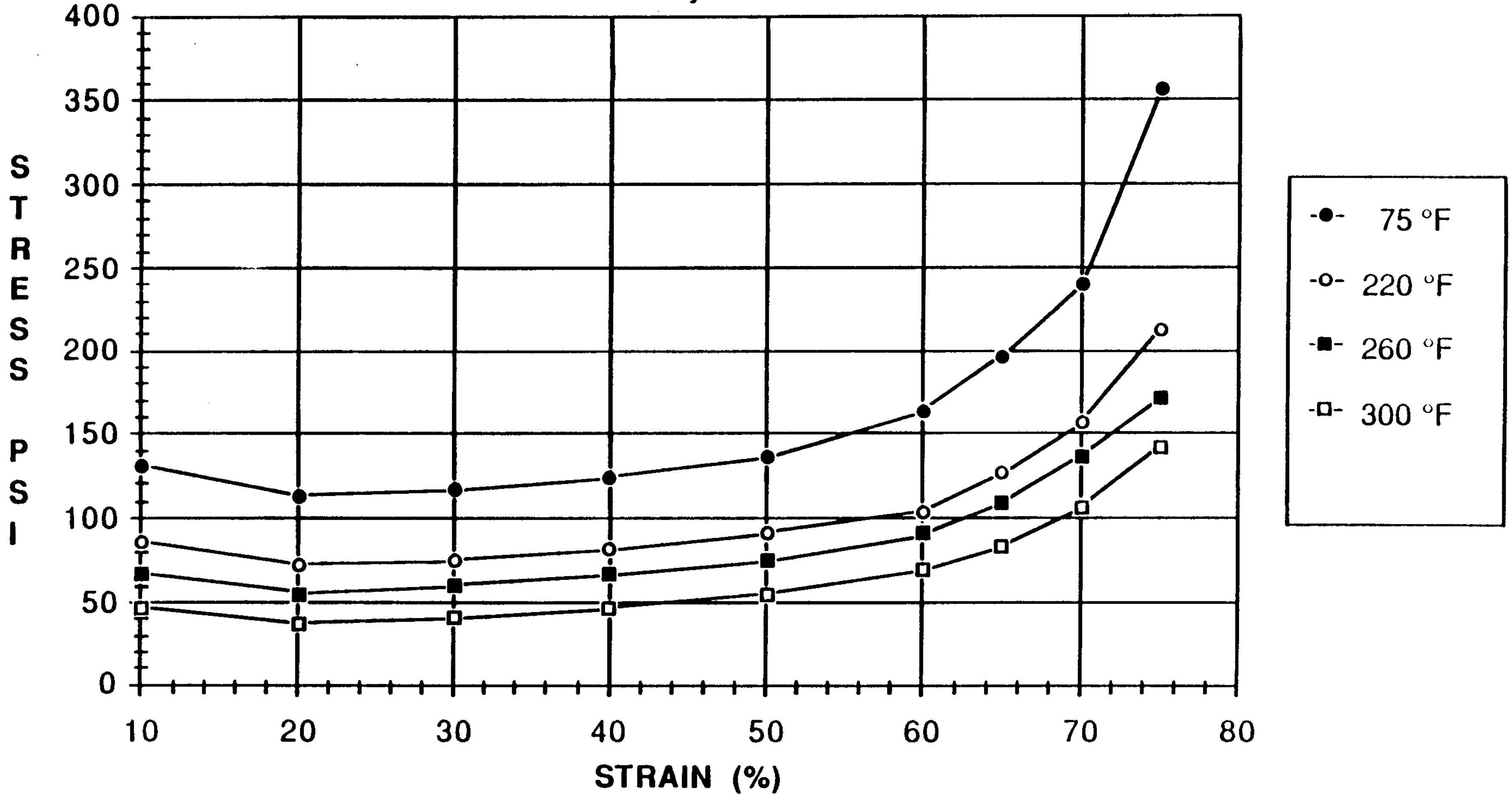
FR-3700 Compressive Strength Parallel to rise

Foam Density 5.0 lbs/ft^3



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LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PARALLEL TO RISE
Strength in (PSI)

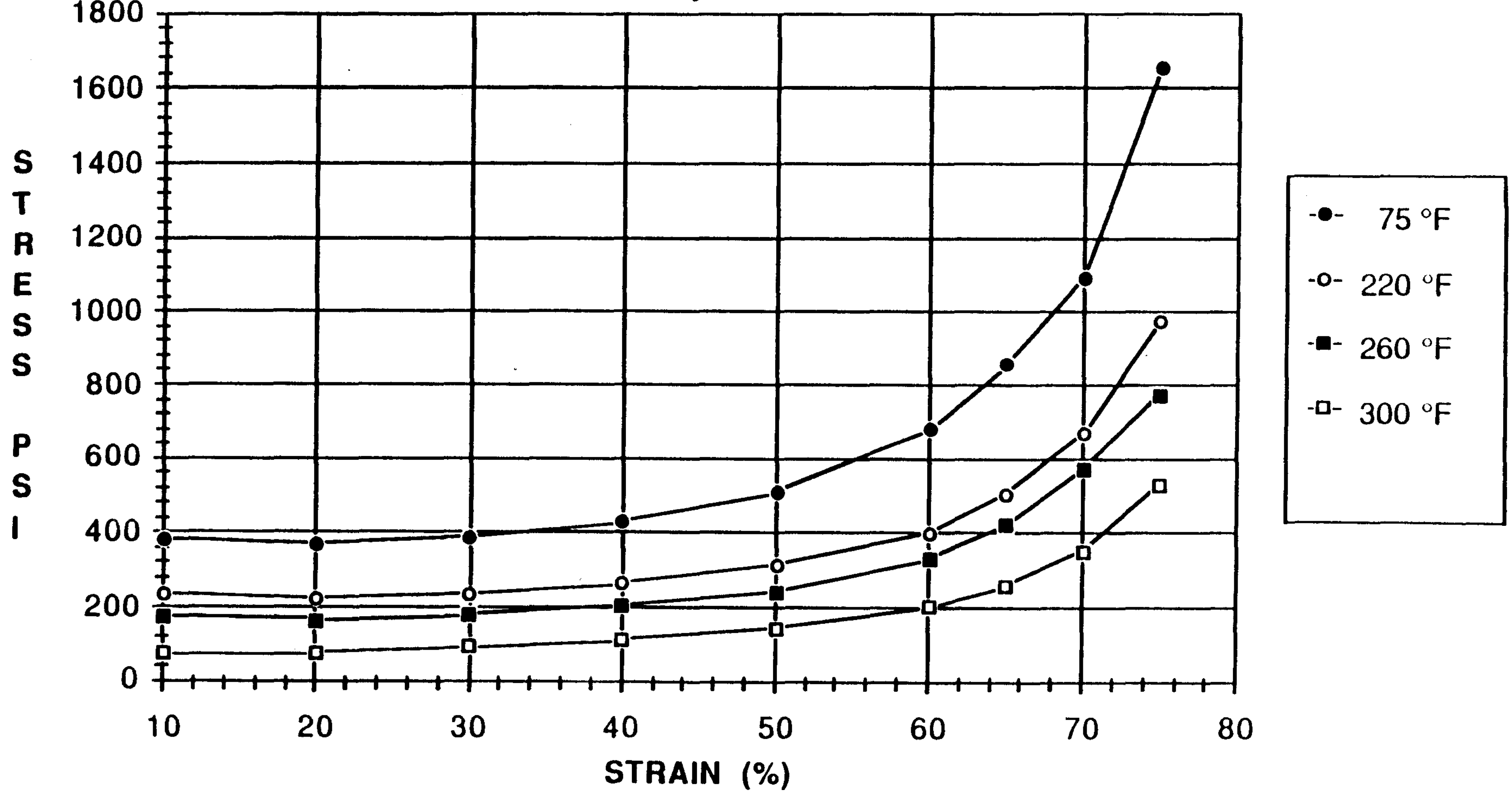
DENSITY= 5.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	132	114	117	125	136	164	197	240	357	580
220 °F	87	73	75	82	92	105	127	157	213	318
260 °F	67	56	60	67	75	91	110	137	172	251
300 °F	47	37	41	47	56	69	84	107	142	210

GENERAL PLASTICS MANUFACTURING COMPANY PO.BOX 9097 TACOMA WA. 98409

FR-3700 Compressive Strength Parallel to rise

Foam Density 10.0 lbs/ft^3



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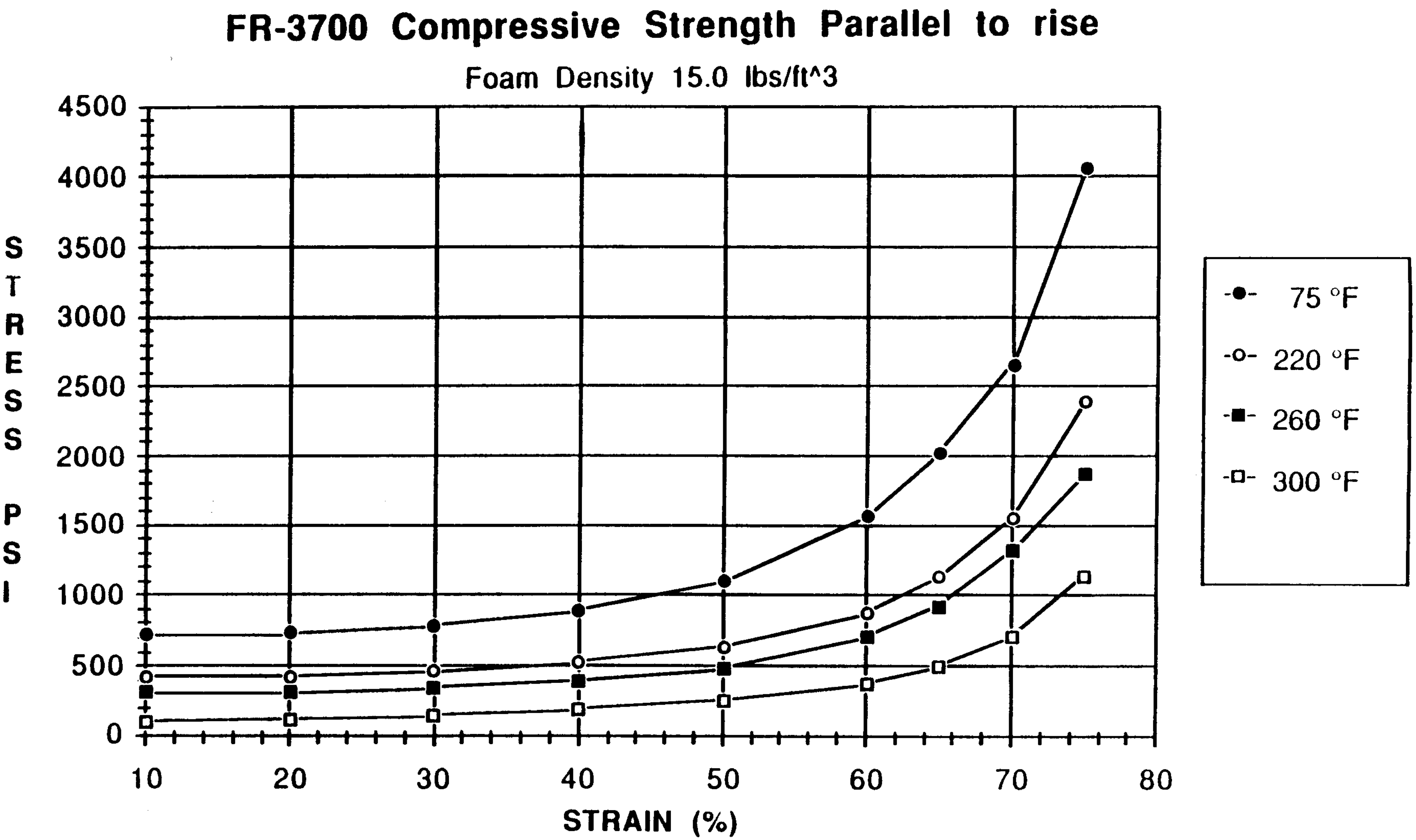
LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PARALLEL TO RISE
Strength in (PSI)

DENSITY= 10.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	386	370	391	434	510	681	858	1094	1655	2724
220 °F	235	222	237	265	314	401	506	668	979	1694
260 °F	175	164	180	206	244	334	423	572	775	1353
300 °F	74	78	92	115	147	203	259	353	531	988

GENERAL PLASTICS MANUFACTURING COMPANY PO.BOX 9097 TACOMA WA. 98409



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LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PARALLEL TO RISE
Strength in (PSI)

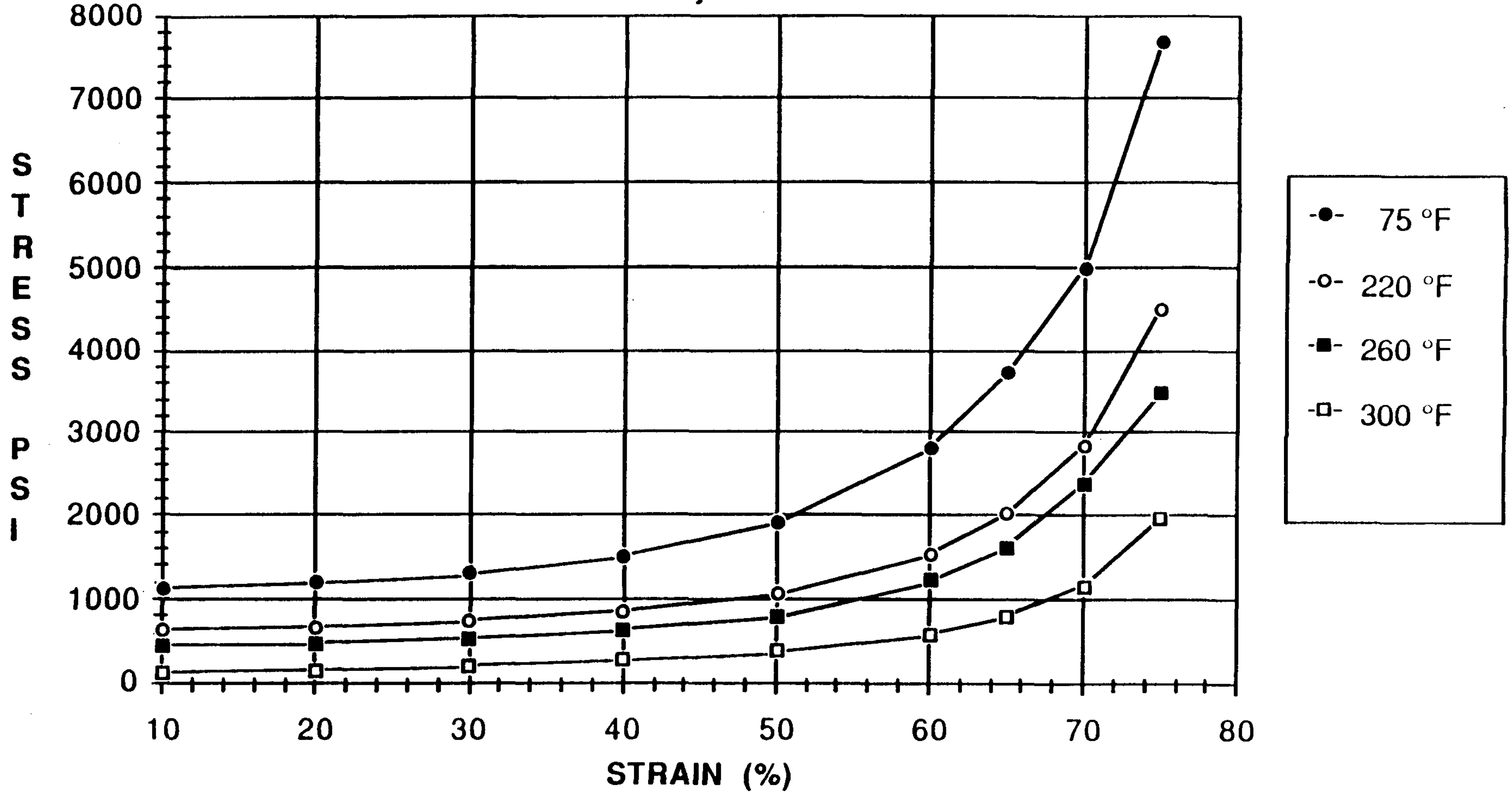
DENSITY= 15.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	723	737	792	900	1103	1564	2026	2660	4060	6735
220 °F	422	427	462	527	641	880	1136	1557	2390	4509
260 °F	307	309	342	397	487	714	931	1318	1871	3620
300 °F	97	119	149	192	258	380	501	711	1147	2441

GENERAL PLASTICS MANUFACTURING COMPANY PO.BOX 9097 TACOMA WA. 98409

FR-3700 Compressive Strength Parallel to rise

Foam Density 20.0 lbs/ft^3



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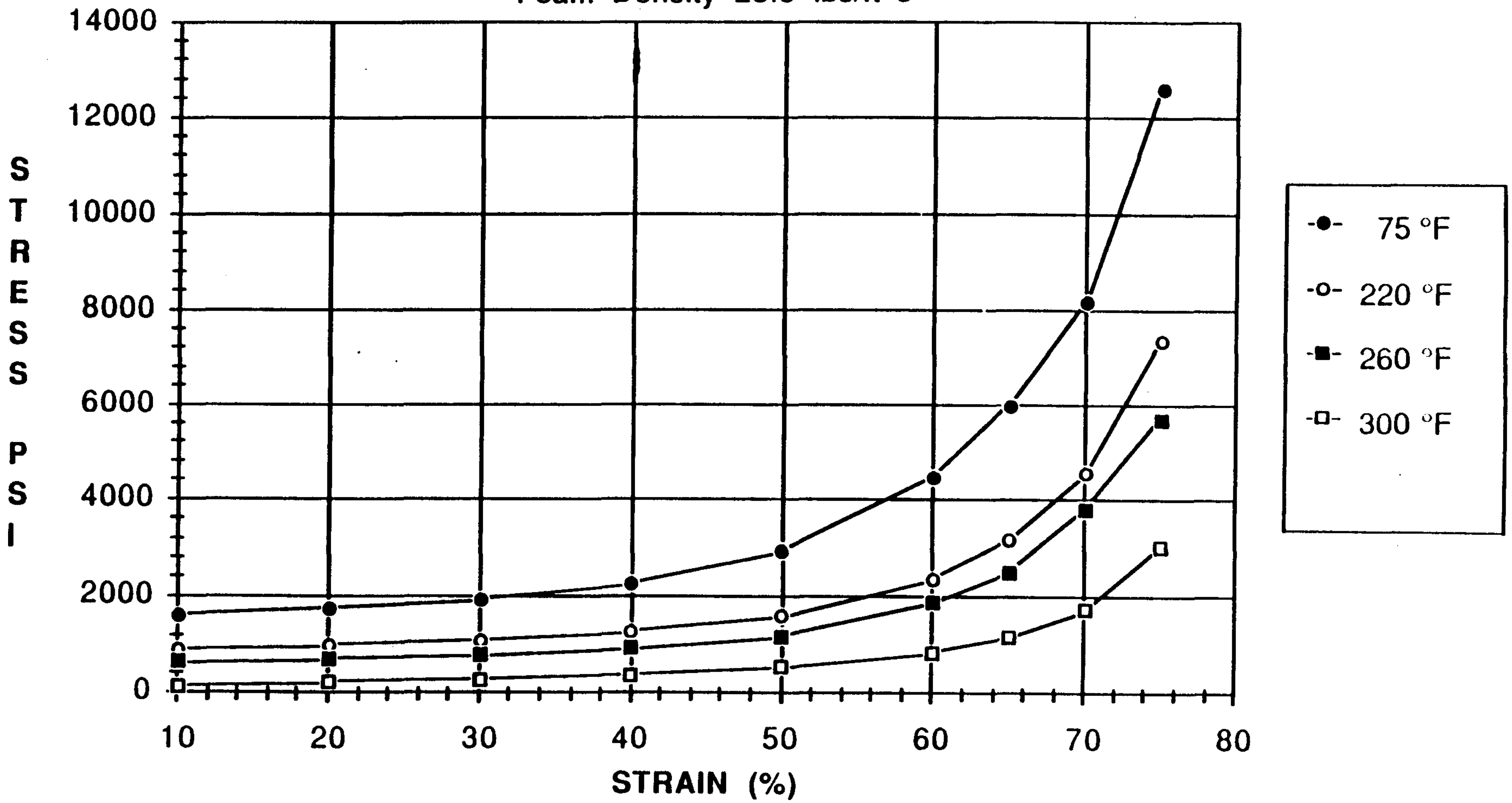
LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PARALLEL TO RISE
Strength in (PSI)

DENSITY= 20.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	1129	1201	1307	1509	1908	2821	3730	4997	7674	12800
220 °F	639	679	742	857	1066	1538	2016	2841	4504	9032
260 °F	457	483	539	634	794	1224	1629	2383	3496	7279
300 °F	117	161	209	278	386	593	799	1169	1981	4639

FR-3700 Compressive Strength Parallel to rise

Foam Density 25.0 lbs/ft^3



LAST-A-FOAM ® FR-3700
COMPRESSIVE STRENGTH PARALLEL TO RISE
Strength in (PSI)

DENSITY= 25.00 Lbs/Ft^3

STRAIN %	10	20	30	40	50	60	65	70	75	80
75 °F	1596	1756	1927	2255	2917	4459	5987	8147	12574	21064
220 °F	881	972	1072	1251	1580	2370	3148	4528	7362	15480
260 °F	622	685	767	911	1161	1859	2515	3773	5677	12512
300 °F	135	204	271	369	526	837	1149	1719	3027	7634

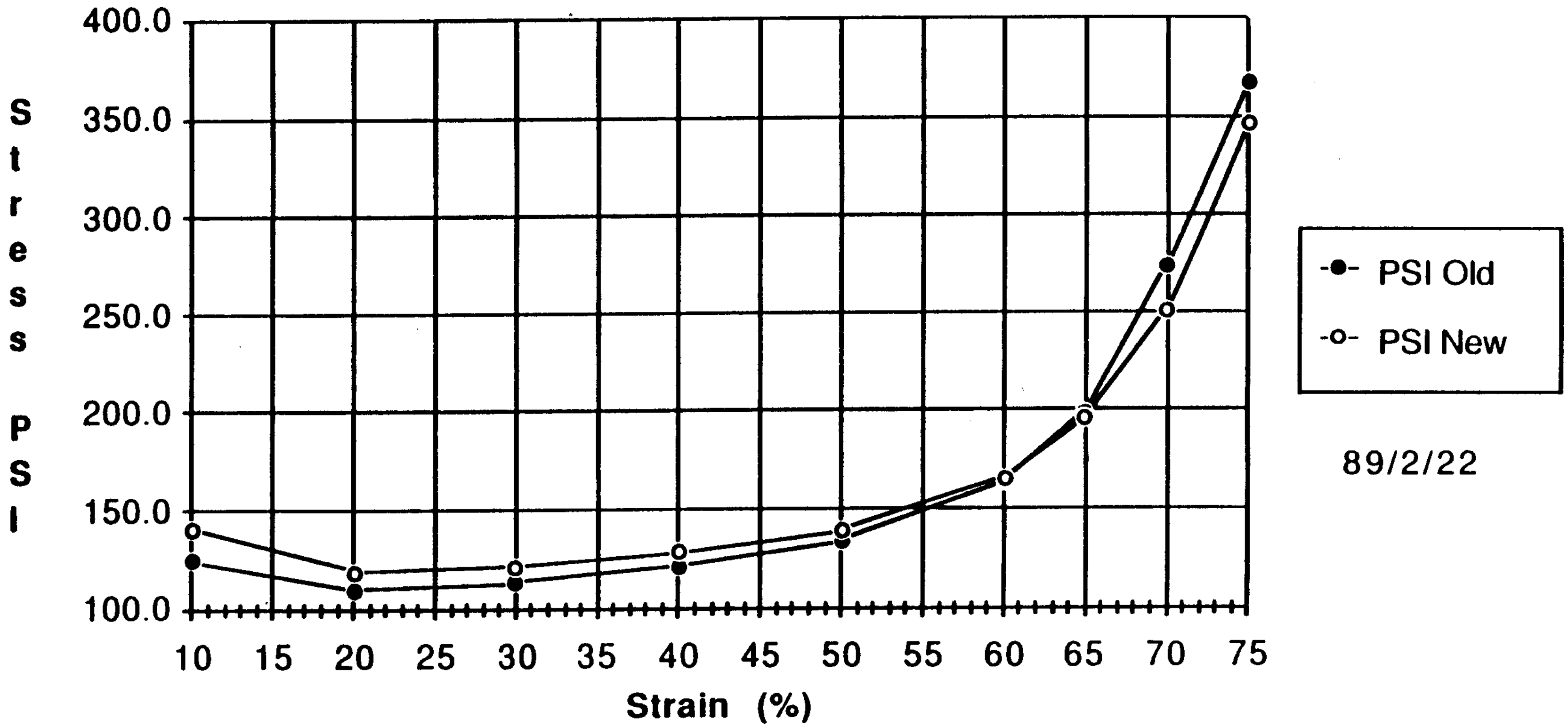
APPENDIX C

Stress vs. Strain Comparisons Of 1985 With 1989 FR-3700 Foam Formulations

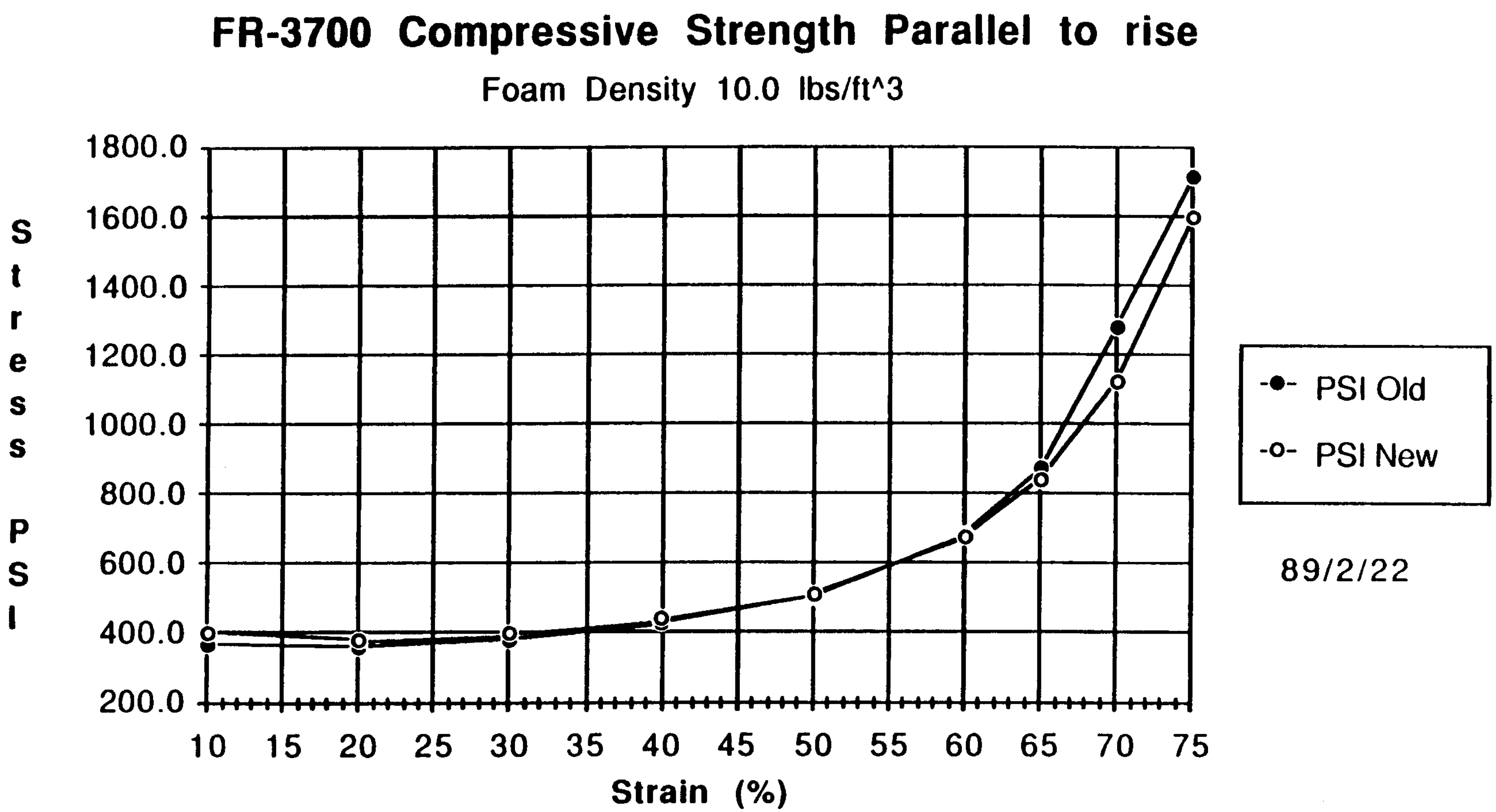
GENERAL PLASTICS MANUFACTURING COMPANY

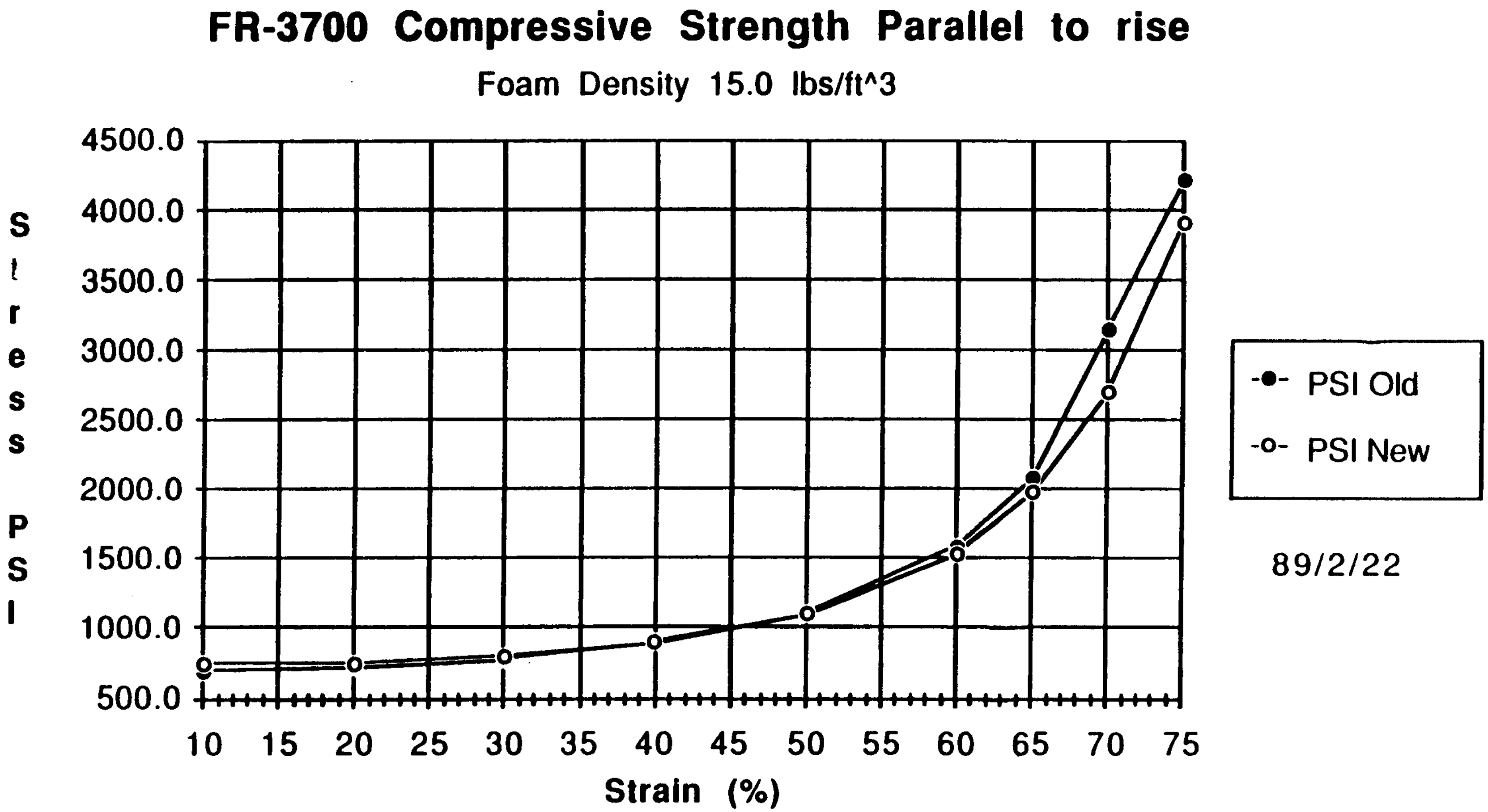
FR-3700 Compressive Strength Parallel to rise

Foam Density 5.0 lbs/ft^3



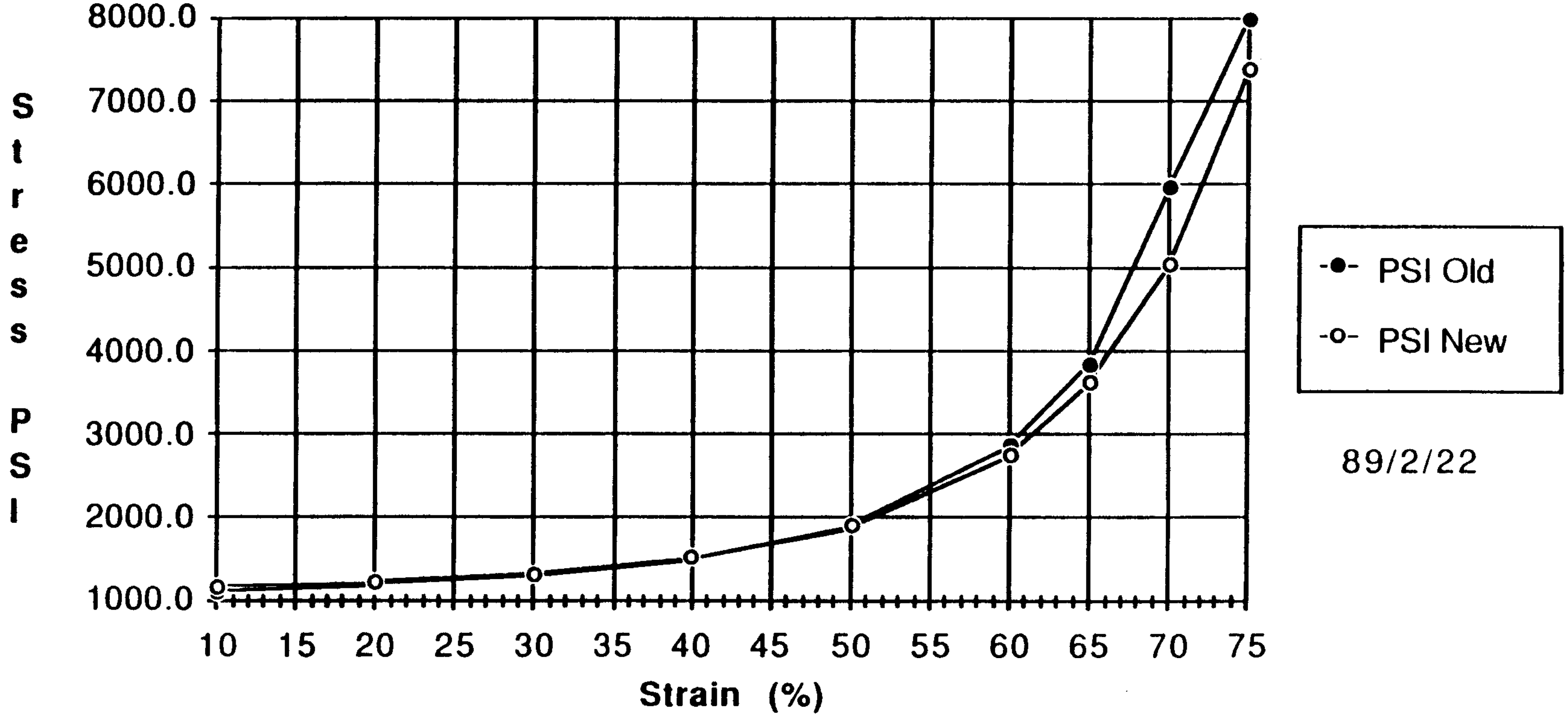
GENERAL PLASTICS MANUFACTURING COMPANY

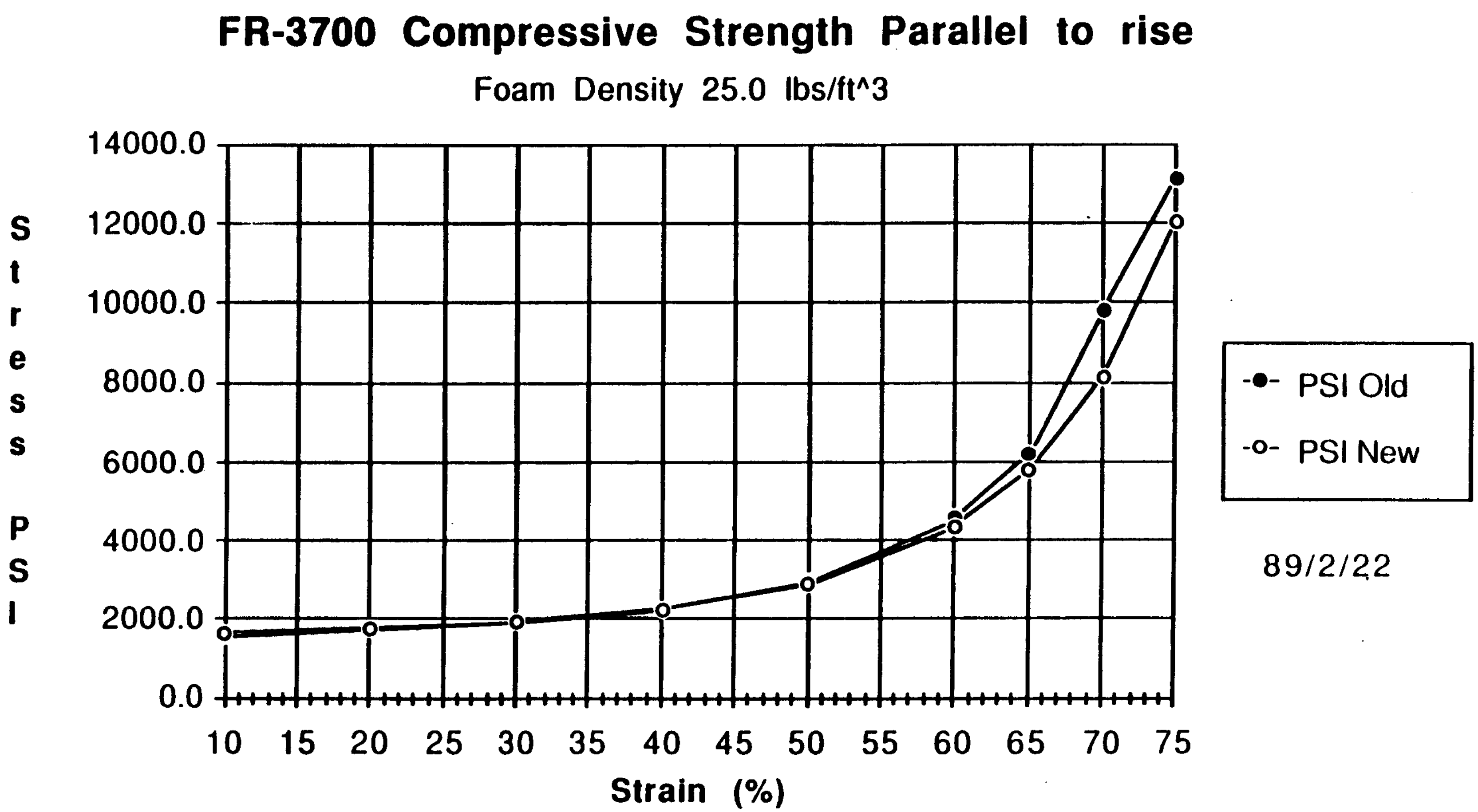



FR-3700 Compressive Strength Parallel to rise
Foam Density 15.0 lbs/ft^3
4500.0
4000.0
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
Stress PSI
10 15 20 25 30 35 40 45 50 55 60 65 70 75
Strain (%)
PSI Old
PSI New
89/2/22

FR-3700 Compressive Strength Parallel to rise

Foam Density 20.0 lbs/ft^3

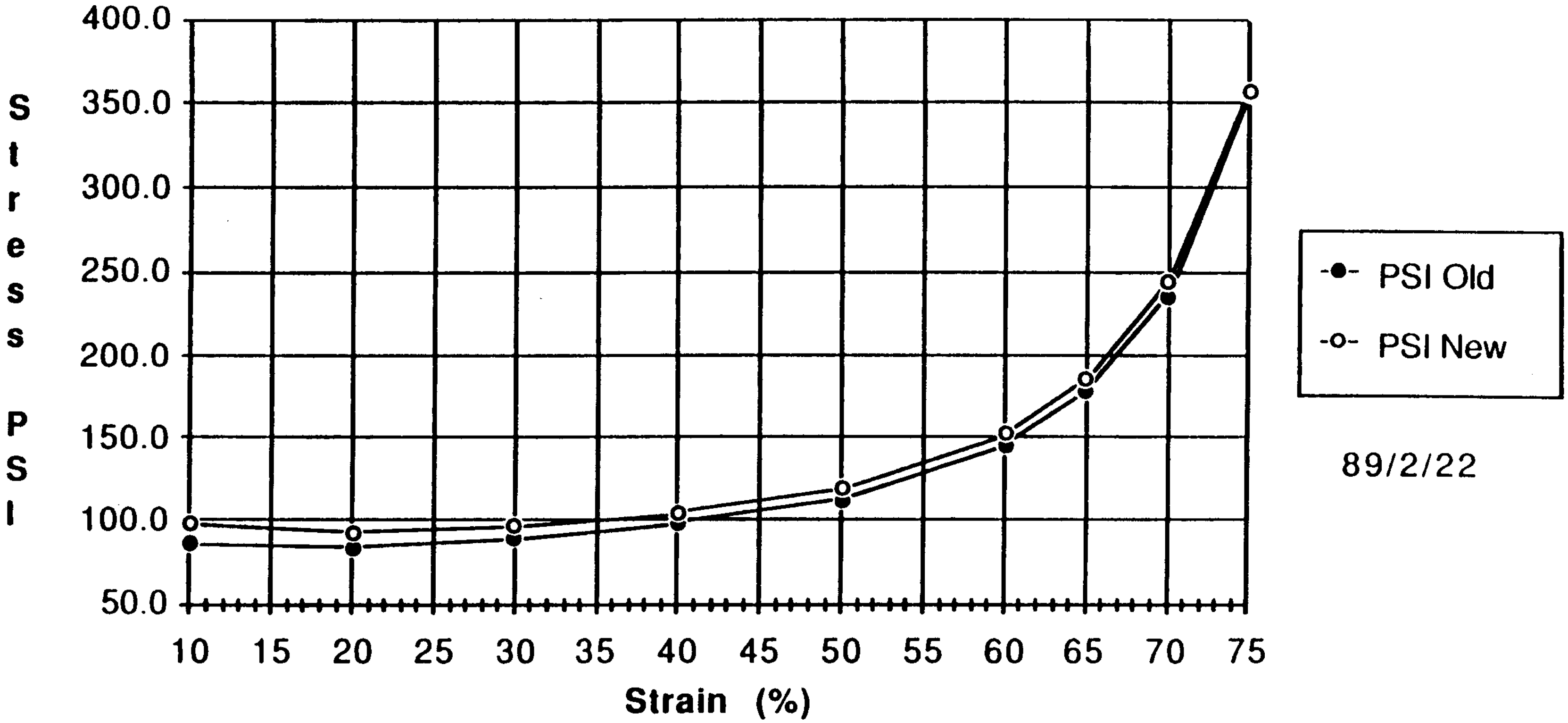


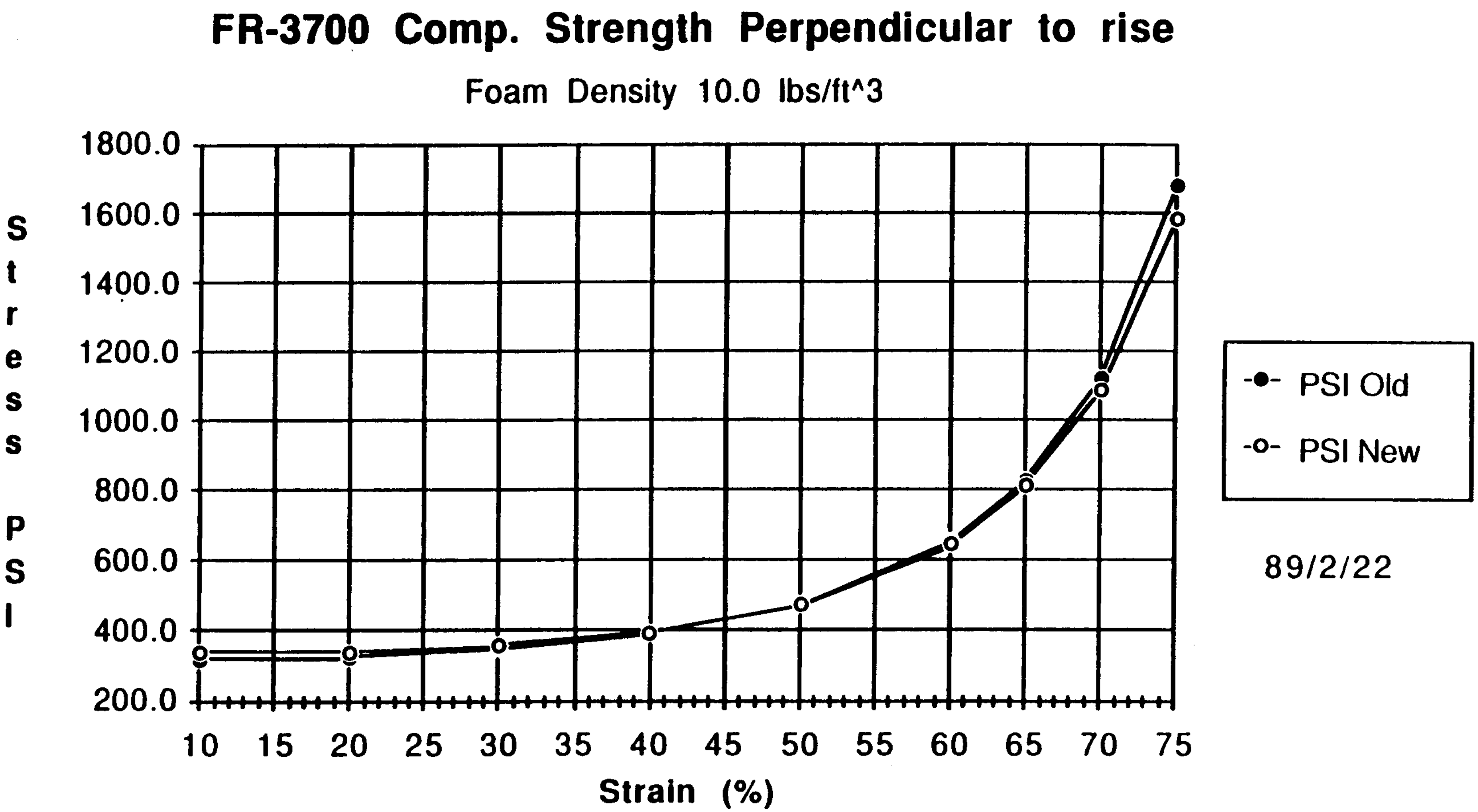

FR-3700 Compressive Strength Parallel to rise
Foam Density 25.0 lbs/ft^3
Stress PSI
14000.0
12000.0
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
10 15 20 25 30 35 40 45 50 55 60 65 70 75
Strain (%)
PSI Old
PSI New
89/2/22

GENERAL PLASTICS MANUFACTURING COMPANY

FR-3700 Comp. Strength Perpendicular to rise

Foam Density 5.0 lbs/ft^3

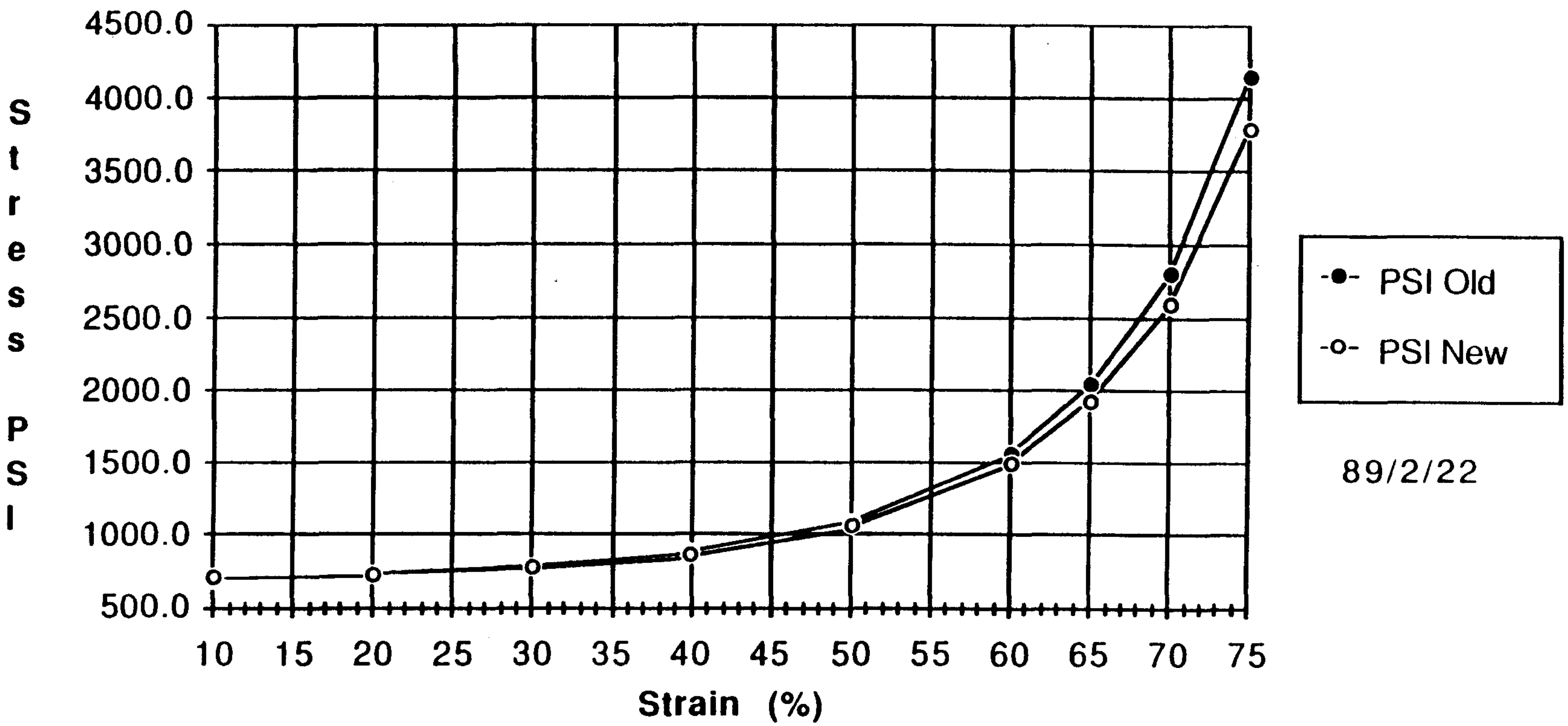



FR-3700 Comp. Strength Perpendicular to rise
Foam Density 10.0 lbs/ft^3
Stress PSI
1800.0
1600.0
1400.0
1200.0
1000.0
800.0
600.0
400.0
200.0
10
15
20
25
30
35
40
45
50
55
60
65
70
75
Strain (%)
PSI Old
PSI New
89/2/22

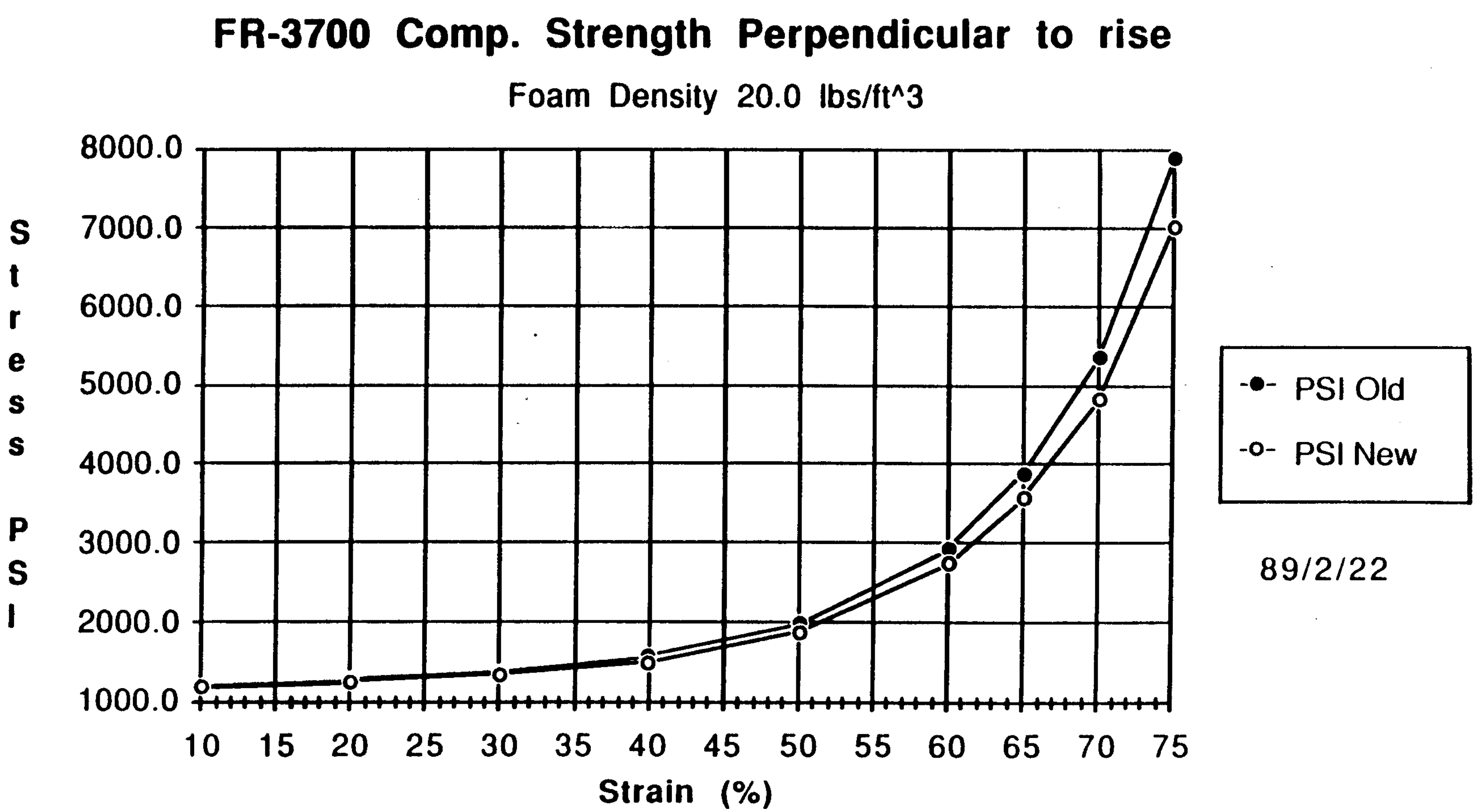
GENERAL PLASTICS MANUFACTURING COMPANY

FR-3700 Comp. Strength Perpendicular to rise

Foam Density 15.0 lbs/ft^3



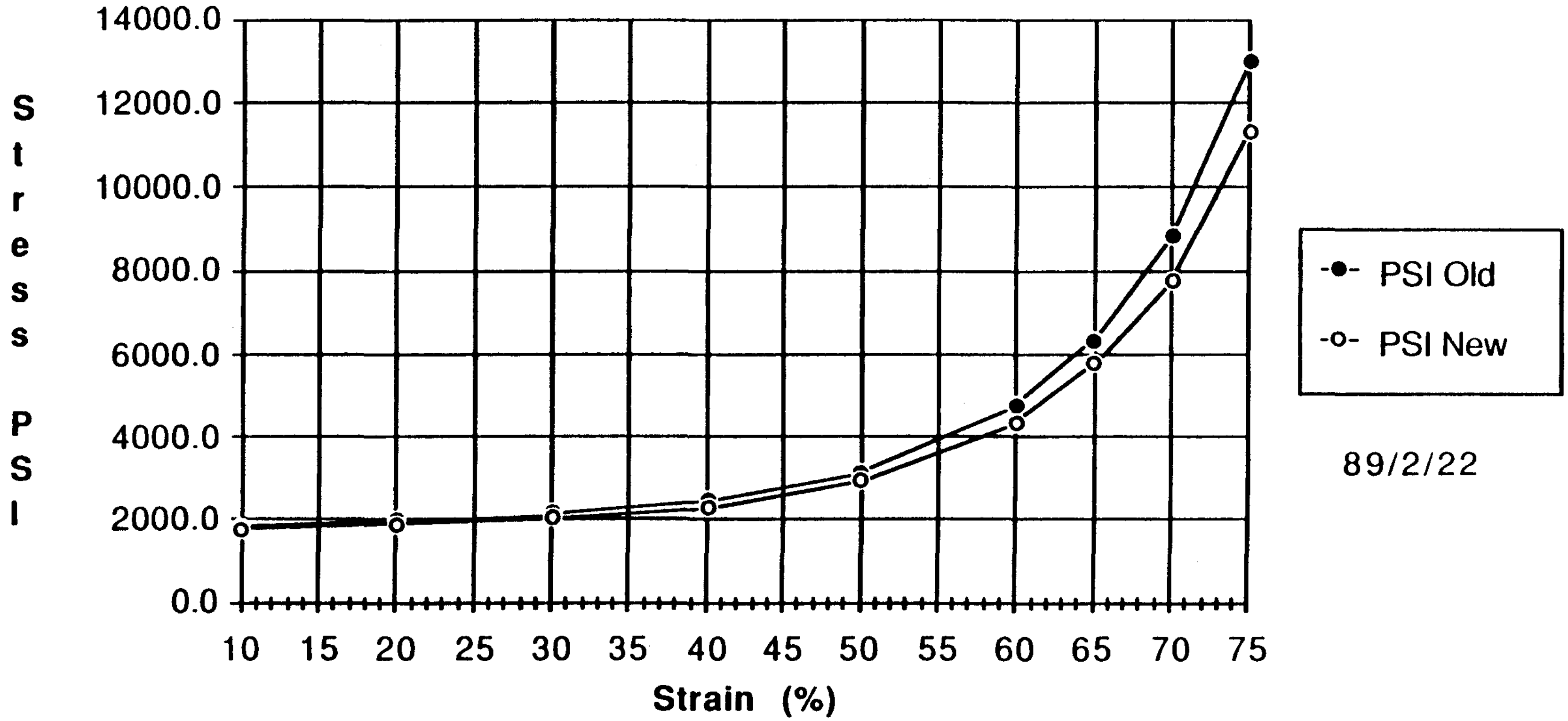
89/2/22


FR-3700 Comp. Strength Perpendicular to rise
Foam Density 20.0 lbs/ft^3
Stress PSI
8000.0
7000.0
6000.0
5000.0
4000.0
3000.0
2000.0
1000.0
10 15 20 25 30 35 40 45 50 55 60 65 70 75
Strain (%)
PSI Old
PSI New
89/2/22

GENERAL PLASTICS MANUFACTURING COMPANY

FR-3700 Comp. Strength Perpendicular to rise

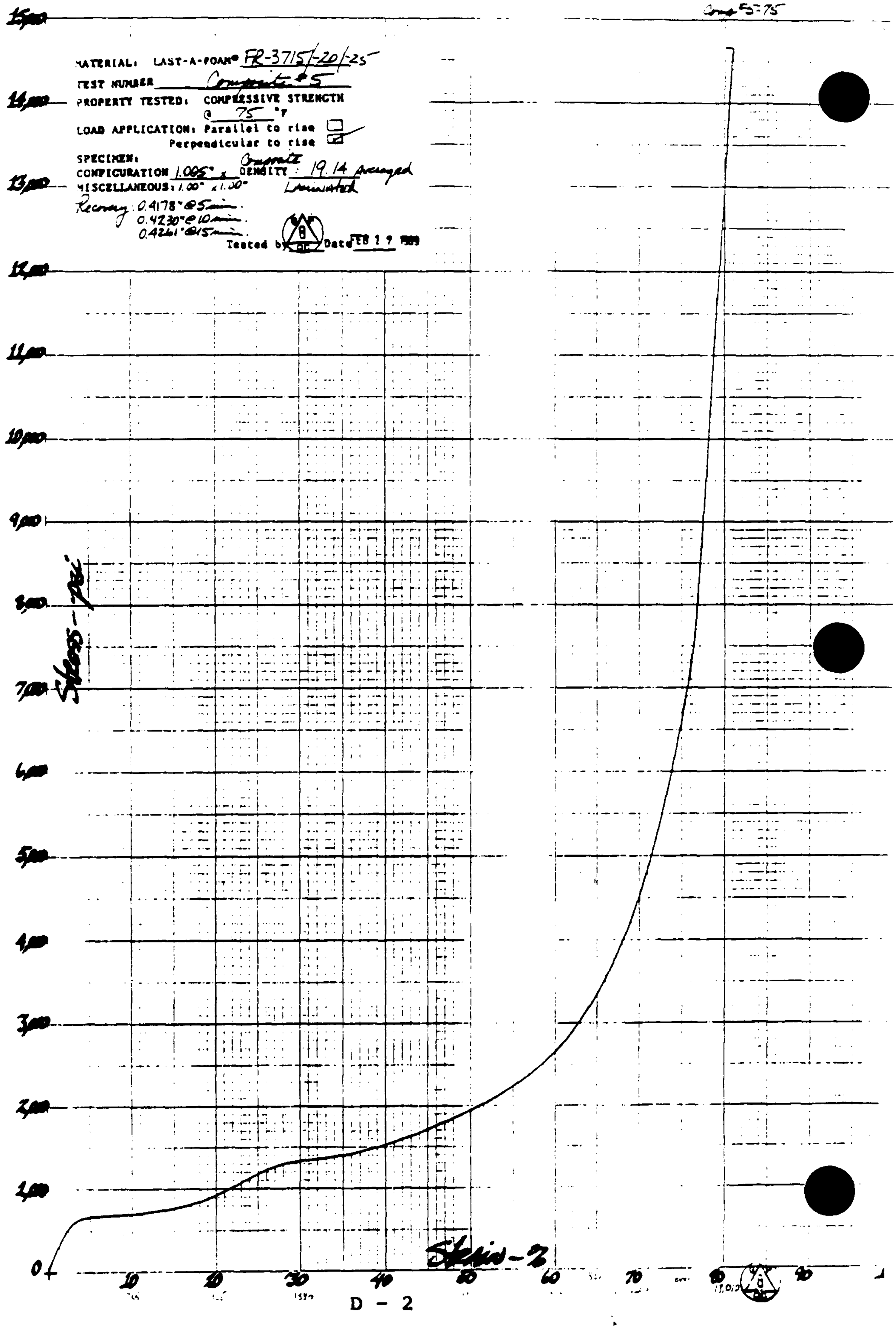
Foam Density 25.0 lbs/ft^3

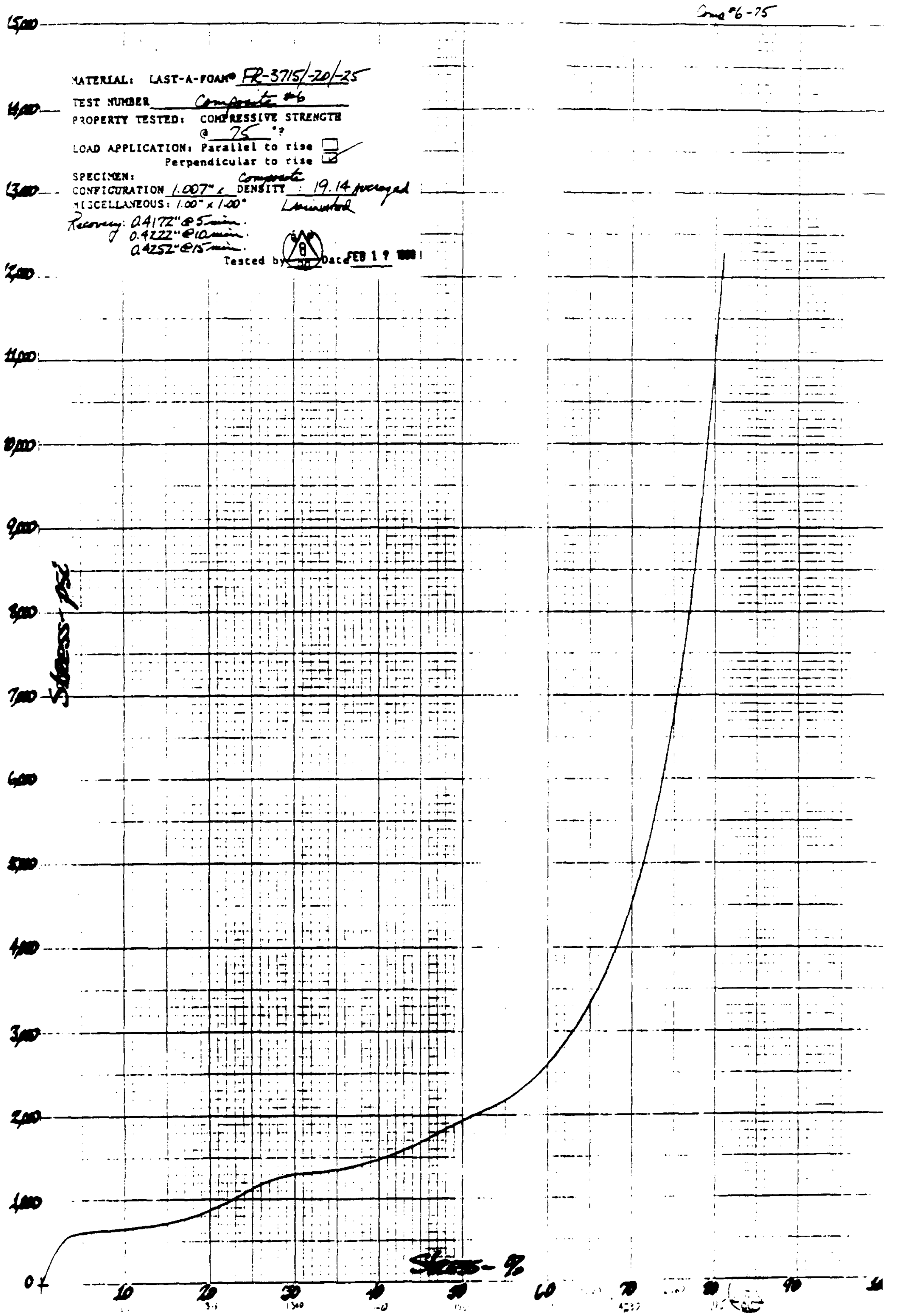


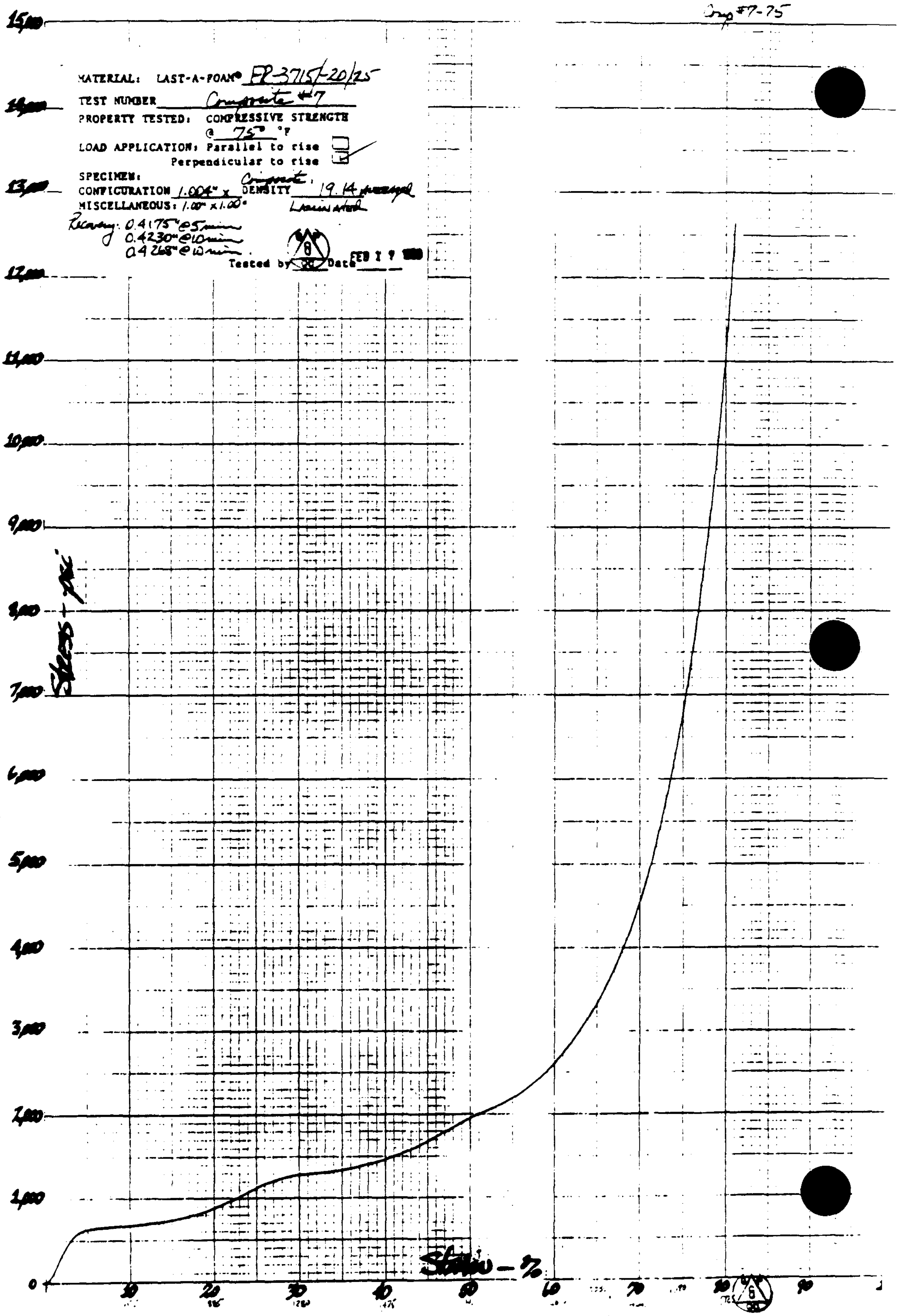
89/2/22

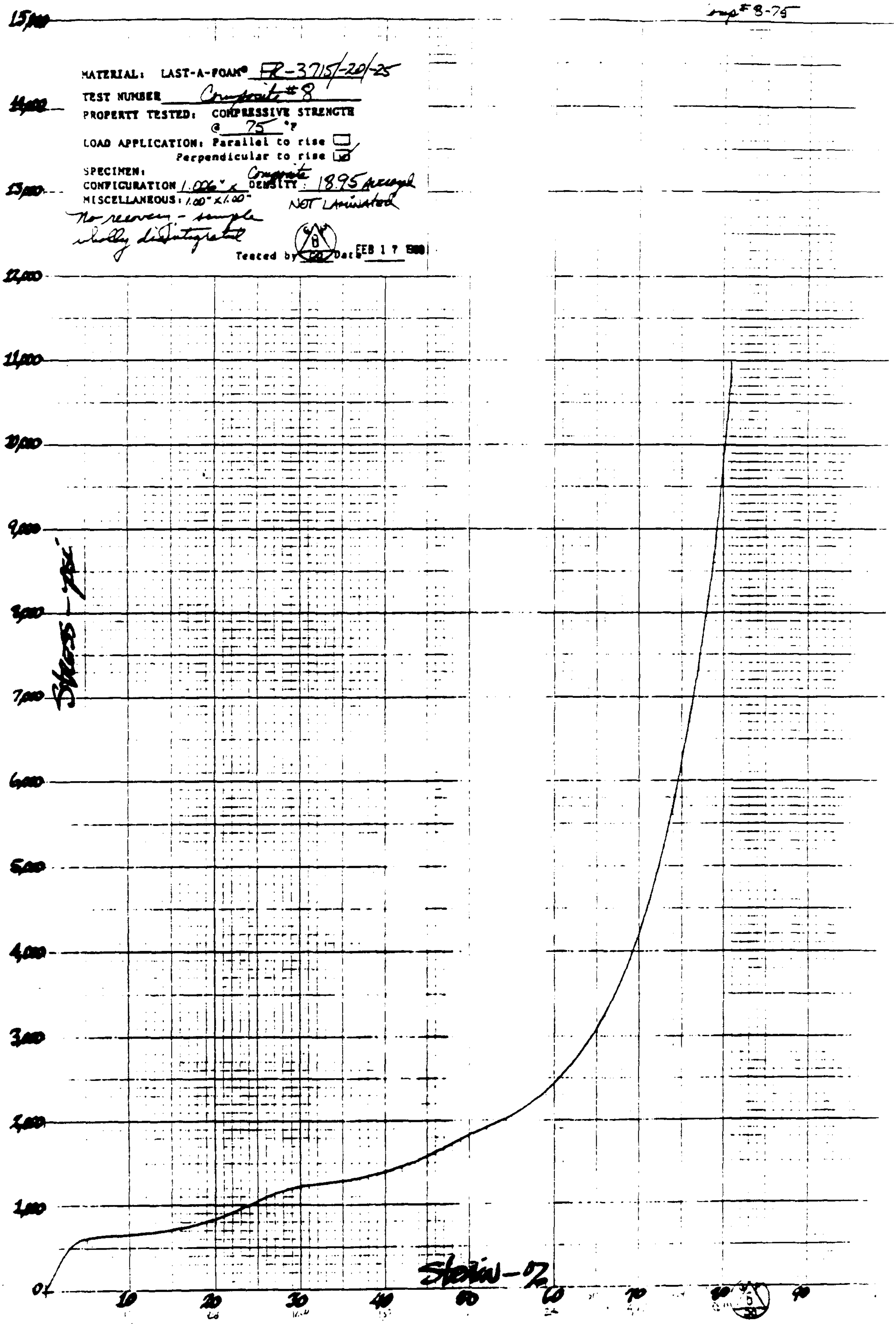
APPENDIX D

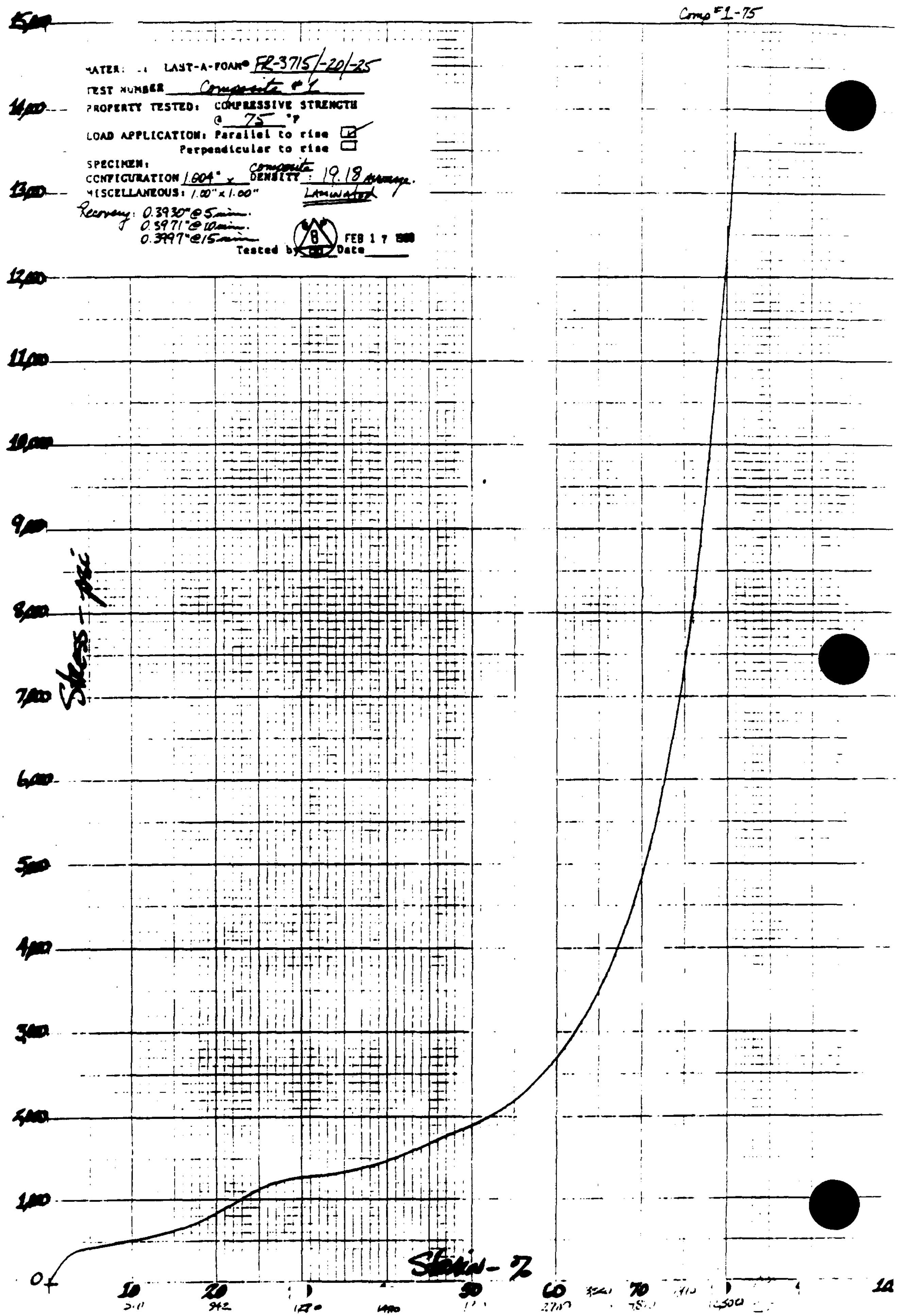
Compressive Stress vs. Strain Data For A Composite Foam Design At Room Temperature And -20° F

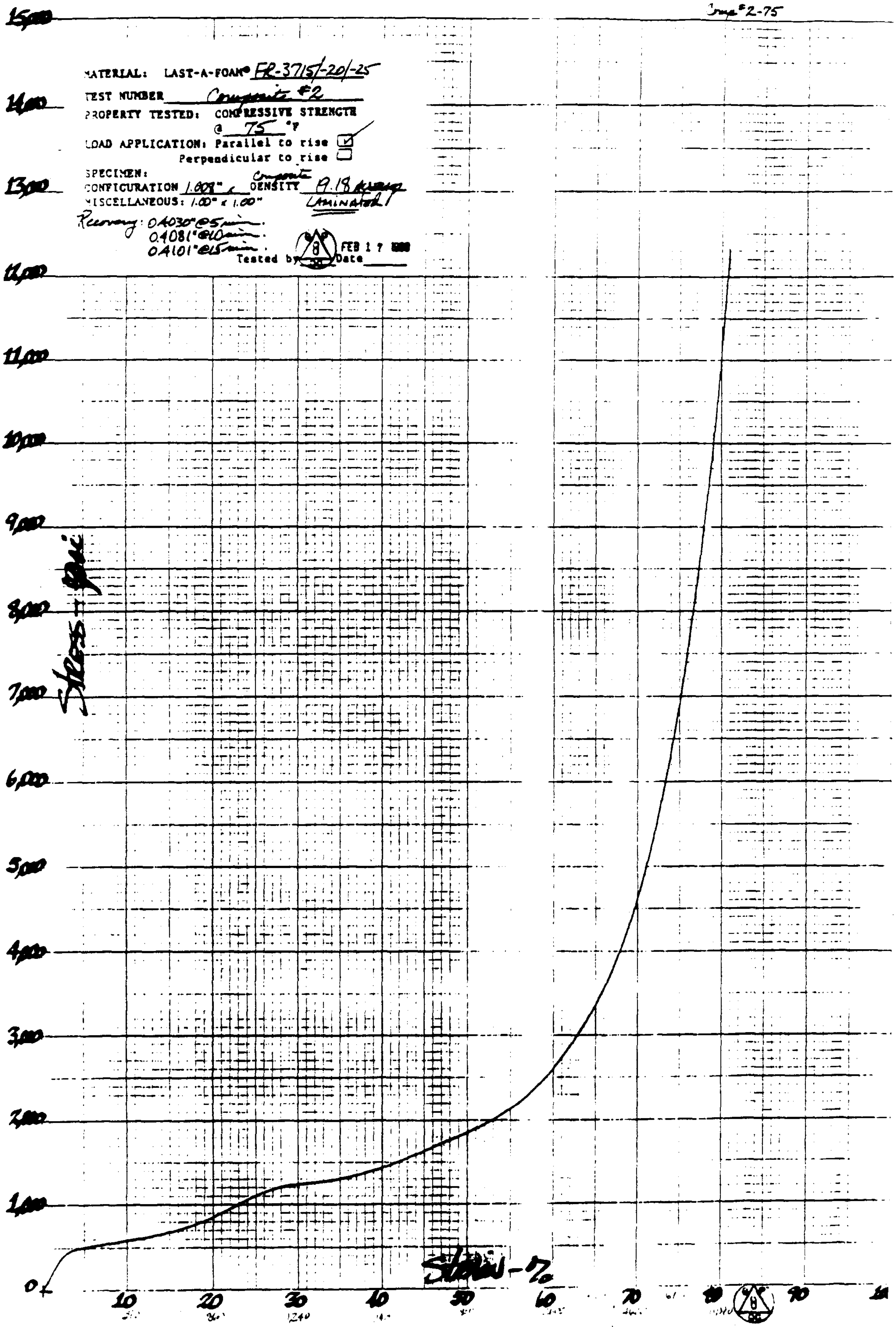

MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #5
PROPERTY TESTED: COMPRESSIVE STRENGTH @ 75 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.005" x Composite DENSITY 19.14 averaged
MISCELLANEOUS: 1.00" x 1.00" Laminated
Recovery 0.4178" @ 5 min.
0.4230" @ 10 min.
0.4261" @ 15 min.
Tested by Date FEB 1 7 1989
Stress - psi
Strain - %
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10
20
30
40
50
60
70
80
90

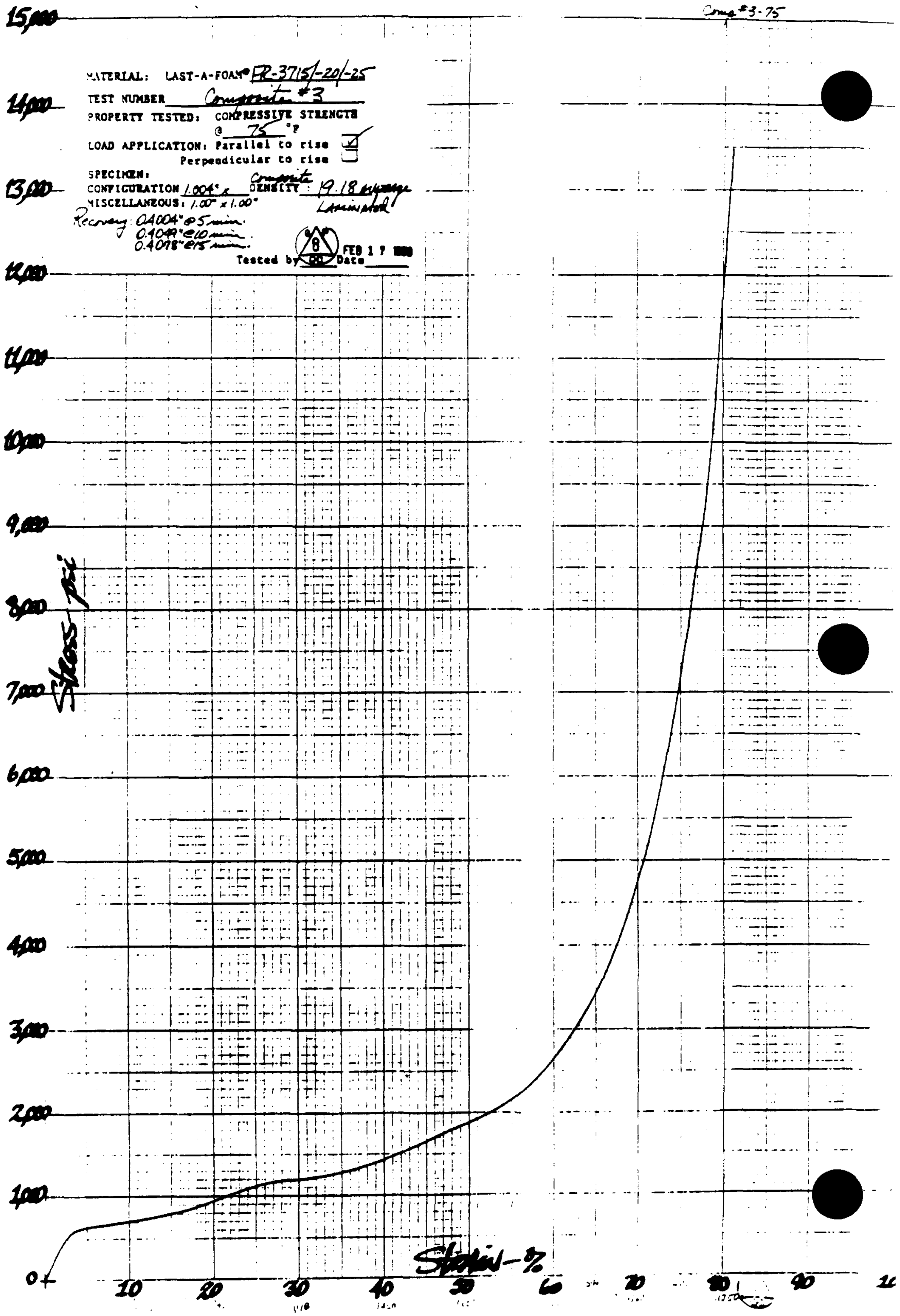

Comp #6-75
MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #6
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ 75 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.007" x Composite
DENSITY: 19.14 averaged
MISCELLANEOUS: 1.00" x 1.00" Laminated
Recovery: 0.4172" @ 5 min.
0.4222" @ 10 min.
0.4252" @ 15 min.
Tested by
Date FEB 1 7 1988
Stress - psi
Strain - %
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10
20
30
40
50
60
70
80
90

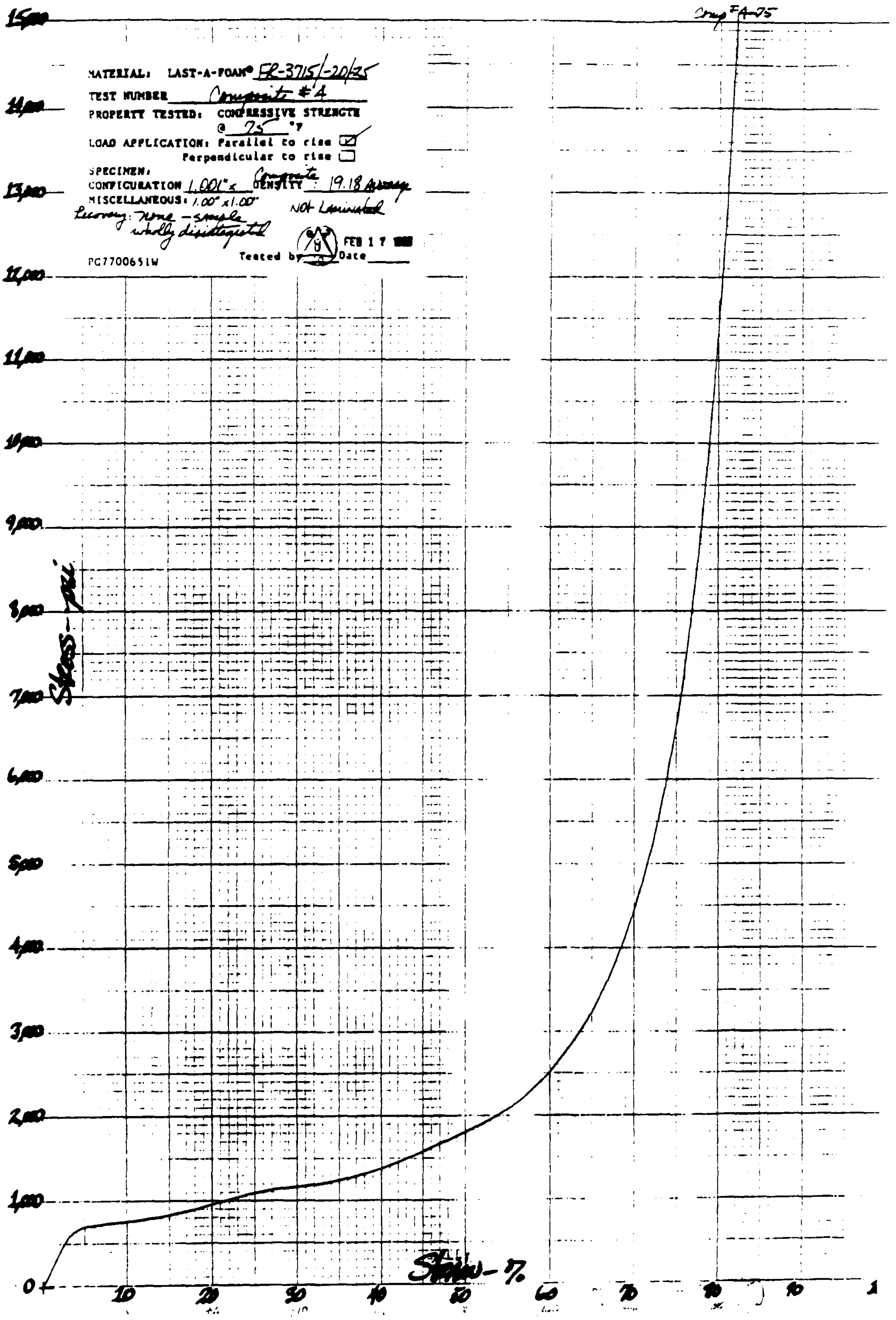

Comp #7-75
MATERIAL: LAST-A-FOAM® FR-3715-20/25
TEST NUMBER Composite #7
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ 75° °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.004" x Composite DENSITY 19.14
MISCELLANEOUS: 1.00" x 1.00" Laminated
Recovery: 0.4175" @ 5 min
0.4230" @ 10 min
0.4268" @ 10 min
Tested by
Date FEB 1 7
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Stress - psi
Strain - %
10
20
30
40
50
60
70
80
90

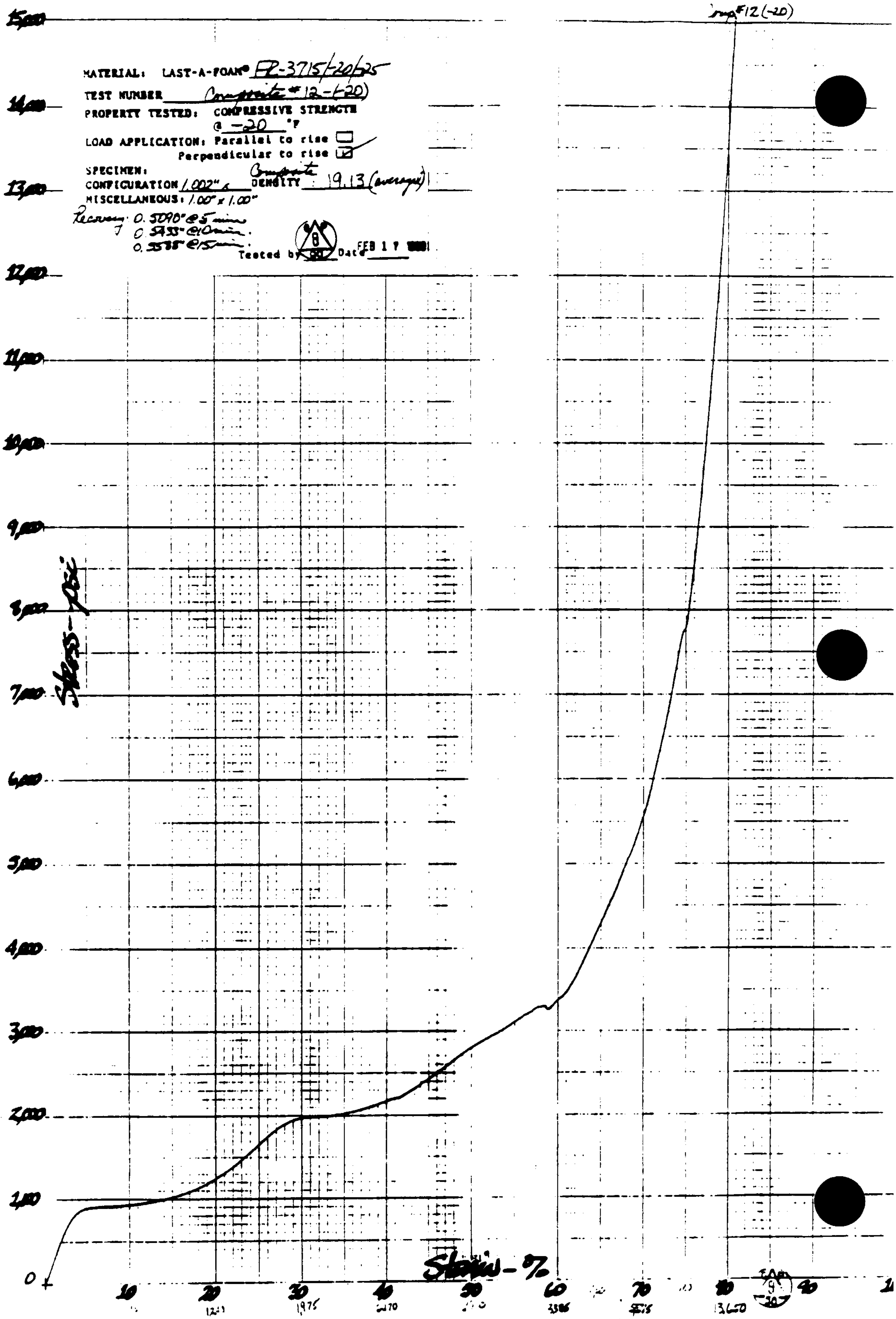

Comp #8-75
MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #8
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ 75 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.006" x 1.00" x 1.00"
Composite DENSITY: 18.95 pcf avg
MISCELLANEOUS:
NOT Laminated
No recovery - sample wholly disintegrated
Tested by
Date FEB 1 7 1988
Stress - psi
Strain - %
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10
20
30
40
50
60
70
80
90

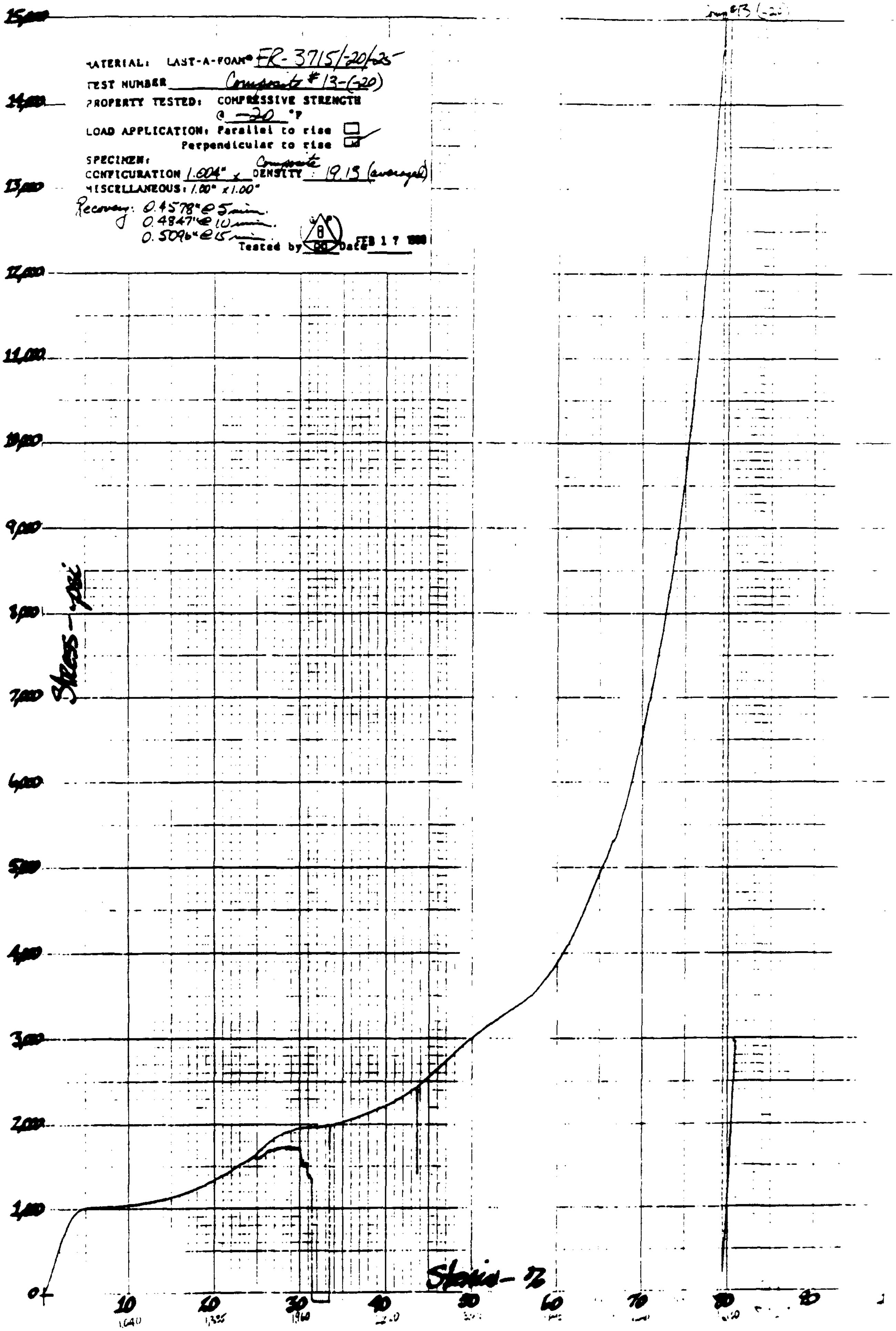

Comp #1-75
MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #1
PROPERTY TESTED: COMPRESSIVE STRENGTH @ 75 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.604" x composite DENSITY 19.18 average
MISCELLANEOUS: 1.00" x 1.00" Laminated
Recovery: 0.3930" @ 5 min. 0.3971" @ 10 min. 0.3997" @ 15 min.
Tested by
Date FEB 1 7 1988
Stress - psi
Strain - %
0
10
20
50
60
70

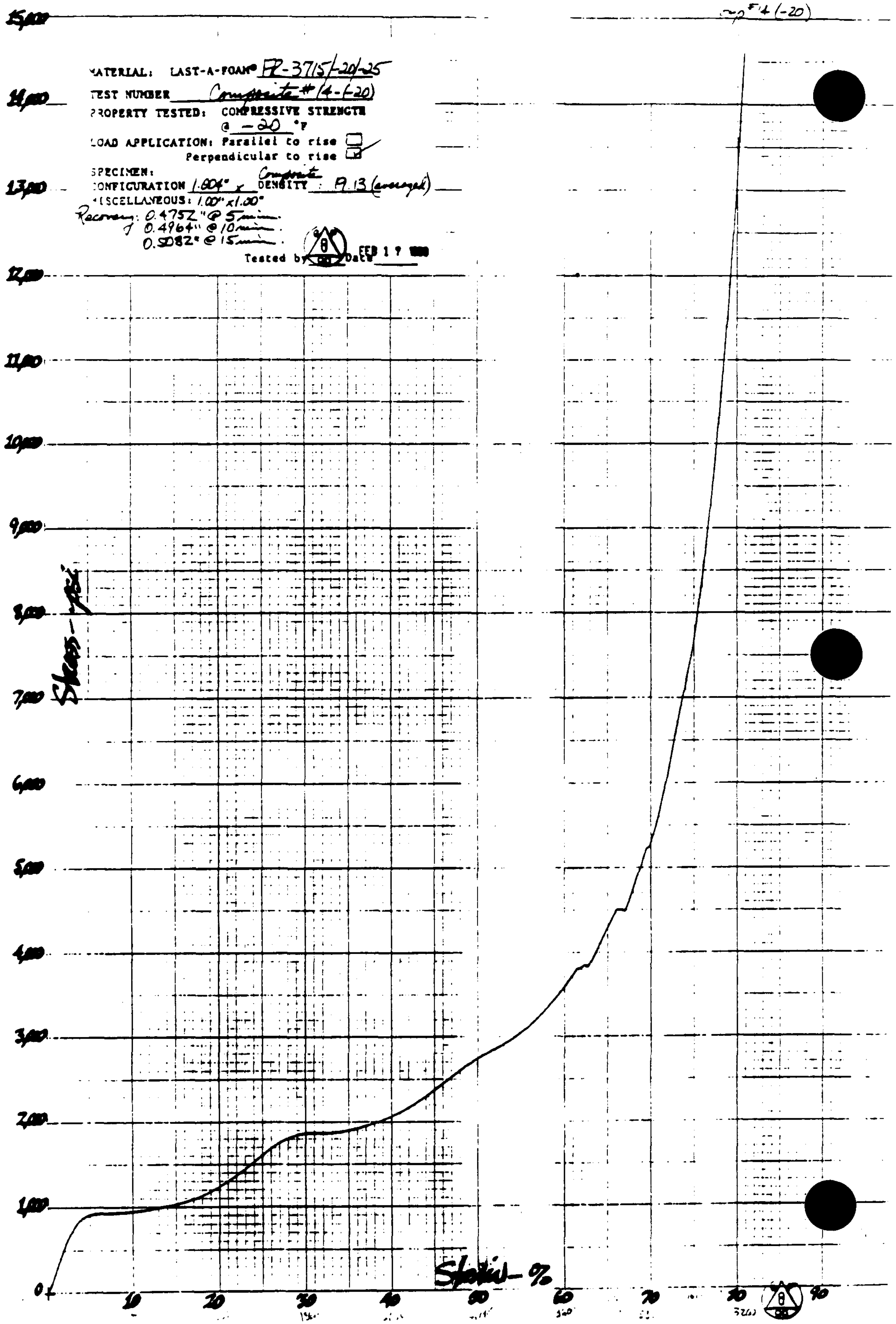

Comp #2-75
MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #2
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ 75 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.008" DENSITY 19.18
MISCELLANEOUS: 1.00" x 1.00"
Laminated
Recovery: 0.4030" @5 min
0.4081" @10 min
0.4101" @15 min
Tested by
Date
FEB 17
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Stress - psi
10
20
30
40
50
60
70
80
90
100
Strain - %

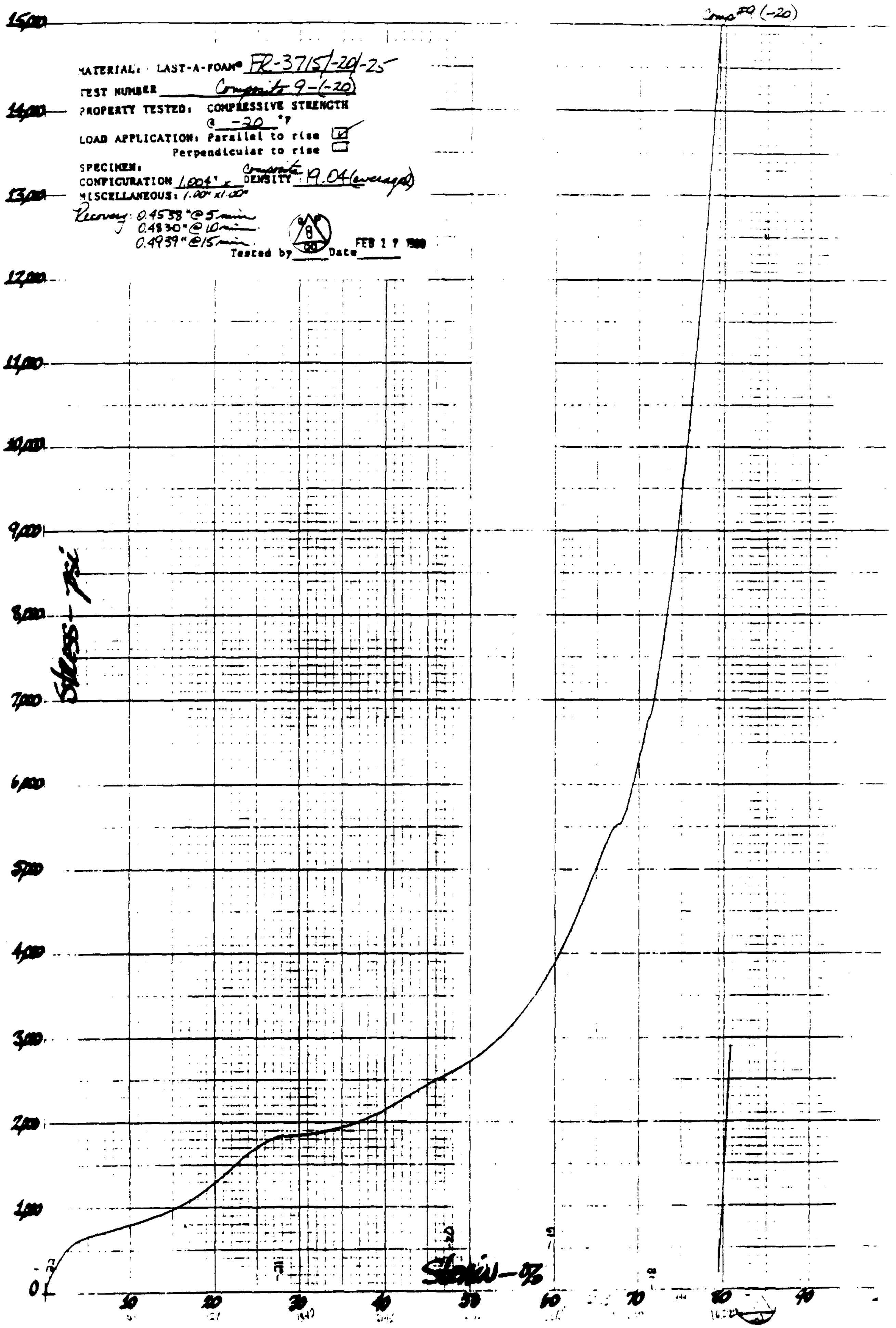

MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #3
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ 75 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.004" x
MISCELLANEOUS: 1.00" x 1.00"
DENSITY: 19.18
Composite
Laminated
Recovery 0.4004" @ 5 min.
0.4049" @ 10 min.
0.4078" @ 15 min.
Tested by
Date
FEB 1 7
Comp #3-75
Stress-psi
Strain-%
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10
20
30
40
50
60
70
80
90

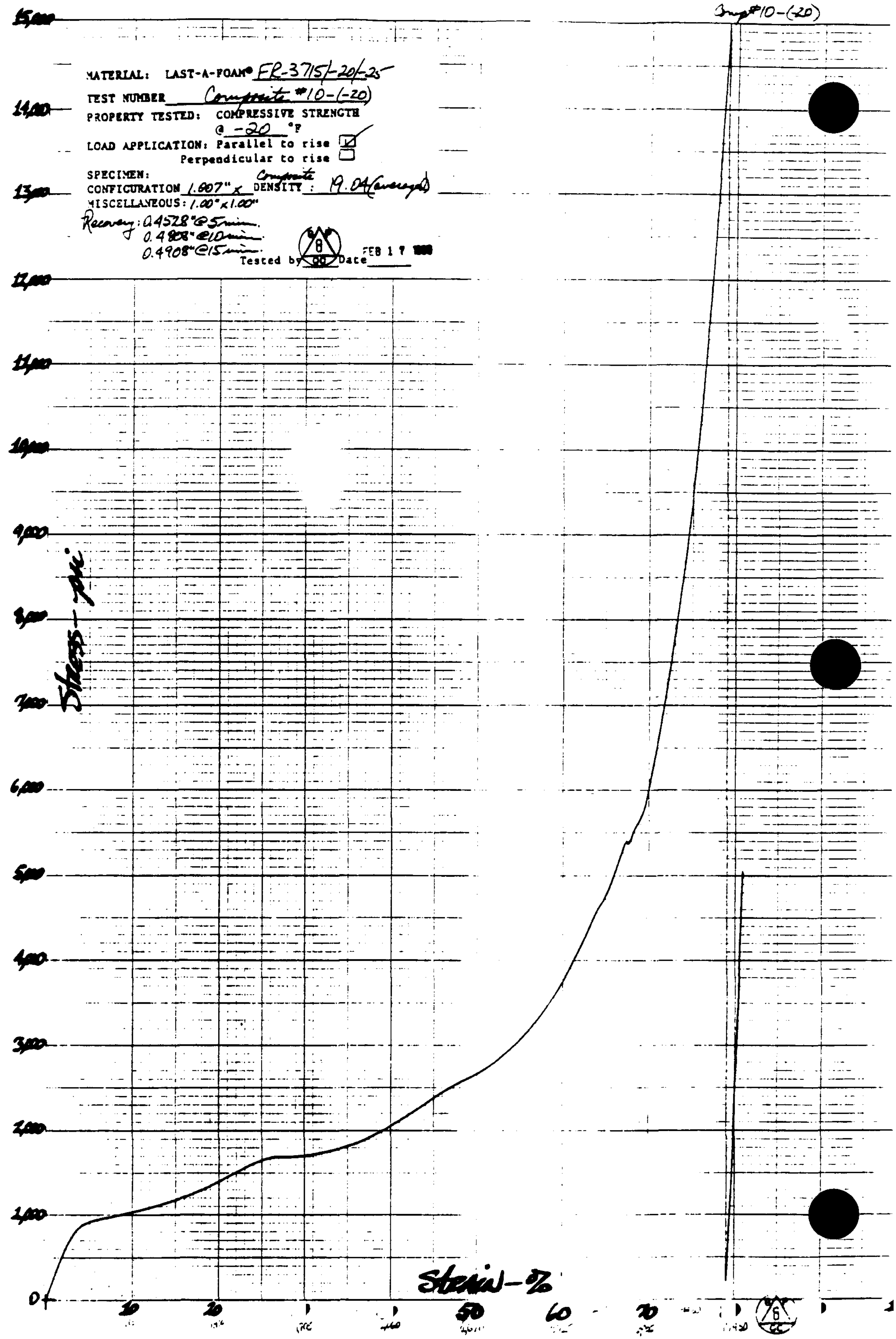

Comp FA-75
MATERIAL: LAST-A-FOAM® FR-3715/-20/35
TEST NUMBER Composite #4
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ 75 °F
LOAD APPLICATION: Parallel to rise ☑
Perpendicular to rise ☐
SPECIMEN,
CONFIGURATION 1.001" x
Composite DENSITY : 19.18 average
MISCELLANEOUS: 1.00" x 1.00"
Not Laminated
Recovery: None - sample wholly disintegrated
FEB 1 7 [redacted]
Tested by
Date
PC7700651W
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Stress - psi
10
20
30
40
50
60
70
80
90
Strain - %

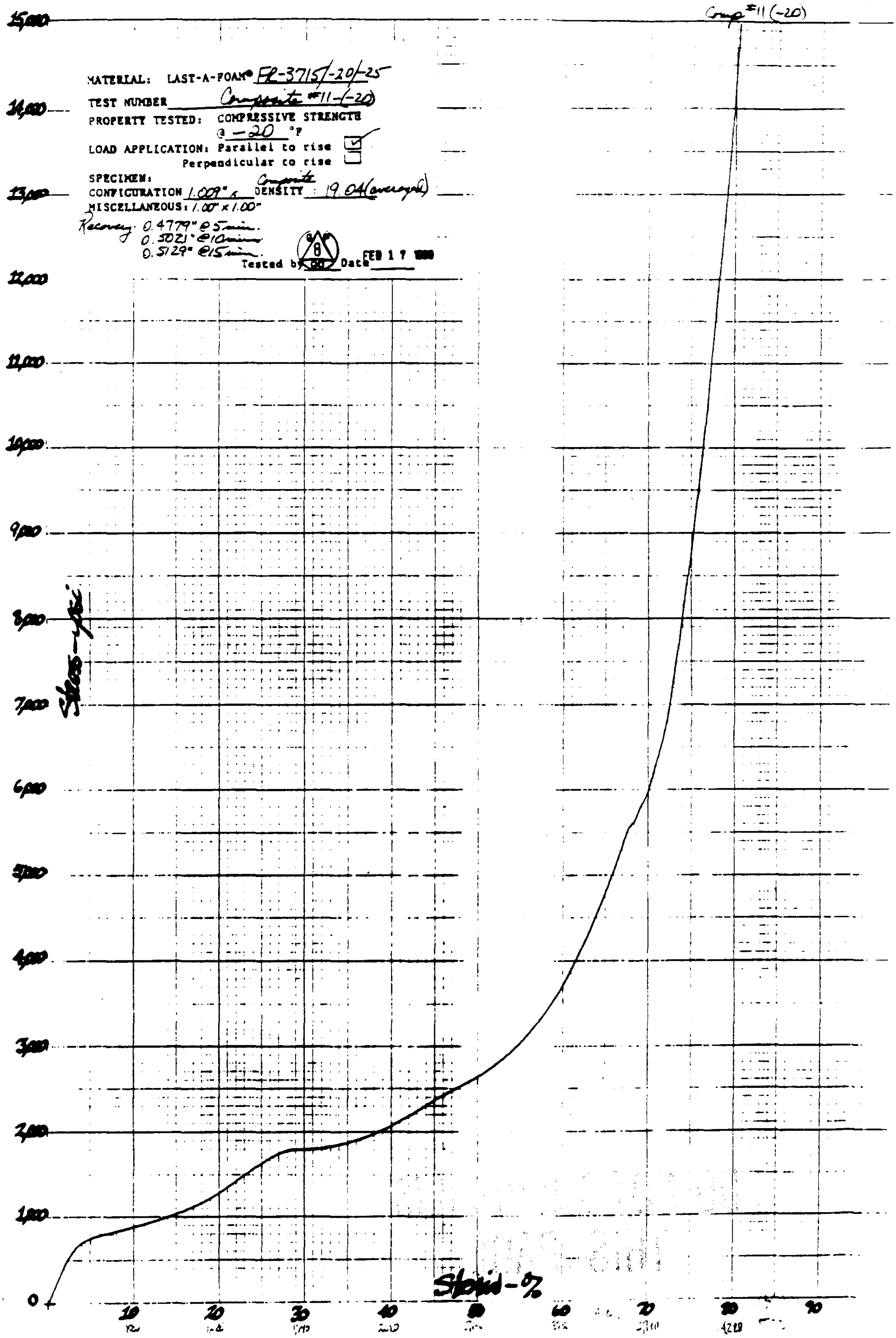

MATERIAL: LAST-A-FOAM® FR-3715(-20)/25
TEST NUMBER Composite #12-(-20)
PROPERTY TESTED: COMPRESSIVE STRENGTH @ -20 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN: Composite
CONFIGURATION 1.002"
DENSITY 19.13 (average)
MISCELLANEOUS: 1.00" x 1.00"
Recovery 0.5090" @ 5 min
0.5435" @ 10 min.
0.5535" @ 15 min.
Tested by
Date FEB 1 7
Stress - PSI
Strain - %
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10
20
30
40
50
60
70
80
90
1975
3650
#12 (-20)


MATERIAL: LAST-A-FOAM® FR-3715/-20/625
TEST NUMBER Composite #13-(-20)
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ -20 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN: Composite
CONFIGURATION 1.004" x
DENSITY 19.13 (averaged)
MISCELLANEOUS: 1.00" x 1.00"
Recovery: 0.4578" @ 5 min.
0.4847" @ 10 min.
0.5096" @ 15 min.
Tested by
Date FEB 1 7 1988
Stress - psi
Strain - %
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
10
20
30
40
50
60
70
80


MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #14-(-20)
PROPERTY TESTED: COMPRESSIVE STRENGTH @ -20 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN: Composite
CONFIGURATION 1.004" x
DENSITY : 19.13 (averaged)
MISCELLANEOUS: 1.00" x 1.00"
Recovery: 0.4752" @ 5 min
0.4964" @ 10 min
0.5082" @ 15 min
Tested by
Date FEB 17
Stress - psi
Strain - %
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000
9,000
10,000
11,000
12,000
13,000
14,000
15,000
10
20
30
40
50
60
70
80
90


Comp#9 (-20)
MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite 9-(-20)
PROPERTY TESTED: COMPRESSIVE STRENGTH
@ -20 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.004" x
Composite DENSITY 19.04 (average)
MISCELLANEOUS: 1.00" x 1.00"
Recovery: 0.4538" @ 5 min
0.4830" @ 10 min
0.4939" @ 15 min
Tested by
Date FEB 1 7 1988
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Stress - psi
Strain - %
10
20
30
40
50
60
70
80
90


MATERIAL: LAST-A-FOAM® FR-3715-20/-25
TEST NUMBER Composite #10-(-20)
PROPERTY TESTED: COMPRESSIVE STRENGTH @ -20 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN: CONFIGURATION 1.007" x
Composite DENSITY: 19.04 (average)
MISCELLANEOUS: 1.00" x 1.00"
Recovery: 0.4528" @ 5 min
0.4808" @ 10 min
0.4908" @ 15 min
Tested by
Date FEB 1 7
Stress - psi
Strain - %


Comp #11 (-20)
MATERIAL: LAST-A-FOAM® FR-3715/-20/-25
TEST NUMBER Composite #11-(-20)
PROPERTY TESTED: COMPRESSIVE STRENGTH @ -20 °F
LOAD APPLICATION: Parallel to rise
Perpendicular to rise
SPECIMEN:
CONFIGURATION 1.009" x
Composite
DENSITY 19.04 (averaged)
MISCELLANEOUS: 1.00" x 1.00"
Recovery 0.4779" @ 5 min.
0.5021" @ 10 min.
0.5129" @ 15 min.
Tested by
Date FEB 1 7 1989
15,000
14,000
13,000
12,000
11,000
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Stress - psi
Strain - %
10
20
30
40
50
60
70
80
90

Average Composite Density = 19.18 p.c.f.

Sample Number	Tested Parallel to Foam Rise @ 75°F									
	10%	20%	30%	40%	50%	60%	65%	70%	75%	80%
# 1 bonded	510	842	1270	1480	1900	2700	3520	4870	7410	12300
# 2 bonded	590	860	1240	1440	1850	2605	3370	4620	6910	11090
# 3 bonded	705	945	1198	1430	1880	2660	3440	4760	7205	11750
Average (bonded)	**602**	**882**	**1236**	**1450**	**1877**	**2655**	**3443**	**4750**	**7175**	**11713**
# 4 Nonbonded	760	955	1170	1380	1805	2525	3260	4460	6655	11395

Average Composite Density = 19.14 p.c.f.

Sample Number	Tested Perpendicular to Foam Rise @ 75°F									
	10%	20%	30%	40%	50%	60%	65%	70%	75%	80%
# 5 bonded	705	925	1330	1525	1945	2660	3360	4520	6620	13010
# 6 bonded	655	875	1300	1480	1930	2600	3330	4530	6760	11015
# 7 bonded	675	885	1280	1475	1945	2610	3335	4545	6790	11085
Average (bonded)	**678**	**895**	**1303**	**1493**	**1940**	**2623**	**3342**	**4532**	**6723**	**11703**
# 8 Nonbonded	660	835	1220	1395	1830	2440	3100	4205	6240	9800

Average Composite Density = 19.14 p.c.f.

Sample Number	Tr[illegible] Parallel to Foam Rise @ -20°F									
	10%	20%	3[illegible]	40%	50%	60%	65%	70%	75%	80%
# 9 bonded	800	1290	1840	2145	2720	3895	5035	6305	9440	[illegible]
# 10 bonded	1030	1400	1705	2060	2670	3755	4770	6035	9460	[illegible]
# 11 bonded	885	1285	1795	2080	2635	3735	4785	5990	8800	14280
Average (bonded)	**905**	**1325**	**1780**	**2095**	**2675**	**3795**	**4863**	**6110**	**9233**	**16003**

Average Composite Density = 19.13 p.c.f.

Sample Number	Tested Perpendicular to Foam Rise @ -20°F									
	10%	20%	30%	40%	50%	60%	65%	70%	75%	80%
# 12 bonded	930	1240	1975	2170	2800	3385	4300	5575	7800	13650
# 13 bonded	1040	1335	1960	2220	3005	3895	4920	6540	9645	16130
# 14 bonded	940	1235	1860	2070	2745	3600	4295	5300	7690	13200
Average (bonded)	**970**	**1270**	**1932**	**2153**	**2850**	**3627**	**4505**	**5005**	**8378**	**14327**

December 1989

Ref: L-9775-2

CASK SYSTEMS DEVELOPMENT

for

100-TON RAIL/BARGE SPENT FUEL CASK

(DOE-OCRWM Contract No. DE-AC07-88ID12700)

O-RING SEAL TEST PROGRAM REPORT

by

Nuclear Packaging, Inc.

1010 South 336th Street

Federal Way, WA 98003

December 1989

TEST REPORT #L-9775

Rev. 2

REVISIONS

Rev.	Pages	Description	By	Appvl.	Date
	ii	(1) Revised Table of Contents to include Section 5.			
	1	(2) Chg'd Radiation from 30mR to 100R to reflect present analysis.			
1	VAR	(3) Grammatical changes made throughout for clarity.			
	29-30	(4) Added Section 5, "Supplemental Testing of an Experimental EPDM Material" as an optional elastomer candidate for preliminary design.			
		Authority: EG&G Submittal No. 40-01-01, Review Comments	GLS 9/28/89	[illegible] 10/4/89	
2	all	Editorial Changes ONLY - - Technical Content NOT CHANGED	[illegible] 12/12/89	[illegible] 12/13/89	

Ref: Rev1408

O-RING SEAL TEST PROGRAM REPORT

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O-RING SEAL TEST PROGRAM REPORT

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Reference	Title
1	"Testing Polymers for Oil, Gas Applications", Energy Rubber Group Presentation, September 27, 1984, by J. C. Vivic
2	Cask Seal Test Program, "Elevated Temperature Compression Set Tests", Procedure #SE-0001-NP, Nuclear Packaging
3	Cask Seal Test Program, "Low Temperature Resilience Test", Procedure #SE-0002-NP, Nuclear Packaging
4	Cask Seal Test Program, "Leak Test", Procedure #LT-0039-NP, Nuclear Packaging
5	"Selection of High Performance Elastomers for Oil and Gas Drilling and Production", The Plastics and Rubber Institute, Institute of Mechanical Engineers, London, dated June 12, 1986; by Bruce G. Parker
6	Ethyl Corporation Technical Data, Performance Properties of Eypel-F Compound, Cat SC-20A, 1987

1.0 INTRODUCTION

1.1 Nuclear Packaging, Inc. (NuPac) is developing a 100-ton Rail/Barge Spent Fuel Shipping Cask. The project is in direct support of U. S. Department of Energy (DOE) under Contract Number DE-AC07-88ID12700. The preliminary cask design, shown in Figure 1, utilizes a large bolted end enclosure lid with O-ring seals for containment. The purpose of the testing reported herein was to identify and select an o-ring seal material for the subject cask during the preliminary design phase, given the following in-service conditions.

1.1.1 The physical and environmental in-service conditions determined to be present at the O-ring boundary are

- o Max. (Loaded) Service Temperature -- 260°F
- o Radiation (Loaded) -- 100 RADS/hr
- o Maximum Pressure (External) -- 260 psia
- o Maximum Pressure (Internal) -- 315 psia

1.1.2 Nuclear Regulatory Commission (NRC) specification (10CFR71) for radioactive material shipping casks also requires the containment to be "leaktight" under the following normal and faulted conditions:

- o Max. Ambient Temperature = 100°F, Normal Static Loads
- o Min. Ambient Temperature = -40°F, Normal Static Loads
- o Thermal Fire External Accident Temperature = 30 min. @ 1,475°F, (calculated as 275°F @ O-ring boundary)
- o Max. Ambient Temperature = 100°F, Faulted Dynamic Loads
- o Min. Ambient Temperature = -20°F, Faulted Dynamic Loads

1.1.3 The following additional criteria also apply:

- o One year continuous at loaded maximum temperature
- o Compatible to solutions of deionized water and common decon solutions

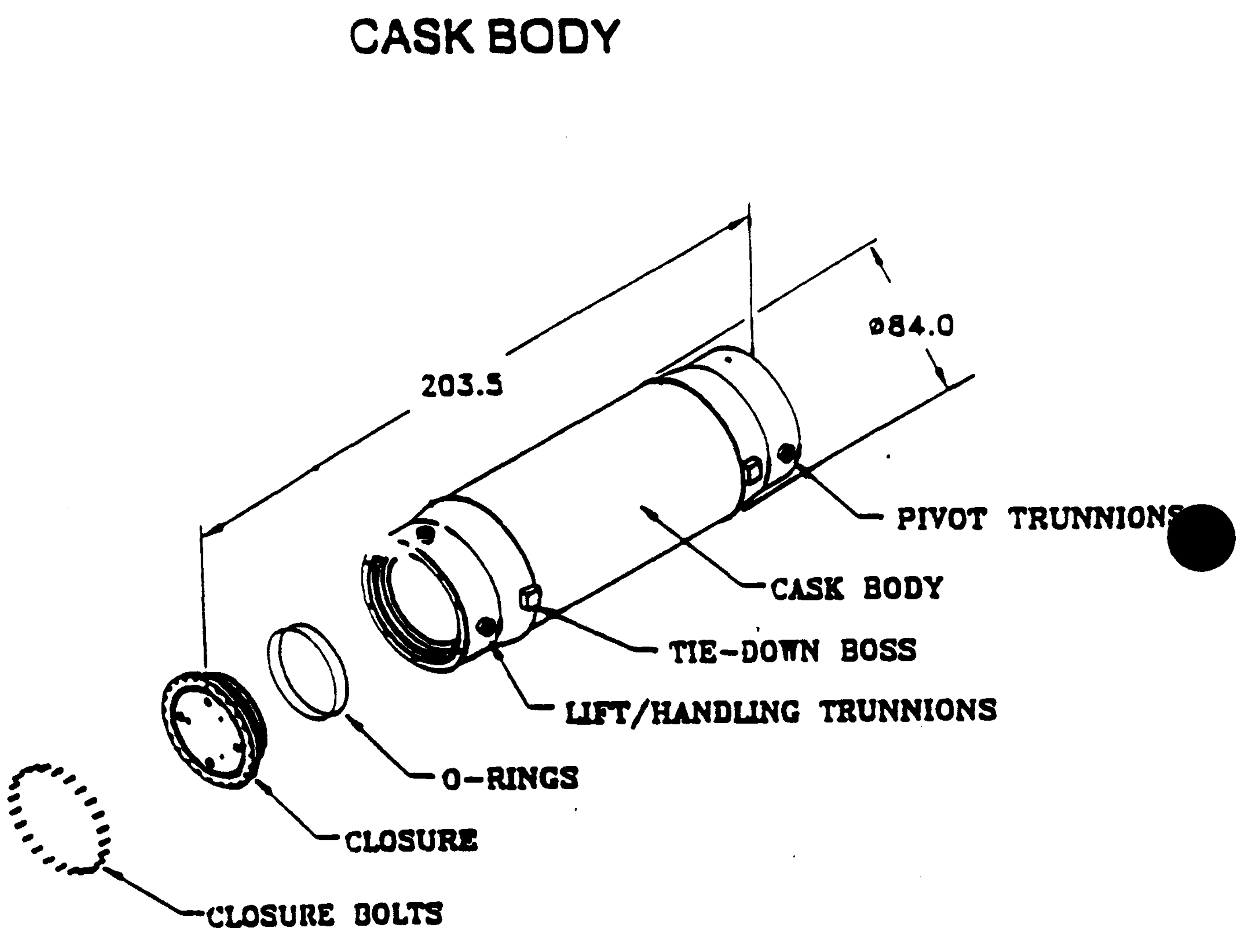

FIGURE 1

100-Ton Rail/Barge Spent Fuel Shipping Cask
Preliminary Design Configuration

1.2 Engineering analyses and design specifications that presented the most stringent set of requirements upon the elastomer seal were:

- o One year continuous leaktight static seal at a constant 260°F; combined with the
- o Retained capability that the seal be able to adhere to dynamic maximum displaced seal boundary surfaces (faulted accident conditions) at an associated extreme cold temperature stabilizing at -20°F.

The temperature extremes of these two conditions are in direct conflict with each other with respect to normal elastomer property behavior. Elastomer mechanical properties are usually time and temperature dependent. Elastomers subjected to a usually continuous exposure to high temperatures have their low temperature performance characteristics altered (usually degraded) through thermochemical restructuring, Reference (1).

1.3 Given the above design and in-service performance requirements, an elastomer evaluation and testing program was developed to select a seal material commensurate with those conditions. The program employed a three-phase testing and evaluation process, wherein each phase employed more stringent testing and evaluation requirements than its preceding phase. The ultimate goal was to establish a candidate material listing from which the best seal material could be identified.

A logic diagram for the overall selection process is illustrated in Figure 2. The illustration depicts each testing and evaluation phase segmented from predecessor or subsequent phases. Each subsequent phase is schematically smaller since the available candidate seal population remaining for more stringent testing and evaluation decreased due to unsatisfactory performance of some seal materials.

1.3.1 Phase I was the evaluation phase. The scope was to identify potential candidate o-ring materials that possessed the mechanical, chemical, and environmental compatible characteristics necessary to meet the required technical design and in-service parameters for this cask. Since numerous candidate elastomer products were available, the initial candidate selection process employed a weighted rank screening methodology. Table 1.3 summarizes the results of that weighted rank screening. Evaluations performed at this screening were based on reviews of existing elastomer research and technical papers, interviews with elastomer vendors, elastomer product literature information and prior NuPac experience with existing in-service cask seals and actual seal testing data.

1.4 Following the Phase I material screeni a select group of o-ring materials were subjected to Phase II laboratory testing. The Phase II tests addressed the general performance parameters of 10CFR71, noted in paragraph 1.1.2, and were intended to ascertain which of the Phase I material selections showed the highest probability of maintaining a leaktight boundary given these general performance conditions. The Phase II testing program consisted of compression set tests, resiliency tests, and seal leak tests using virgin samples of Phase I identified elastomers.

1.5 Candidate o-ring materials that performed successfully during Phase II were further tested under the Phase III performance criteria requirements. Phase III tests were similar to Phase II tests, except the test samples were compression set tested at higher temperatures, and the resiliency and leak tests utilized seal material that had been preconditioned (exposed to a 300°F high-temperature environment). This conditioning was done to induce potential thermochemical changes in the sample elastomers prior to testing (similar to what may be anticipated to occur during the in-service periods).

The results of the Phase III tests were evaluated according to a "pass/fail" rating system. All candidate materials rated as "passing" the Phase III tests were considered as acceptable elastomers for preliminary design use in the cask system.

1.6 This report addresses physical testing for compression set, resiliency, and leakage rates only. Other O-ring performance factors (e.g. impermeability, fatigue, radiation resistance) were evaluated on the basis of prior research data performed by others.

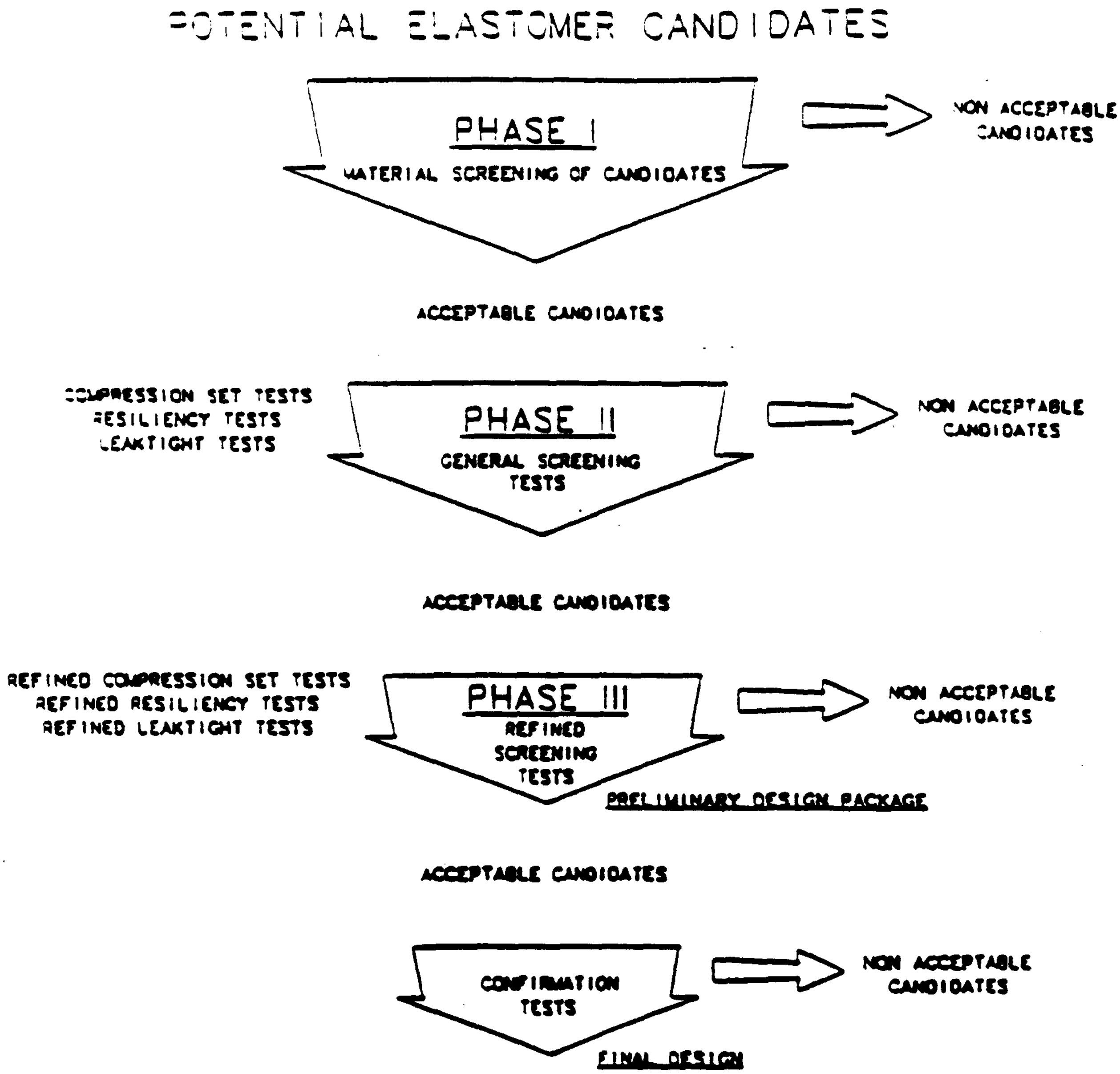

FIGURE 2

O-Ring Material Testing and Evaluation Logic Diagram

TABLE 1.3

Seal Material (Weighted) Screening Selection Summary

Initial Screening Selection of Seal Materials

Material	Weighted Rate	Rank	Compound
Ethelene Propylene	74	1	E529-60
Arctic Nitrile	68	2	AS568-453
Fluorocarbon (GLT)	68	2	MIL-R-83485
Fluorosilicon	65	4	L449-65
Phosphonitril Fluorophosphazene	61	5	EYPEL-F, S705
Butyl	61	5	B-3
Neoprene	59	7	BMS 1-11

2.0 SCOPE OF TESTS

2.1 The Phase I evaluation required no actual physical tests of elastomers. The material evaluation process consisted of ranking potential candidate materials using performance criteria (ten total) that parallel the operational parameter requirements for the subject cask system. The performance criteria considered were:

- Continuous one-year service at 300°F
- Impermeability to gases
- Aqueous solutions compatability
- Leaktight seal capability at 300°F
- Leaktight seal capability at -40°F
- Radiation resistance
- High resiliency at -20°F
- Low compression set at 300°F
- Abrasive resistance
- Fatigue resistance

Using technical references, supplier published material references, direct communication with seal material suppliers, and NuPac's existing testing and personal experience resources, materials were chosen for Phase II testing. They are listed in Table 1.3.

2.2 The Phase II testing program implemented three basic laboratory test methods to further screen potential candidate o-ring materials. Each material identified during the Phase I evaluation was laboratory tested to determine:

(a) compression set, Ref. (2)
(b) resiliency, Ref. (3)
(c) leaktight capability, Ref. (4).

Material samples chosen had a nominal cross-section of 0.390 inch, the nominal size (thickness) intended for the preliminary cask design. The Phase II screening process required each sample to meet the acceptance criteria of each of these tests, in the sequence shown, before being considered eligible for further testing. Acceptable candidates passing each of the three tests became denoted as Phase III candidate materials.

Results of the Phase II tests are also considered important source data for validating the preliminary cask design seal geometry and installation/manufacturing tolerance geometry. Additionally, the results established by the compression set and resiliency tests performed under Phase II tests were examined to determine if any correlation could be made between compression set data, resiliency data, and subsequent Phase II and III leak test results.

2.2.1 Compression Set Tests

2.2.1.1 Compression set testing was performed on o-ring materials in accordance with the basic procedure of ASTM D-395 and ASTM D-1414. The test temperature used was 300°F to simulate the predicted maximum long-term seal boundary temperature of the 100-ton cask. The 300°F includes a +40°F margin of safety. This particular test was selected because in the 100-ton cask design, the o-rings are assembled with an initial compressive load of 25% squeeze and held in place at a constant strain until some outside force (either intentionally or accidentally) causes an unloaded condition. While installed and constantly strained in a 300°F environment, the eventual seal material will most likely slowly deform or relax, and take on a permanent displacement set. The rate of relaxation of a seal material is temperature and time dependent, with usually a majority of the nonrecoverable deformation occurring within the first 168 hours of compressed, high-temperature exposure.

2.2.1.2 Candidate O-ring materials with nominal dimensions of 0.390 inches cross-section by two inches long were inserted into a compression set test fixture, Figure 3, at an initial compression displacement equal to 25%; i.e. approximately 0.293 inches.

2.2.1.3 The O-ring samples were then tested for compression set at 300°F for periods of 8, 22, 72 and 168 hours. O-ring materials that exhibited a compression set of less than 50% over 168 hours were considered as likely final candidates. The 50% compression set value was selected since it was determined that permanent displacement set (after 168 hours at 300°F) would result in a 10- 1/2% loss of installed o-ring compression for the full scale cask installation (from 25% to 14 1/2%), which is considered acceptable and allows some reasonable margin of further compression set to occur over continued 300°F exposure. The minimum installation squeeze initially assumed as acceptable for the 100-ton cask is 10%, which allows approximately 70% compression set for the present seal groove geometry used.

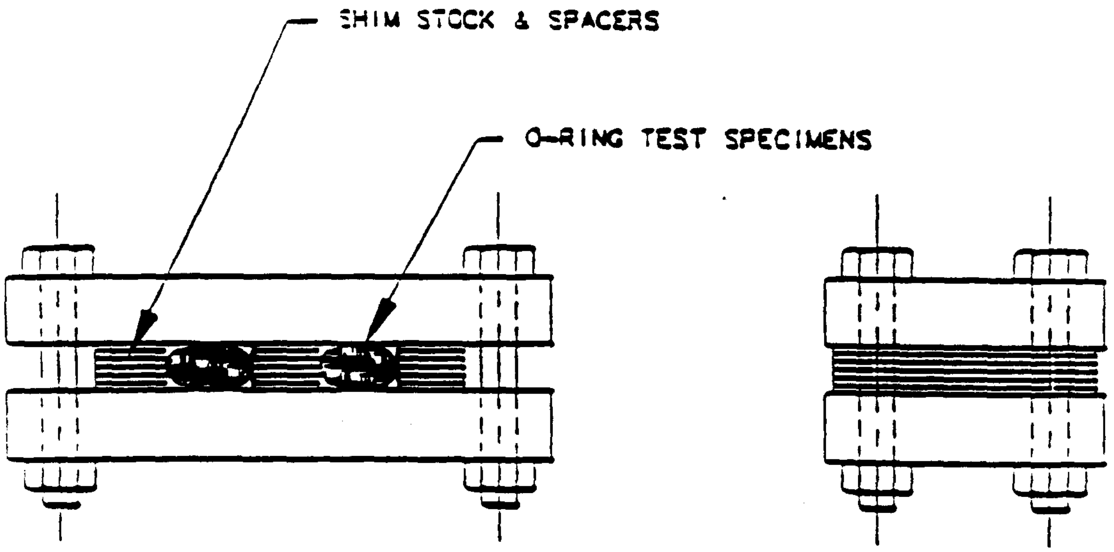

FIGURE 3

O-Ring Compression Set Text Fixture

2.2.2 Resiliency Tests

2.2.2.1 The Phase II resiliency testing program was developed to generate a data base of o-ring material response rates following exposure to -20°F and -40°F. The collected data was used to compare the displacement recovery rates of the various candidate o-ring seal materials. The -20°F and -40°F low temperature parameters selected for this test correspond with both low temperature specification requirements established for the 100-ton cask system; normal maximum low temperature and the faulted accident low temperature. In order to expedite the development of a comparative material resiliency data base, the tests performed during this phase utilized the same sample sizes, fixtures, and initial installation compression displacement (25%) as the earlier Phase II compression set tests.

2.2.2.2 O-ring samples were loaded into the test fixture at 25% compressive displacement and initially placed into a -20°F environment. After stabilizing at -20°F, the test samples were suddenly removed from the load and cross-sectional measurements made with vernier calipers every 15 seconds for two minutes minimum. Resiliency was calculated as the percentage recovered of the original compressed cross-sectional displacement. The results were plotted against time.

Since no prescribed national, international, or industry standards exist for this type of testing, acceptance criteria were established that had some physical significance with respect to the 100-ton cask operational and environmental envelope. The -20°F condition had been previously noted to be synonymous to the coldest cask faulted accident condition. The cold accident scenario can effectively cause an instantaneous maximum displacement between seal boundary surfaces. The preliminary cask design allows a maximum displacement of 0.015 between the lid and the bore diameter and a simultaneous minimum displacement of 0.000 at a position 180° opposite the same lid-to-bore diameter. For the elastomer to respond to a sudden impact and fill the 0.015 inch void, a quick seal response is required. The ideal condition is one in which the seal instantaneously tracks the seal boundary. If an initial response time of 60 seconds and a resilience of 60% were allowed, the elastomer could respond to the fault-created gap in 16 secs, assuming a linear relationship exists. Allowing for some tolerance, we selected an acceptance criteria of 60% resiliency over 30 seconds.

2.2.2.3 Candidate materials passing the -20°F resiliency tests were retested in a like manner at -40°F. Since the only operational scenario requirements for the -40°F environment are static sealing conditions, this test was a data gathering effort for comparing the -20°F and -40°F resiliency response data. Since normal transport minor-load-induced deflections in a -40°F environment may be addressed by this data, an arbitrary acceptance criteria of 50% resiliency over one minute was selected.

2.2.3 Leaktight Seal Tests

2.2.3.1 Materials successfully passing the Phase II compression set tests were subjected to a series of general leaktight tests using seals made with the selected preliminary design cross-sectional diameter of 0.390 inches. A fixture utilizing a 3% installation stretch factor on an 11.8 inch diameter groove diameter was fabricated to test the leaktight integrity (using helium) between the annulus of 2 seals. The test conditions required helium leak tests at an ambient condition with the lid assembled and centered in the bore, at -40°F normal low temperature centered lid to bore assembled condition, and at the -20°F faulted assembled condition with the o- ring retaining disk (simulating a lid) offset from the bore (simulating the inner cask) by a minimum of 0.015 inches. The test fixture assembly is shown by Figure 4.

2.2.3.2 The acceptance criteria established for the leaktight test at all temperatures is the same as the criteria presently applicable for the cask seals utilized for the 100-Ton Rail/Barge Spent Fuel Cask; ANSI 14.5 leak rates shall not exceed 1×10^{-7} std cm^3/sec for these conditions.

2.3 Materials failing to meet all the acceptance criteria established by the Phase II testing procedures were withheld from Phase III testing, and no longer considered viable candidates for this cask application.

The Phase III testing program was similar to the Phase II program, except the final candidate materials were subjected to longer term 300°F exposures; i.e. higher temperature compression set exposures. These more stringent factors were used to determine if any latent thermochemical failure mechanisms were present in the candidate materials that were not previously identified by prior tests, at or near the anticipated service conditions.

2.3.1 The compression set tests performed under this phase were done at 350°F for the 8, 22, 72, and 168-hour durations. Acceptance criteria at the 350°F temperature range was established as 60% compression set maximum.

2.3.2 The resiliency tests for this phase utilized an automatic fixture and data chart recorder for more precise measurements of the material recovery rates. O-ring samples (0.390 cross-section x 2 inches long) were placed into the fixture at 20% to 25% displaced compression. The fixture and the o-rings were placed in a -20°F environmental chamber until all components stabilized at -20°F. While still at -20°F, the compressed load was then released allowing the o-ring to freely recover by its inherent elastic energy. LVDTs sensed both the maximum released opening and the displacement recovered. A recording pen scribed the displacement position on the x-axis of the chart. Time was recorded on the y-axis. A secondary pen also charted the compressed and uncompressed load exerted on the o-ring through a load sensor at the bottom of the o-ring retainer. The test fixture is shown in Figure 5.

One difference between the Phase II resiliency tests and the Phase III tests was that the Phase II tests utilized calipers and a stop watch to measure the displacement recovery rates, while Phase III tests utilized transducer electronics and chart recorders. The second difference was that this test equipment allowed recovery displacement rate measurements to be done in the cold environment, whereas the prior method required the technician to pull the samples out of the -20°F and -40°F environment and perform the required measurements. The Phase II method was considered adequate for establishing a data base relationship between a large variety of samples. However, the Phase III test provided more precise information to determine the exact response characteristics of the candidate materials in their lower temperature service conditions without the influence of natural thermal expansion.

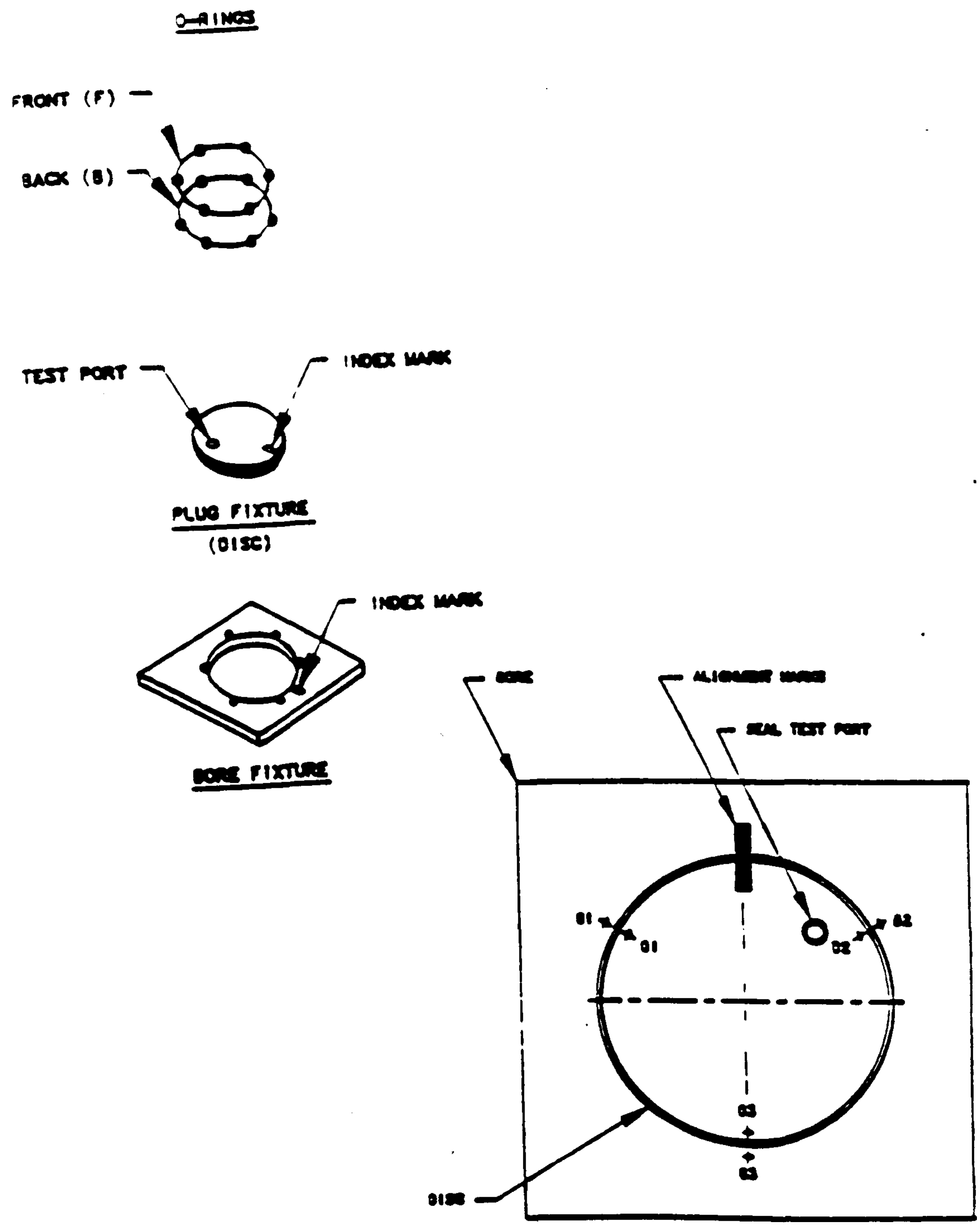

FIGURE 4

O-Ring Leak Test Fixture

The acceptance criteria used for the Phase III resiliency tests were identical to those used for the earlier Phase II tests. Candidate o-ring materials satisfying the -20°F resiliency test criteria were tested again at -40°F.

An additional -20°F resiliency test was also developed for final candidate materials to establish a data base of retained material resiliency following a period of high-temperature exposure in a compressed state. Although no acceptance criteria was established, this test data was considered important since it recognized the probability of elastomer mechanical property changes following continued high-temperature conditioning. The material conditioning was 168 hours at 300°F at 25% compressed displacement (the same used in earlier compression set tests).

2.3.3 Phase III leaktight tests were performed to the same measurement criteria as the earlier Phase II tests. The test conditions were more stringent in that the candidate o-rings were leaktight tested at 300°F and -20°F following a 300°F exposure for 168 hours using a 25% initial installed compression on the o-rings. This test was developed to simulate actual operating conditions, and prove the o-ring material sealing integrity at the cold temperature faulted condition following a period of stress relaxation induced by high operating temperature stress.

The Phase III candidate o-rings were initially compressed into the leak test fixture and leaktight tested at ambient, -40°F, and -20°F (offset) conditions as was done in Phase II. Following verification of their tightness, the o-ring lid disc was recentered and the entire fixture heated and held at 300°F. Seven days or 168 hours later at 300°F, the o-rings were vacuum or helium leaktight tested at 300°F. If there was no measurable leak-age, the device was cooled to -20°F. Once stabil-ized at -20°F, the o-rings were forced off-center and leaktight tested. The entire sequence allowed for a reasonable worst case compression set and also utilized the maximum capabilities of resiliency after thermal conditioning.

O-ring materials able to maintain a leaktight condition following this test, were designated as final candidate materials and approved for inclusion in the cask preliminary design package. If more than one candidate met the criteria of this test, then the candidate with the highest resiliency rate would be given priority over the other qualified candidates.

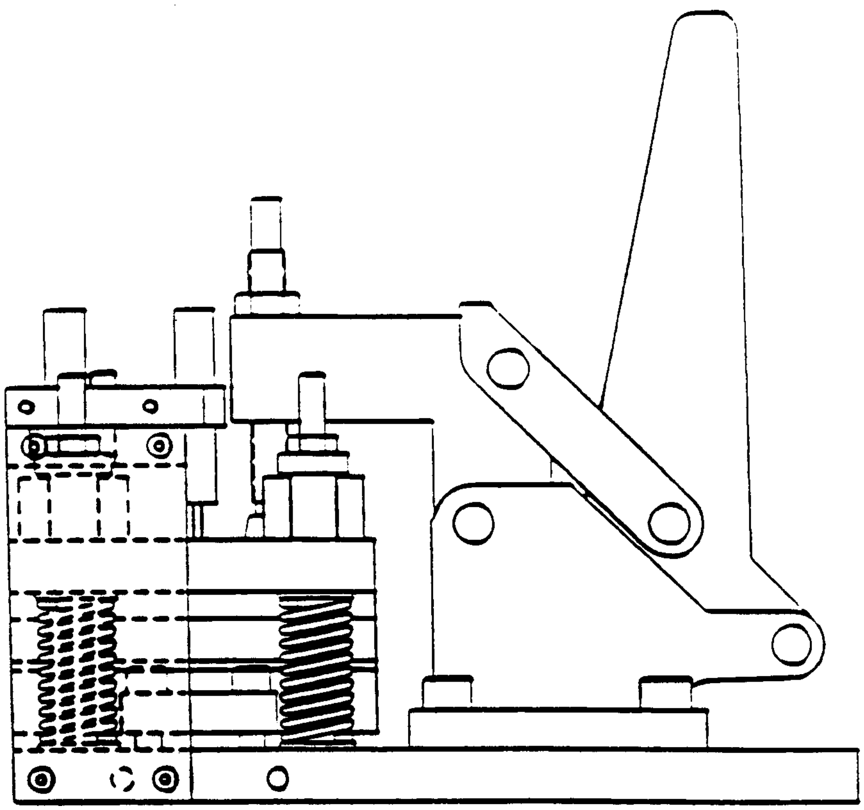

FIGURE 5

O-Ring Resiliency Test Fixture

3.0 TEST RESULTS

3.1 Phase II Tests

3.1.1 The compression set test data from the Phase II (300°F compression set tests) are shown in Figure 6. Phase I candidate materials failing to meet the acceptability limits of compression set of less than 50% over 168 hours were Butyl B-3, Neoprene BMS 1-11, and ethylene propylene E529-60. The remaining four Phase I candidate materials all met or exceeded the acceptable compression se criteria.

3.1.2 All Phase I candidate materials were subjected to the Phase II resiliency tests at -20°F. As shown in Figure 7, five materials met or exceeded the 60% resiliency acceptance criteria within the prescribed 30-second response time. The two materials observed to have a slow response recovery rate were ethylene propylene E529-60 and fluorocarbon (GLT). For comparison, Figure 8 shows material recovery rates at -40°F.

3.1.3 As noted in paragraph 2.2.3.1, Phase I candidate o-ring materials subject to leaktight testing were limited to those candidates having successfully met the acceptance criteria of the Phase II compression set tests. Therefore, leaktight tests were performed on all but three sample o-ring materials. Those tests were done on:

- Arctic Nitrile
- Eypel F
- Fluorosilicon
- Fluorocarbon (GLT)

Of these four materials subje[illegible] to the ambient, -40°F, and -20°F leaktight tests, the fluoroc[illegible]n (GLT) o-rings were the only material samples unable to sat[illegible] the leaktight criteria. The leak was measured during the -20°F off[illegible]t test. During retest of a second sample, the same problem was noted. Table 3.1 summarizes the Phase II leak tests on all candidate materials.

3.1.4 Phase II testing showed the following o-ring materials to be acceptable for further testing:

- Arctic Nitrile
- Eypel F
- Fluorosilicon

3.2 Phase III Tests

3.2.1 Sample materials subjected to Phase III tests were not performed to any particular test sequence, since the results of the Phase III tests were evaluated according to a "pass/fail" system as noted earlier in paragraph 1.5.

Consequently, the three materials remaining were tested for compression set, resiliency, and leaktightness in parallel with one another. The results of Phase III tests are summarized in Table 3.2.

3.2.2 Fluorosilicon and Eypel F satisfactorily met the 350°F compression set criteria. Arctic Nitrile was not compression set tested at 350°F, because the physical examination of arctic nitrile o-rings following the 168 hour 300°F Phase III leaktight test showed some material embrittlement had occurred. The manufacturer concurred that it was highly probable that the continued high temperature exposure would cause cross-linking changes in the polymer, and further exposure would propagate the failure. Given the physical evidence and this additional vendor information, the compression set test on arctic nitrile at 350°F was cancelled, and arctic nitrile was eliminated from further compression set testing.

3.2.3 For Phase III resiliency tests performed at -20°F and -40°F temperatures using virgin elastomer samples, a slight variation was observed in resiliency rates versus the Phase II testing methods.

However, these variations at these conditions were not significan enough to affect the selection of the final candidates.

For materials tested for resiliency after the 300°F - 168 hour conditioning, it is interesting to note the accompanying loss in resiliency. Especially interesting is the fact that arctic nitrile still had a large amount of inherent elastic energy in it even after it had become embrittled by the high- temperature exposure.

3.2.4 Phase III leaktight tests performed on the three materials showed in satisfactory results for both arctic nitrile and Eypel-F. Fluorosilicon was unable to remain leaktight following the 300°F - 168 hour conditioning period. The failure may have been caused by a tendency for fluorosilicon to allow gas permeation leakage, since all prior compression set and resiliency test data indicated the fluorosilicon should have otherwise satisfied the leaktight test.

3.2.5 The Phase III test results eliminated both arctic nitrile and fluorosilicon as viable candidates. Eypel-F, a compound blended by the Ethel corporation, met or exceeded all Phase III tests.

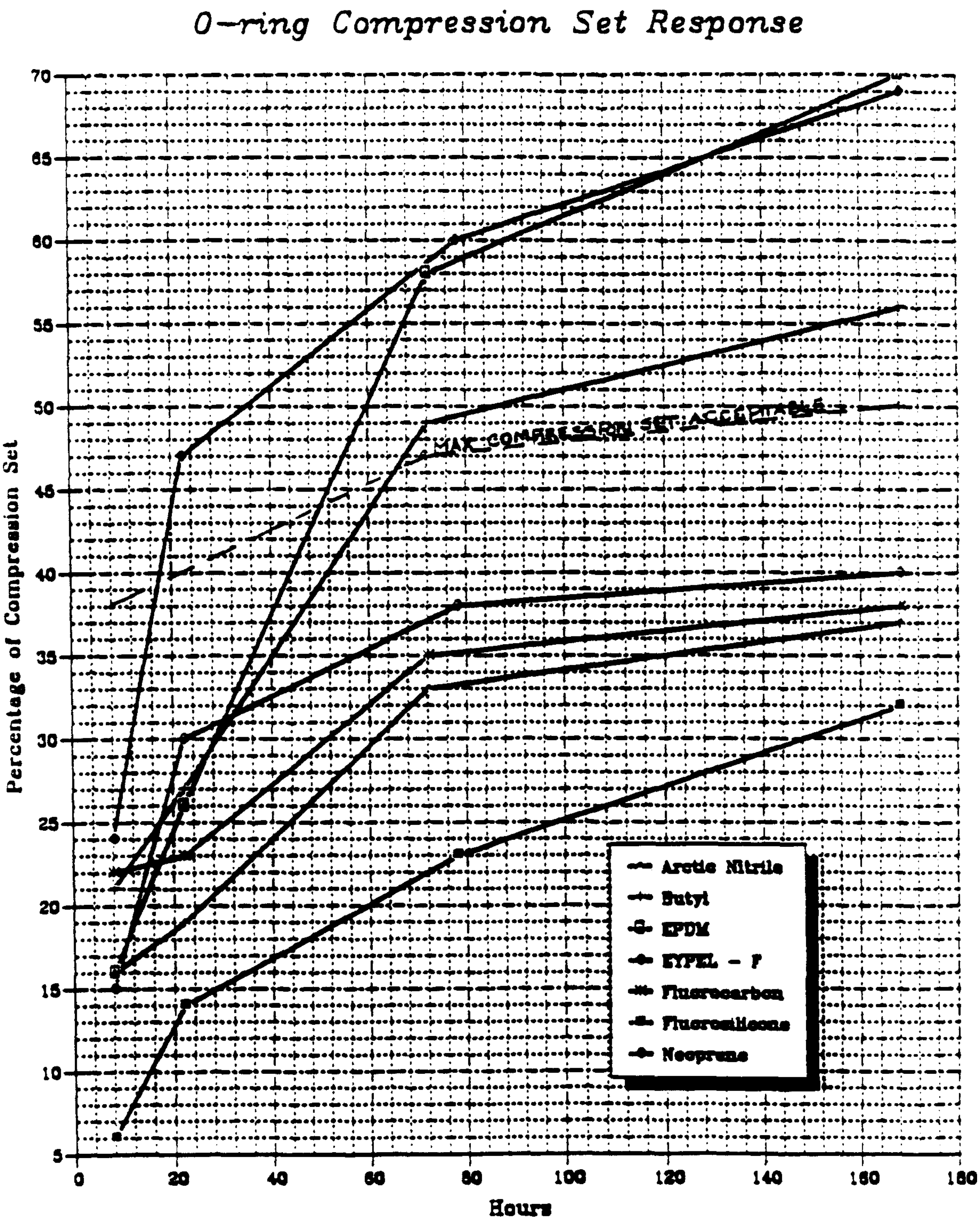

FIGURE 6

Compression Set Data (+300°F)

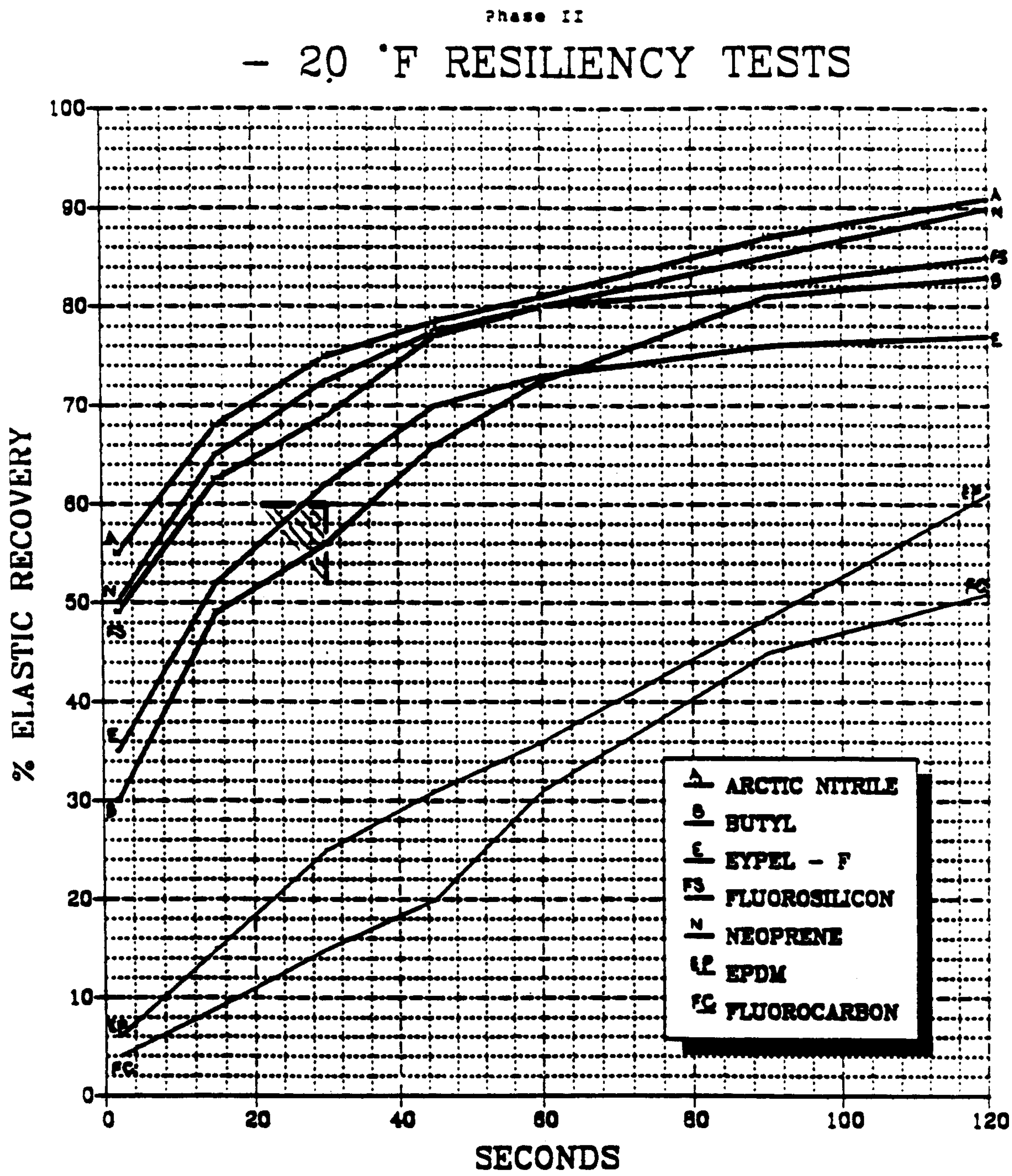

FIGURE 7

Resiliency Test Data, Phase II, -20°F

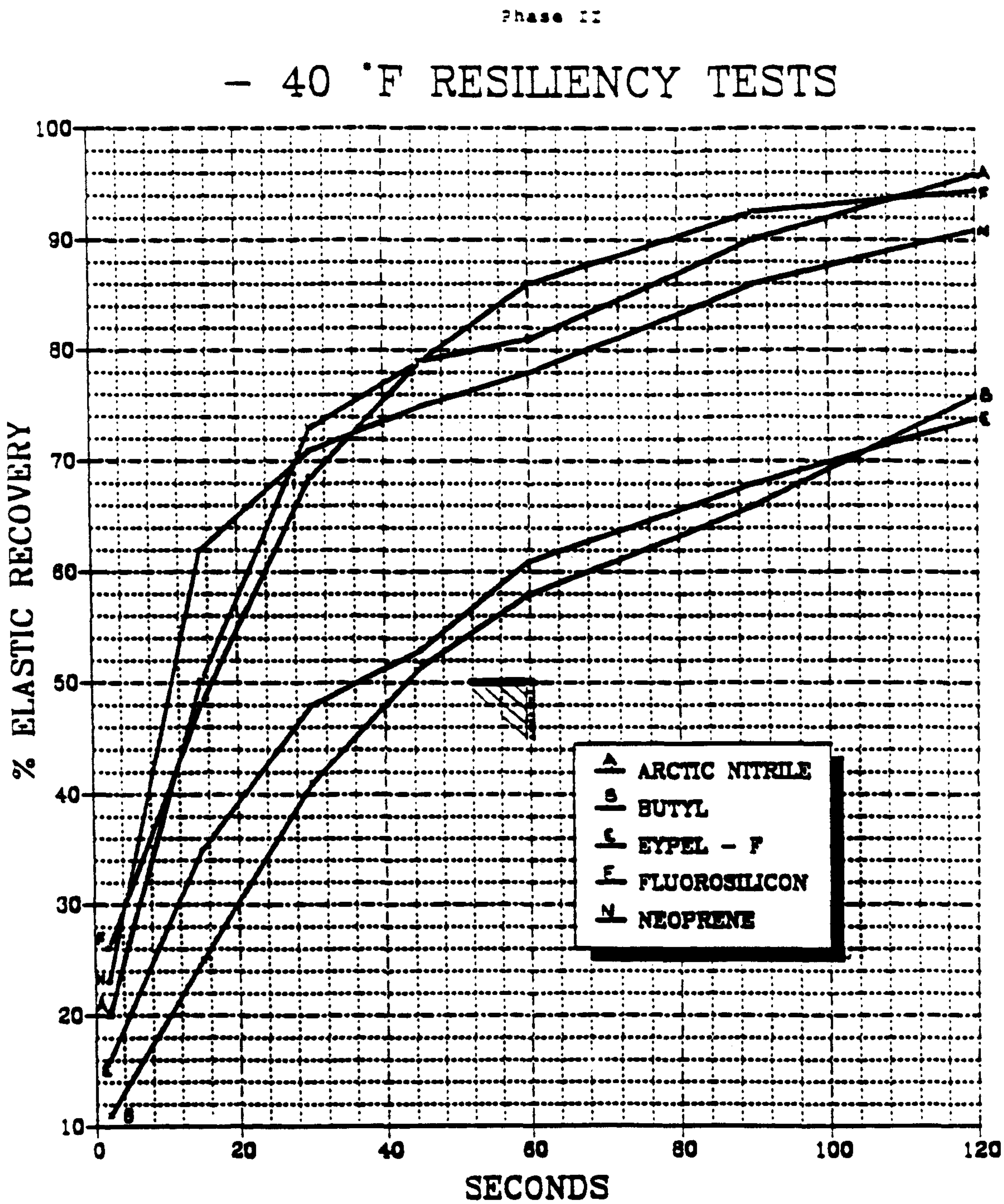

FIGURE 8

Resilience Test Data, Phase II, -40°F

TABLE 3.1

PHASE II LEAK TEST SUMMARY

Material Tested	O-Ring Cross Section Diameter				Maximum Gap (inches)		Minimum Compression (Percent)				Helium Leak Tight (Leak Rate Less Than $2x10^{-8}$ He cc		
	O-Ring 1		O-Ring 2		Disc Centered	Disc Offset	Disc Centered		Disc Offset		Ambient Temp	-40F	-20F (Disc Off-Set)
	Min	Max	Min	Max			Min	Max	Min	Max			
Arctic Nitrile	392	.393	.393	.397	0.027	0.047	24.7	25	18.6	20.7	Sat	Sat	Sat
Arctic Nitrile	392	.393	.393	.397	0.027	0.053	24.7	25	18.6	20.7	Sat	Sat	Sat
Eypel-F	377	.385	.378	.381	0.027	0.047	20.8	22.4	15.5	17.2	Sat	Sat	Sat
Eypel-F	384	.388	.388	.390	0.027	0.044	22.2	23.4	17.8	19	Sat	Sat	Sat
Eypel-F	389	.391	.389	.391	0.027	0.043	23.2	23.6	19	19.5	Sat	Sat	Sat
Fluorosil-icon	385	.388	.386	.387	0.027	0.047	22.4	23	17	17.8	Sat	Sat	Sat
FluoroCarbn	383	.385	.386	.392	0.027	0.042	22	23	18	19.9	Sat	Sat	Unsat

Notes:

(1) Minimum Stretch is 2% and maximum is 4.1% based on fixture seal diameter tolerance and O-ring diameters of 11.8±0.15 inches. 1½% of compression is assumed for stretch.

(2) O-ring groove depths are 0.264/0.266 in. for the fixture.

Table 3.2
Summary of Phase III Test Results

Material Sample	Compression Set 350F (%)				Resiliency %			Helium Leak Tight (Leakage Rate Less Than 2.0×10^{-8} He cc/sec)					
	8Hr	22Hr	72Hr	168Hr	-20F	-40F	-20F after 168Hrs At Temp	Ambient Disc Ctr	-40F Disc Ctr	-20F Disc Offst	After 300F 168 Hr Disc Ctr	-20 Disc Offst	
Arctic Nitrile	(1)	(1)	(1)	(1)	80	79	56	Sat	Sat	Sat	Sat (3)	Sat (3)	
Fluoro-Silicon	12	16	33	38	68	(2)	(2)	Sat	Sat	Sat	Sat (4)	Unsat	
Eypel-F	25	31	56	65	77	80	47	Sat	Sat	Sat	Sat	Sat	

Notes:

(1) Compression set testing of Arctic Nitrile negated by unsatisfactory physical changes observed during 168 hours, 300F exposure period.

(2) Continued resiliency testing fluorosilicon samples abandoned following unsatisfactory leaktight tests at -20F.

(3) Arctic Nitrile underwent unsatisfactory physical changes after 168 hour, 300F exposure; extreme embrittlement and hardening.

(4) Vacuum test at 20 millitorr to alleviate high risk of helium permeability

4.0 CONCLUSIONS

4.1 Phase II compression set test results clearly indicated the behavior of permanent stress relaxation by the elastomers, and the interdependence of that phenomena with respect to temperature and time. Available published material for elastomer compression set percentage values commonly states values from tests performed at standard 22 or 70-hour periods and at test temperatures of 75°F to 140°F. Although those values were helpful for making initial elastomer property comparisons, the potential user needs to at least consider the effects of actual higher or lower service temperatures, service life, and initial installation squeeze for the actual elastomer seal installation intended.

Using 300°F as the service temperature environment, and a nominal 25% initial installation squeeze, compression set test results (Figure 6) show a fast rate of permanent compression set from 8 to 22 hours. The rate of compression set falls off significantly from 70 to 168 hours. Projecting compression set beyond the 168 hour time frame is uncertain. However, if we assume the rate of compression set increase stayed relatively constant, then the final compression set values for any of the Phase II candidates would not be anticipated to exceed 50% for a 1-year (8760 hours) maximum service life.

Increasing the temperature to 350°F, and compression set retesting the acceptable Phase II candidate o-rings of Eypel-F and Fluorosilicon at the same 25% nominal initial installation squeeze, a slight increase in compression set values did result. Once again, the plotted rates of compression set slowed significantly after the first 70 hours. Projected final compression set for either of these two materials is not expected to exceed 70% for a 1 year period.

4.2 Phase II, -20°F, resiliency test results of the Phase I screened candidate materials showed that all but two elastomers possessed an inherent amount of elastic energy to track the interface surfaces of a displaced seal boundary within 30 to 60 seconds (see Figure 6). The ethylene propylene and the fluorocarbon (GLT) exhibited slow rates of response, indicating that cold temperature conditions would effectively de-energize those materials. This phenomenon is commonly referred to as "a dead material" in the elastomer industry, vice a "live material" for those materials capable of quick response rates.

The Phase III, -20°F resiliency tests confirmed that the slowest recovery rates did in fact occur with the ethylene propylene and fluorocarbon (GLT) o-rings. For example, the Phase III, -20°F, resiliency test on fluorocarbon (GLT) recorded a 19% recovered displacement in four minutes.

Earlier Phase II resiliency tests for fluorocarbon indicated approximately 40% recovered displacement in one-and-a-half minutes, but it was noted earlier in this report that the Phase II resiliency tests were probably not as accurate as the Phase III tests due to thermal expansion effects and hand measuring techniques used. Applying the recorded 19% fluorocarbon (GLT) rate of response for the subject cask design, and given an initial installation squeeze of 25% for a 0.390 o-ring and a maximum possible accident scenario of a 0.015 inch displaced lid to cask bore offset, we would project a virgin fluorocarbon (GLT) seal to allow bypass leakage to continue for approximately 11 minutes.

The -20°F sealing conditions are based on seals that are new and have had no prior 300°F high temperature exposure in a pre-compressed assembly. Actual sealing applications, however, cannot be disassociated from that pre-conditioning and hence, a permanent compression set influencing the final assembly recovery rate.

Therefore, for materials passing all initial Phase II and initial Phase III tests, a secondary Phase III resiliency test was performed using elastomer samples that had been preconditioned in a 25% compressed state at 300°F for 168 hours. The materials of arctic nitrile and Eypel-F were selected. Using those resiliency values, and given the previous -20°F displacement and installation parameters, the calculated times for those materials to effectively seal bypass leakages are 6.4 seconds and 101 seconds, respectively. This calculation utilized the measured rate of response taken by the resiliency fixture sensors from preconditioned arctic nitrile and Eypel-F, Appendix III.

Material	Permanent Set Loss	Response Rate	25% Initial Squeeze	Max. Displacement 10% Seal Compression	Sealing Time
Fluorocarbon	None Used	0.017"/4 min.	0.293"	0.015" plus 0.031"	11 min.
Arctic Nitrile	37%	0.0215"/3 secs.	0.293"	0.015" plus 0.031"	6.4 sec.
Eypel F	40%	0.0272"/60 secs.	0.293"	0.015" plus 0.031"	101 sec.

*10% is various manufacturers recommended minimum o-ring compression force required to sustain leaktight seal.

These rates and associated resealing times are reasonably responsive to effectively seal the cask during the -20°F faulted conditions prescribed in the design specifications.

4.3 The Phase III leak tests were developed to confirm the final o-ring seal material capability to retain a leaktight seal in a -20°F faulted condition following a long-term high-temperature (300°F) static sealing state. This scenario again allowed the installed o-rings to become compression set and stress relaxed prior to the -20°F faulted off-centered displacement situation. This Phase III test was the last laboratory simulated fixture test prior to final confirmation scale testing. Materials passing this test were essentially approved for consideration in the final cask design program.

Phase III leaktight tests were performed on arctic nitrile, fluorosilicon, and Eypel F. Only fluorosilicon was unable to meet the acceptance criteria, and it failed the -20°F faulted condition offset test following the 168-hour/300°F installation period. Why it failed is not readily apparent from a review of the earlier compression set or resiliency test data. It is suspected that another variable may have influenced the results (i.e., gas permeation).

Published sources and NuPac's prior seal experience reflects that there is a high probability that silicon and fluorosilicon are highly susceptible to helium gas permeation leakages, especially following a high temperature air exposure for short periods. Some thermochemical change may have occurred in the elastomer bonds or cross links after the 168-hour/300°F exposure period, making the material more likely to allow helium gas permeation. We did not attempt to investigate the cause, because we felt it to be academic at this time since our acceptance criteria was pass or fail.

The arctic nitrile and Eypel-F o-rings successfully passed the leaktight tests. One could conclude their success was predictable based on a review of the earlier compression set and resiliency test data. Although the materials did meet the leaktight tests, one glitch did develop. The samples were always disassembled after testing and physically examined. The arctic nitrile physical exam, after the 168-hour/300°F exposure, showed that a major change had occurred within the polymer, its binding agents, or its cross-links; it had become embrittled.

However, close physical examination of arctic nitrile showed some material embrittleness had occurred as a result of the longer-time high-temperature exposure. The durometer rating also showed it to be harder and the slightest additional stress tension caused cracking. The manufacturer indicated that it was highly likely that mechanical failure had been initiated due to the high temperature causing cross- linking changes, and further future exposure of the material at the 300°F temperature would cause continued failures.

This situation was concluded as unsatisfactory, leaving Eypel-F as the final candidate for use.

4.4 After review of all test data, it was concluded that Eypel-F would be the final candidate material. During compression tests, Eypel-F indicated an average range of compression set. Although average, its values were within acceptable limits. During resiliency tests, Eypel-F exhibited a little less than the average range of response. Again, the values were still within the acceptable limits.

Eypel-F also successfully passed all hot and cold temperature leak tests. Other problems were not witnessed (e.g., silicon and Fluorosilicon helium permeation problem, and embrittlement in arqtic nitrile).

Eypel-F compound and test data published by the manufacturer also indicates Eypel-F has good long-term high-temperature life expectancies of over 10,000 hours at exposures to 291°F.

In summary, all test and published data on Eypel-F show it to be NuPac's best choice for use on the 140B Rail/Barge Cask. Final proof tests are recommended to be done in the field and in the laboratory for final verification of this material. Final proof tests will consist of confirmation leaktight seal testing, and physical tests not included in the scope of this initial test program. We are reasonably certain at this time, however, that these tests will provide further evidence that Eypel-F is the best choice for this cask application.

5.0 SUPPLEMENTAL TESTING OF AN EXPERIMENTAL EPDM MATERIAL

5.1 A cursory review of those seal candidates tested during preliminary design of those approved for consideration for final design show that one viable candidate material passed all tests out of the original seven potential candidates selected. We had anticipated a somewhat higher candidate success ratio (3 out of 7). Naturally, additional candidates approved for consideration for the final design would likewise increase the probability of achieving a successful confirmation test on the basis of population alone. Concerned about our limited population choices for final design, we revisited our Phase I material selection matrix and decided to pursue other material sources for the top ranked ethylene propylene (EPDM) material. All EPDM suppliers contacted were unable to assure us that they could provide an EPDM material that would satisfy the operational and test parameters the 100-Ton Rail/Barge Cask demanded. One supplier, Cameron Elastomer Technologies, did agree that EPDM should satisfy all our conditions except for resiliency. Cameron Elastomer Technologies volunteered to formulate an experimental EPDM for us to include in our preliminary seal testing program. NuPac labeled the material EXP-C, and Cameron Elastomer Technologies labeled it as P/N 599508-10-08, BATCH 111-54-3.

5.2 The EXP-C material became available for NuPac testing during the last two weeks of our seal test program. Due to the late availability of the material, we elected to bypass the Phase II general testing exercise and proceeded instead with the more stringent Phase III testing.

5.2.1 Compression Set tests performed at a 300°F/168-hour exposure, resulted in a compression set of 37%. That value is considered well within our acceptabilitv limits and closely compares to the compression set values achieved for Eypel-F at the same temperature and time period.

5.2.2 Resiliency tests were performed at -20°F and -40°F using virgin samples of EXP-C, and repeated at -20°F and -40°F using 300°F/168-hour preconditioned samples of EXP-C. The -20°F resiliency test on virgin samples resulted in a 50% resiliency value in 10 seconds, and over 80% in sixty seconds. The -20°F resiliency tests on preconditioned samples yielded almost identical results, therefore indicating the 300°F had negligible impact on the material.

5.2.3 Leaktight helium leak tests were performed on EXP-C in accordance with Ref. 4, Rev. 1. No leaks occurred at any O-ring centered or offset condition tested. Those conditions included ambient (simulated centered lid and bore), -40°F (simulated centered lid and bore), -20°F (simulated offset lid and bore), 300°F (simulated centered and offset lid to bore) after 168 hours constant exposure, and -20°F (simulated offset lid to bore) after 168-hour exposure at 300°F.

5.2.4 Therefore, as a result of this supplemental test, EXP-C (EPDM) is also an approved candidate for final cask design and subsequent confirmation tests on the basis of these test results.

C.1.0 SPENT FUEL RAIL SHIPMENT TURNAROUND TIME

C.1.1 General

This section contains cask a summary of turnaround times the bases for the times.

C.1.1.1 Turnaround times

- BWR Reactor with Redundant Crane - 46 hrs.
- PWR Reactor Non Redundant Crane - 40 hrs.
- Dry Unloading at MRS/Repository - 20.5 hrs. for BWR and 18 hours for PWR fuel.

C.1.1.2 Bases for turnaround time estimates

C.1.1.2.1 Reactor turnaround time is based on experience with our IF-300 Casks.

C.1.1.2.2 Dry unloading is based on using "remote-automated handling methods" and applying 25 to 75 % reduction in time based on IF-300 Cask experience.

C.1.1.2.3 Turnaround time is from receipt of the cask at loading/unloading site until it is ready to ship. (multiple cask shipments are not included).

C.1.1.2.4 Time is estimate for major work stations or functions, details for each step in the procedure are not practical at this design phase.

C.1.1.2.5 No time estimate for vacuum drying is used in these turnaround times. However if vacuum drying is done it would add approximately 16 hours to the cask loading time.

C.1.2 Turnaround Time Estimate At A BWR Reactor with Redundant Crane

NOTES:

1. "Etc." as used in this estimate is for performance of minor tasks such as removal of valve covers, wetting down the cask while lowering it into the pool, and/or removing and installing of safety wire.

2. Continuous operation is assumed. (No time allowed for shift change or breaks).

3. It is assumed that the operations are performed by an experienced crew using special tooling.

4. Turnaround time is dependent upon specific methods of operation at a given utility, such as site specific hold points and radiation work permit requirements which will effect turnaround time.

C.1.2.1 Cask Receiving

C.1.2.1.1 Incoming search and inspection

C.1.2.1.2 Open sunshield/personnel barrier

C.1.2.1.3 Incoming radiation survey

C.1.2.1.4 Etc. 2 hours

C.1.2.2 Cask Preparation On Rail Car

C.1.2.2.1 Place railcar in airlock

C.1.2.2.2 Remove impact limiters

C.1.2.2.3 Install rotating device

C.1.2.2.4 Rotate cask vertical

C.1.2.2.5 Install dual lifting device

C.1.2.2.6 Lift cask to decon pad

C.1.2.2.7 Etc. 6 hours

C.1.2.3 <u>Cask Preparation On Decon Pad</u>

C.1.2.3.1 Remove road dirt

C.1.2.3.2 Vent cask

C.1.2.3.3 Fill cask with water

C.1.2.3.4 Unbolt cask lid

C.1.2.3.5 Engage yoke and cask lid lifting bolts

C.1.2.3.6 Etc. 4 hours

C.1.2.4 <u>Load Cask</u>

C.1.2.4.1 Lower cask into pool

C.1.2.4.2 Disengage yoke and remove cask lid

C.1.2.4.3 Install seal surface protector on cask

C.1.2.4.4 Load cask with spent fuel (10 minutes a bundle)

C.1.2.4.5 Inspect o-rings on cask lid

C.1.2.4.6 Remove seal surface protector from cask

C.1.2.4.7 Replace cask lid on cask

C.1.2.4.8 Engage yoke to cask and place cask on decon pad

C.1.2.4.9 Etc. 14 hours

C.1.2.5 Cask Preparation On Decon Pad

C.1.2.5.1 Decon cask

C.1.2.5.2 Torque cask lid bolts

C.1.2.5.3 Drain cask, inert and verify that water is drained

C.1.2.5.4 Preform leak tests

C.1.2.5.5 Etc. 12 hours

NOTE: If vacuum drying is used, an additional 16 hours would be required and would be done during step C.1.2.5.3. (Based on NUHOMS experience at CP&L Robinson, 12 to 16 hours with the IF-300.)

C.1.2.6 Load Casks On Rail Car

C.1.2.6.1 Engage yokes

C.1.2.6.2 Lower cask to rail car

C.1.2.6.3 Remove one yoke

C.1.2.6.4 Rotate cask to horizontal

C.1.2.6.5 Disengage yoke

C.1.2.6.6 Decontaminate cask as required

C.1.2.6.7 Etc. 4 hours

C.1.2.7 <u>Preparation Of Cask For Shipment</u>

C.1.2.7.1 Remove tilting device from rail car

C.1.2.7.2 Install impact limiters

C.1.2.7.3 Move cask to outside airlock

C.1.2.7.4 Take final survey and install labels

C.1.2.7.5 Install sunshield/personnel barrier

C.1.2.7.6 Install placards

C.1.2.7.7 Prepare shipping papers

C.1.2.7.8 Etc. 4 hours

Total 46 hours

C.1.3 Turnaround Time Estimate At A PWR Reactor With A Single Yoke

NOTES:

1. Etc. is for the performance of the minor tasks such as removal of valve covers, wetting down the cask while placing in pool, and/or removing and installing of safety wire.

2. Continuous operation is assumed. (No time allowed for shift change or breaks.)

3. It is assumed that the operations are performed by an experienced crew using special tooling.

4. Turnaround time is dependent upon specific methods of operation at a given utility, such as site specific hold points and radiation work permit requirements which will effect turnaround time.

C.1.3.1 Cask Receiving

C.1.3.1.1 Incoming search and inspection

C.1.3.1.2 Open sunshield/personnel barrier

C.1.3.1.3 Incoming radiation survey

C.1.3.1.4 Etc. 2 hours

C.1.3.2 Cask Preparation On Rail Car

C.1.3.2.1 Place rail car under crane

C.1.3.2.2 Remove impact limiters

C.1.3.2.3 Install rotating device

C.1.3.2.4 Rotate cask vertical

C.1.3.2.5 Lift cask to decon pad

C.1.3.2.6 Etc. 5 hours

C.1.3.3 <u>Cask Preparation On Decon Pad</u>

C.1.3.3.1 Remove road dirt

C.1.3.3.2 Vent cask

C.1.3.3.3 Fill cask with water

C.1.3.3.4 Unbolt cask lid

C.1.3.3.5 Engage yoke and headlifting bolts

C.1.3.3.6 Etc. 4 hours

C.1.3.4 <u>Load Cask</u>

C.1.3.4.1 Lower cask into pool

C.1.3.4.2 Remove cask lid

C.1.3.4.3 Install seal surface protector on cask

C.1.3.4.4 Load cask with spent fuel (10 minutes a bundle /21 bundles)

C.1.3.4.5 Inspect o-rings on cask lid

C.1.3.4.6 Remove seal surface protector from cask

C.1.3.4.7 Replace cask lid on cask

C.1.3.4.8 Engage yoke to cask and place cask on decon pad

C.1.3.4.9 Etc. 10 hours

C.1.3.5 Cask Preparation On Decon Pad

C.1.3.5.1 Decon cask

C.1.3.5.2 Torque cask lid bolts

C.1.3.5.3 Drain cask, inert and verify that water is drained

C.1.3.5.4 Preform leak tests

C.1.3.5.5 Etc. 12 hours

NOTE: If vacuum drying is used, an additional 16 hours would be required and would be done during step C.1.2.5.3. (Based on NUHOMS experience (12 to 16 hrs with the IF-300.)

C.1.3.6 Load Casks On Rail Car

C.1.3.6.1 Engage yokes

C.1.3.6.2 Lower cask to rail car

C.1.3.6.3 Rotate cask to horizontal

C.1.3.6.4 Disengage yoke

C.1.3.6.5 Decontaminate cask as required

C.1.3.6.6 Etc. 3 hours

C.1.3.7 Preparation Of Cask For Shipment

C.1.3.7.1 Remove tilting device from rail car

C.1.3.7.2	Install impact limiter	
C.1.3.7.3	Move cask to outside	
C.1.3.7.4	Take final survey and install labels	
C.1.3.7.5	Install sunshield/ personnel barrier	
C.1.3.7.6	Install placards	
C.1.3.7.7	Prepare shipping papers	
C.1.3.7.8	Etc.	<u>4 hours</u>
	Total	40 hours

C.1.4 Turnaround Time Estimate Using A Hot Cell

NOTE:

1. Etc. is for the performance of the minor tasks such as removal of valve covers, wetting down the cask while placing in pool, or removing and installing of safety wire.

2. Turnaround time is based on use of a cask work station where lid unbolting, lid bolting, venting, spot deconning cask, leak testing, etc, is performed.

3. It is assumed that a transfer dolly is used for moving the Cask to the Hot Cell Opening.

4. This estimate is for unloading 52 BWR fuel assemblies at 5 minutes a assembly unloading time. For PWR unloading, the turnaround time would be reduced by 2.5 hours for PWR unloading since only 21 fuel assemblies are unloaded.

C.1.4.1 Cask Receiving

C.1.4.1.1 Incoming inspection

C.1.4.1.2 Open sunshield/personnel barrier

C.1.4.1.3 Incoming radiation survey

C.1.4.1.4 Etc. 1.5 hours

C.1.4.2 Cask Preparation On Rail Car

C.1.4.2.1 Place rail car under crane

C.1.4.2.2 Remove impact limiters

C.1.4.2.3 Install rotating device

C.1.4.2.4 Rotate cask vertical

C.1.4.2.5 Move cask to cask work station

C.1.4.2.6 Etc. 3 hours

C.1.4.3 <u>Cask Preparation At Work Station</u>

C.1.4.3.1 Vent cask

C.1.4.3.2 Unbolt cask lid

C.1.4.3.3 Install cask lid lifting fixtures

C.1.4.3.4 Place cask on transfer dolly 2.5 hours

C.1.4.4 <u>Cask Unloading In Hot Cell</u>

C.1.4.4.1 Place cask under Hot Cell opening

C.1.4.4.2 Engage cask to Hot Cell and seal

C.1.4.4.3 Engage crane hook to lid lifting fixture

C.1.4.4.4 Remove cask lid

C.1.4.4.5 Unload fuel assemblies

C.1.4.4.6 Use remote viewing device and inspect o-ring seals

C.1.4.4.7 Install cask lid and disengage crane hook

C.1.4.4.8 Disengage cask from Hot Cell

C.1.4.4.9 Move cask from Hot Cell

C.1.4.4.10 Etc. 6.5 hours

C.1.4.5 Cask Preparation At Work Station

C.1.4.5.1 Torque cask lid bolts

C.1.4.5.2 Decon cask if required (note: casks do weep in transit).

C.1.4.5.3 Preform leak tests if residue in cask is greater then Type A quantity (for large cas -his may be true after 5 or 6 loads)

C.1.4.5.4 Etc. 4 hours

C.1.4.6 Load Casks On Rail Car

C.1.4.6.1 Engage yoke to cask

C.1.4.6.2 Move cask to rail car

C.1.4.6.3 Rotate cask to horizontal

C.1.4.6.4 Disengage yoke

C.1.4.6.5 Etc. 1 hour

C.1.4.7 Preparation Of Cask For Shipment

C.1.4.7.1 Remove tilting device

C.1.4.7.2 Install impact limiters

C.1.4.7.3 Move cask to outside (away from any background radiation)

C.1.4.7.4 Take final survey and label

C.1.4.7.5 Install sunshield/personnel barrier

C.1.4.7.6 Prepare shipping papers (Note: Placards are not normally required for empty Cask).

C.1.4.7.7 Etc. 2 hours

BWR Total 20.5 hours
PWR Total 18.0 hours

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C.2.0 SAFETY COMPLIANCE

C.2.1 Introduction

This section is designed to recap and summarize the report in light of the safety requirements of 10 CFR 71, Subpart C and 49 CFR 173.

C.2.2 10 CFR 71

C.2.2.1 General Standards for All Packaging

C.2.2.1.1 No Internal Reactions

The cask surfaces and the outer surfaces of the fuel baskets are stainless steel. This material does not react with steam or water either chemically of galvanically. The fuel is designed to be nonreactive in waterfilled systems. The lead gamma shielding is totally clad in stainless steel. The entire shipping package in chemically and galvanically inert.

C.2.2.1.2 Positive Closure

The 140-B cask head is held in place by 32 closure bolts. The mating surfaces are sealed with two (2) O-rings. Two tapered guide pins ensure proper head alignment during lid installation.

C.2.2.1.3 Lifting Device

The lifting devices of both the cask and the cask lid are capable of supporting three times their respective design loads without generating stresses in excess of their yield strengths. The cask design is such that there are no possible lifting points other than those intended. In addition, the failure of any of the intended lifting structures will not result in a redistribution of shielding or a loss of cask integrity.

C.2.2.1.4 Tie Down Devices

Both the front and rear cask supports are capable of sustaining the combined 10 g longitudinal, 5 g transverse and 2 g vertical forces without generating stresses in excess of their yield strengths.

The cask is designed to have only one tiedown method. The failure of either, or both supports will not impair the ability of the package to meet all other requirements. There will be no shielding redistribution or loss of cask integrity.

C.2.2.2 Structural Standards for Large Quantity Shipping

C.2.2.2.1 Load Resistance

With the package considered as a simple beam loaded with five times its own weight, the cask body outer shell safety factors in shear and bending are sufficiently large such that the stresses do not exceed allowables.

C.2.2.2.2 External Pressure

When subjected to an external pressure of 284 psig, (200 meter submergence) the package outer shell safety factors in elastic stability and axial failure exceed unity, based on allowable stresses.

C.2.2.3 Criticality Standards for Fissile Material Packages

C.2.2.3.1 Maximum Credible Configuration

Fuel element spacing is provided by the fuel baskets. The stress analysis of Section 2.0 shows that during accident conditions there is no redistribution of fuel. The normal transport arrangement is the maximum credible configuration.

C.2.2.3.2 Optimal Moderation

The criticality analysis of Section 6.0 shows that the water filled cask is the most reactive configuration. There is a significant reduction in k_{eff} as the water density is reduced.

C.2.2.3.3 Fully Reflected

The criticality analysis used full reflection as part of calculation. The presence of lead as a shield makes the cask highly reflective by design.

C.2.2.3.4 Results

Calculations show that both of the reference design fuel loadings have a k_{eff} of less than 0.95 under the above conditions. Both the BWR and PWR baskets require criticality control. This is accomplished by using neutron absorbing material as part of the basket structure.

C.2.2.4 Evaluation of a Single Package

The)-B spent fuel shipping cask is being designed for both the normal transport and hypothetical conditions of 10 CFR 71. The effects of these conditions are being evaluated using standard computational techniques. The completed cask will undergo a series of demonstration tests prior to acceptance.

C.2.2.5 Standards for Normal Conditions of Transport for a Single Package

The thermal analysis of Section 3.0 considers the cases of still air. The penetration test and the free drop fall within the accident analysis of Section 2.0. The 140-B cask is so designed that there will be no release of radioactive material.

The analysis of Section 6.0 indicates that even in the most reactive condition, the cask contents remain substantially subcritical. The package and contents geometries remain unchanged under all conditions of transport.

C.2.2.6 Standards for Hypothetical Accident Conditions for a Single Package

Section 2.0 analyzes the effects of a 30-foot free drop and the 40-inch puncture tests on the 140-B cask. Section 3.0 examines the 30-minute fire criteria.

Under the hypothetical accident conditions, the external radiation (gamma and neutron) is less than regulatory requirements. Following the 30-minute fire, no radiation releases are made from the cask.

There is no redistribution of fissile material to a more reactive condition following the hypothetical accident. The Section 6.0 analysis indicates that the normal shipping configuration is the most reactive array. The basic package geometry remains unchanged under the hypothetical accident conditions.

C.2.3 49 CFR 173

C.2.3.1 General Packaging Requirements

The 140-B cask in meeting the requirements of 10 CFR 71 also complies with the criteria of 49 CFR 173. Article 173.393 limits the cask dose rate at six feet from the nearest accessible surface to 10 mr.hr. Section 5.0 shows that this criteria is adequately met.

All cask losure bolts will be safety red prior to shipment. In addition, enclosure panels will be locked in place during transit.

Under the normal shipping conditions, the nearest accessible surface temperature remains below regulatory limits.

C.2.4 Basic Components (Safety Related)

Certain components and structures of the 140-B cask are safety related and as such will be identified as Basic Components. A listing of Basic Components for the 140-B cask will be developed during final design.

SECTION C.3.0

TRADE OFF STUDIES

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Section

C.1.0 Introduction

The design of the NuPac 140-B shipping cask has been optimized for the design conditions described in the preliminary design report. In order to assess the potential impacts of shipping fuel with different characteristics, a series of six tradeoff studies has been performed. The effects on cask capacity and cost have been evaluated for the following cases:

1. Allowance of fuel burnup credit for criticality evaluations.

2. Reduction of the allowable 2-meter dose rate from 10 mrem/hr to 2 mrem/hr

3. Transportation of fuel aged 5 years after discharge versus design basis 10 year cooled fuel

4. Transportation of high burnup fuel

5. Transportation of consolidated fuel assuming consolidation ratios ranging from 1.2:1 to 2.0:1

6. The effects of nonstandard and failed fuel and nonfuel-bearing components (NFBC) on cask payloads

This appendix describes the methodology and results of the tradeoff studies.

C.2.0 Assumptions

The tradeoff studies are performed assuming that the cask body baseline design is frozen and only the basket design may be modified to accept different fuel or fuel arrangements. Baseline design limits must not be exceeded as a result of alternate fuel loading. The following list summarizes the major assumptions:

1.) The 140-B cask body design is fixed.

2.) The basket design may be altered to accommodate different fuel or fuel arrangements.

3.) The design basis fuel heat load must not be exceeded.

4.) The design basis radiological source terms must not be exceeded.

5.) Other design basis constraints, such as structural, criticality, and mechanical criteria, must not be exceeded.

C.3.0 Design Constraints

Ultimately, the payload capacity and cost of the cask are driven by the design constraints placed upon the system. The following sections summarize the important design constraints which bear on this evaluation. Discussion is presented regarding the effects of the design tradeoffs on each engineering discipline.

The discussion of design constraints is divided into the major engineering disciplines which may impact cask capacity or cost: structural, thermal, shielding, criticality, and mechanical. Table 1 contains a matrix which indicates which discipline is considered limiting, or potentially limiting, for each of the tradeoff scenarios.

C.3.1 Structural Design Constraints

The structural design of the cask and basket is limited by the allowable stresses in each material of construction. Since most of the tradeoff studies involve a reduction in the number of fuel assemblies which can be shipped, structural design margins will not be reduced. The exception to this is the case of consolidated fuel shipment, which will be discussed below.

C.3.2 Thermal Design Constraints

The baseline maximum decay heat for either 21 PWR assemblies or 52 BWR assemblies is 11 Kw. Changes to fuel specification parameters which increase the fuel decay heat will result in decreases to the cask payload in order to maintain existing design margins for fuel cladding and other materials temperatures.

The two fuel specification parameters which most affect the thermal output of the payload are the fuel post-irradiation cooling time and the fuel burnup. Design basis fuel specification parameters are listed in Table 2.

The fuel decay heat generation rates, in units of Kw/Metric Tons of Initial Heavy Metal (MTIHM) are shown in Table 3 for a variety of combinations of burnup and fuel cooling times.

C.3.3 Shielding Design Constraints

The baseline radiological source strengths for PWR and BWR assemblies are Table 4. Changes to fuel specification parameters which increase the fuel radiological source term will result in decreases to the cask payload in order to maintain existing design margins for cask dose rates.

The two fuel specification parameters which most affect the radiological source strength are closely tied to the thermal power: fuel post-irradiation cooling time and the fuel burnup. The design basis fuel specification parameters were listed above in Table 2.

The fuel radiological sources, in units of neutrons or gammas per second per MTIHM for design basis fuel are shown in Table 4. By changing the burnup or cooling time, the design basis sources are changed as shown in Table 5 (neutrons) and Table 6 (gammas).

C.3.4 Criticality Design Constraints

The cask and basket are designed to assure that under no credible event will the reactivity of the payload, k_{eff}, exceed 0.95. The calculation of k_{eff} is dependent on several key assumptions.

The calculation of k_{eff} may be performed assuming that the fuel is in its most reactive state (unirradiated), or the properties of irradiated fuel, which is less reactive, may be used. The latter approach is referred to as using burnup credit and is the topic of one of the tradeoff studies.

When burnup credit is used, the fuel burnup and cooling time become important parameters. Otherwise, they do not impact the calculation of k_{eff}. For all cases, the basket geometry, initial enrichment of the fuel, fuel type, and so forth are the parameters which affect the reactivity.

For these impact evaluations, criticality becomes a limiting factor only for the case of miscellaneous fuel types or the storage of nonfuel bearing components (NFBC) in which case the design fuel/moderator volume may be affected.

C.3.5 Mechanical Design Constraints

Mechanical design constraints such as the weight of the basket and fuel, or the dimensions of the cask cavity limit the number of fuel assemblies which may be shipped. Table 7 lists the mechanical design constraints relevant to the tradeoff studies.

Mechanical design constraints do not limit the cask capacity for the tradeoff study cases where the number of fuel assemblies must be reduced to meet thermal or shielding criteria. The exceptions to this are the cases of consolidated fuel shipment and irregular fuel, which will be discussed below.

C.4.0 Cask Capacity Impact Evaluations

C.4.1 Capacity Effects of Burnup Credit

By utilizing burnup credit, it is possible to accept either more fuel assemblies or fuel which is more highly reactive (higher U235 enrichment). The preliminary design analysis included burnup credit calculations where it was determined that by taking credit for fuel burnup, the PWR basket capacity could be maintained at 21 assemblies for up to 4.5% initial enrichment fuel.

Due to mechanical, thermal, structural, and shielding constraints, however, increases in package capacity are not feasible with the use of burnup credit.

C.4.2 Capacity Effects of Reduced Surface Dose Rate

10CFR71 specifies the design criteria that the dose rate at 2 meters from the cask surface shall not exceed 10 mrem/hr. To reduce this dose rate, the cask's radiological source term must be reduced.

Since the dose rate is directly proportional to the neutron and gamma source strength, the source strength required to meet a design requirement of 2 mrem/hr maximum dose rate at 2 meters will be 1/5 that which yielded 10 mrem/hr. The approach of this evaluation will be to achieve the reduction in source strength by reducing the number of fuel assemblies to be transported within the cask.

The impact evaluation was performed for the baseline design cases plus several variations in fuel burnup and fuel cooling time which will be discussed below. The results of the evaluation are provided in Table 8 (10 mrem/hr case) and Table 9 (2 mrem/hr case). For the design basis fuel parameters, it can be seen that the PWR capacity must be reduced from 21 to 4 or 5 assemblies in order to achieve the lower dose rate. The BWR capacity must be reduced from 52 to between 16 or 17 assemblies. Note that the information in Table 8 and Table 9 also involves the effects of reduced fuel cooling time and extended burnup. These items will be discussed in the following two sections.

One alternative strategy for lowering the exterior dose rate without suffering a capacity penalty is to load low burnup, high cooling time fuel on the perimeter of the cask. The self shielding effects of the cooler fuel assemblies would reduce exterior exposures at the expense of additional administrative controls rather than reduced capacity.

C.4.3 Capacity Effects of Reduced Fuel Cooling Time

Reducing the design basis fuel cooling time from the 10 years to 5 years results in increased thermal and radiological source terms. This reduces the number of fuel assemblies which may be shipped without exceeding shielding or thermal constraints.

Table 8 provides the capacities for a 10 mrem/hr cask with reduced cooling time fuel. Changing the fuel cooling time from the design basis 10 years to 5 years results in a decrease from 21 to 14 PWR assemblies and from 52 to 43 BWR assemblies.

Table 9 provides similar information for the reduced dose rate cask.

C.4.4 Capacity Effects of High Burnup Fuel

The effects of shipping high burnup fuel are similar to the effects of reduced fuel cooling time in that the radiological and thermal source strengths are both increased. These increases reduce the potential number of fuel assemblies that may be shipped without exceeding the design margins.

Refer to the results presented above in Table 8 and Table 9 which include high burnup fuel. By changing the design basis PWR fuel from 35,000 to 60,000 MWd/MTU, the capacity is decreased from 21 to 9 or 10 assemblies. Likewise, changing the design basis BWR fuel from 30,000 to 50,000 MWd/MTU, the capacity is decreased from 52 to 34 assemblies.

C.4.5 Capacity Effects of Consolidated Fuel

In order to determine the impact of shipping consolidated fuel, an analysis was prepared based on thermal and shielding constraints. The radiological analysis was performed assuming that only fuel rods were included as consolidated fuel. All the neutron source and 90% of the gamma source terms were assumed to be present in the fuel rods. Calculations determined that approximately 10% of the gamma inventory would be present in the NFBC and thus was not included in the fuel rods. All the heat source was assumed to be present in the fuel rods.

Consolidation ratios of 1.2:1 and 2.0:1 were analyzed to determine for each case the maximum number of fuel assemblies which could be shipped in the cask. The results are presented in Table 10 (1.2:1 ratio) and Table 11 (2.0:1 ratio). The number of assemblies should be interpreted as the number of assemblies prior to consolidation. As in the previous tradeoff studies, a range of fuel burnup and cooling times is presented.

C.4.6 Capacity Effects of Nonstandard/Failed Fuel, NFBC

The baseline design cask and baskets are not designed to ship the several non-standard fuel types which are described in Section 1.3.13.1 of the PDR.

Failed fuel may be shipped provided that it is suitably overpacked in a manner which does not exceed the design constraints. The overall cask capacity would not be impacted unless a basket redesign is necessary for mechanical reasons or criticality design margins are impacted.

The shipment of NFBC is feasible provided that the material is suitably canisterized. Since the NFBC material has lower thermal and radiological sources than design basis fuel, there is no impact on cask capacity.

C.5.0 Cask Cost Impact Evaluations

Cost impact evaluations are made for each of the tradeoff study cases by estimating the cost savings or burdens which would be imposed by changes in the basket design. Since one premise of the tradeoff studies are that the design of the cask body remains frozen, the only hardware costs would be associated with the basket or basket interfaces.

The evaluations are made using a baseline fabrication cost estimate of $445k and $595k for the PWR and BWR basket assemblies, respectively. The baseline PWR basket cost is split 80/20 of which 80% is a cost per storage cell which may be factored according to the number of storage locations or by differences in per cell material costs. The baseline BWR basket cost is split 60/40 of which 60% is a cost per storage cell. Costs per storage cell are assumed to be 70% materials and 30% labor. Furthermore, it is assumed that a flat amount of $80k in engineering and fabrication setup costs would be incurred for any change to a basket design.

C.5.1 Cost Impact of Burnup Credit

By taking burnup credit, it would be possible to reduce or eliminate the neutron poison from the basket design. Assuming that basket cell material savings would be 90% for the PWR basket and 70% for the BWR basket, the estimated cost savings which could be achieved by taking burnup credit are $224k for the PWR design and $175k for the BWR design as compared to the baseline basket costs.

C.5.2 Cost Impact of Reduced Surface Dose Rate

There would be no cost impact due to reducing the design 2-meter dose rate from 10 to 2 mrem/hr if a staggered fuel loading pattern is employed or if relatively cool fuel assemblies were loaded around the perimeter of the cask in order to reduce the surface dose rates.

C.5.3 Cost Impact of Reduced Fuel Cooling Time

There would be no cost impact due to reducing the design fuel cooling time from 10 years to 5 years if a staggered fuel loading pattern is employed or if relatively cool fuel assemblies were loaded around the perimeter of the cask in order to reduce the surface dose rates.

C.5.4 Cost Impact of High Burnup Fuel

There would be no cost impact due to increasing the design fuel burnup if a staggered fuel loading pattern is employed or if relatively cool fuel assemblies were loaded around the perimeter of the cask in order to reduce the surface dose rates.

C.5.5 Cost Impact of Consolidated Fuel

The shipment of consolidated fuel would require modifications to the existing fuel baskets in order to maintain structural safety margins. Since consolidation would reduce the number of fuel locations in the cask, basket costs would be reduced. The estimated cost impact for a 1.2:1 consolidation ratio basket is a cost savings of $102k for PWR fuel and $55k for BWR fuel as compared to the baseline basket costs. For a 2.0:1 consolidation ratio, the basket cost savings are $254k and $247k, respectively.

Case	STR	THE	SHI	CRI	MEC
Burnup Credit	X	X	X		X
Lower Surface Dose			X		
Shorter Cooling Time		X	X		
Higher Burnup		X	X		
Consolidated Fuel	X	X			X
Misc/Failed Fuel, NFBC				X	X

Notes: STR = Structural
THE = Thermal
SHI = Shielding
CRI = Criticality
MEC = Mechanical

Table 1
Design Constraint Matrix

Design Basis Fuel Specification	PWR Fuel	BWR Fuel
Maximum Burnup, MWd/MTU	35,000	30,000
Cooling Time, Months	120	120
Number of Fuel Assemblies	21	52

Table 2
Design Basis Fuel Parameters

Burnup (MWd/MTU)	Fuel Decay Heat, kW/MTIHM			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	0.971	1.420
35,000	1.163	1.787	1.160	1.680
40,000	1.360	2.092	1.380	2.040
45,000	N/E	N/E	1.600	2.400
50,000	1.807	2.766	1.820	2.760
60,000	2.347	3.580	N/E	N/E

N/E = Not Evaluated

Table 3
Fuel Thermal Sources

Design Basis Fuel Radiological Source	PWR Fuel	BWR Fuel
Gamma Ray, #/sec-MTIHM	8.165E+15	6.790E+15
Neutron, #/sec-MTIHM	1.331E+08	9.345E+07

Table 4
Design Basis Fuel Radiological Sources

Burnup (MWd/MTU)	Neutron Source Term, #/sec-MTIHM			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	1.114E+08	9.345E+07
35,000	1.331E+08	1.590E+08	2.374E+08	1.980E+08
40,000	2.553E+08	3.040E+08	4.585E+08	3.811E+08
45,000	4.373E+08	5.262E+08	8.855E+08	5.640E+08
50,000	7.116E+08	8.574E+08	1.710E+09	7.470E+08
55,000	1.075E+09	1.269E+09	N/E	N/E
60,000	1.565E+09	1.889E+09	N/E	N/E

N/E = Not Evaluated

Table 5
Neutron Source Strengths

Burnup (MWd/MTU)	Gamma Source Term, #/sec-MTIHM			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	1.069E+16	6.790E+16
35,000	8.165E+15	1.346E+16	1.231E+16	7.829E+16
40,000	9.361E+15	1.579E+16	1.456E+16	8.957E+16
45,000	1.041E+16	1.741E+16	1.681E+16	1.034E+17
50,000	1.158E+16	1.983E+16	1.906E+16	1.173E+16
55,000	1.255E+16	2.130E+16	N/E	N/E
60,000	1.369E+16	2.373E+16	N/E	N/E

N/E = Not Evaluated

Table 6
Gamma Source Strengths

Mechanical Parameter	Value
Cask Cavity Diameter	57.00 inches
Cask Cavity Length	180.5 inches
Fuel and Basket Weight	52,076 lbs

Table 7
Mechanical Design Parameters

Burnup (MWd/MTU)	Cask Capacity - 10 mrem/hr Cask			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	52	52
35,000	21	14	52	37
40,000	16-17	11-12	45	30
45,000	N/E	N/E	38	26
50,000	14-15	9	34	22
60,000	9-10	6-7	N/E	N/E

N/E = Not Evaluated

Table 8
10 mrem/hr Cask Capacities

Burnup (MWd/MTU)	Cask Capacity - 2 mrem/hr Cask			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	16-17	10-11
35,000	4-5	3	13-14	9
40,000	3-4	2-3	11-12	7-8
45,000	N/E	N/E	10-11	6-7
50,000	3	2	9-10	5-6
60,000	2	1	N/E	N/E

N/E = Not Evaluated

Table 9
2 mrem/hr Cask Capacities

Burnup (MWd/MTU)	Cask Capacity - 1.2:1 Consolidation Ratio			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	52	36
35,000	17	12	43	31
40,000	9	10	38	25
45,000	N/E	N/E	32	22
50,000	7	8	28	18
60,000	5	6	N/E	N/E

N/E = Not Evaluated

Table 10
1.2:1 Consolidation Ratio Capacities

Burnup (MWd/MTU)	Cask Capacity - 2.0:1 Consolidation Ratio			
	10 yr PWR	5 yr PWR	10 yr BWR	5 yr BWR
30,000	N/E	N/E	32	22
35,000	11	7	27	19
40,000	9	6	23	15
45,000	N/E	N/E	19	13
50,000	7	5	17	11
60,000	5	3	N/E	N/E

N/E = Not Evaluated

Table 11
2.0:1 Consolidation Ratio Capacities

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ADDITIONAL TRADE-OFF STUDIES

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1.0 INTRODUCTION

The design of the NuPac 140-B shipping cask has been optimized for the design conditions described in the preliminary design report (PDR) (Reference 1). Additional trade-off studies (Reference 2), which are the subject of this report, were performed to assess the effect on cask capacity for various enrichment, burnup, and decay time assumptions for PWR and BWR spent fuel assemblies. The study considers these variables in a parametric fashion to provide sufficient technical and economic information to support the selection of an optimum cask design basis for final design and NRC certification. The redesign studies to accommodate increased capacity were performed using specific combinations of enrichment, burnup and decay time for the PWR and BWR cask capacities as outlined in Reference 2.

The neutron and gamma radiological source strengths and the decay heat per assembly were determined using the ORIGEN2 computer code (Reference 3). These values were used in the ANISN computer code (Reference 4) to determine the cask shielding thicknesses (neutron and gamma shield) to meet the 10CFR71 requirements for contact dose rate and dose versus distance criteria.

The studies were performed by developing scoping algorithms for the basic cask design parameters as a function of the varying fuel parameters. The resulting shield thicknesses and cask inside diameter were input to the algorithm. Cask system weights and temperatures were outputs from the algorithm. Once these output parameters were determined for the various cask capacities, an economic evaluation was performed to assess the impact on cost and schedule of proceeding with a redesigned cask system. The results are summarized in graphical and tabular form. Presenting the results in this manner permits each of the combinations of burnup, enrichment, and decay time to be independently considered, which ensures ease of interpretation of the results.

The following sections of this report summarize the calculational methodology used to perform the trade-off studies and the results.

2.0 SUMMARY OF CALCULATION METHODS

The computer code ORIGEN2 (Reference 3) is used to determine the neutron and gamma source strengths and the decay heat per fuel assembly for the given parameters. These parameters include the weight percent initial enrichment of U-235, the burnup or fissile material depletion resulting from irradiation, and the decay times following reactor discharge for the PWR and BWR fuel assemblies. Discrete neutron and gamma source strengths are used to determine the total cask neutron and gamma source strengths for shielding evaluation with various cask payloads. These source strengths are used in the computer code ANISN (Reference 4) to determine the optimum neutron and gamma shield layer thicknesses to satisfy the 10CFR71 dose rate limit of 10 mrem/hr at two meters from the cask surfaces which is the limiting condition.

The neutron and gamma shield layer thicknesses were used to calculate the total weight of the cask on the hook and transporter for various cask payloads using the algorithms described in Appendix D. These shield layer thicknesses and the decay heat values from ORIGEN2 results were used to calculate the temperature distribution in the cask layers for various cask payloads using the algorithms described in Appendix C. The following sections describe these calculation methods in more detail.

2.1 Computer Codes Used

ORIGEN2

The ORIGEN2 code (Reference 3) computes the concentrations and radioactivity of fuel assemblies which undergo irradiation in a nuclear reactor and decay after removal from the reactor core. It has the ability to compute the isotopic fractions, radioactivity, decay thermal power, toxicity, neutron absorption, neutron emission, and photon emission for various isotopes in the fuel assembly.

ORIGEN2 is applicable to spent fuel shipping package analysis for developing neutron and gamma radioactive decay source strengths to be used in shielding analysis, and to provide thermal energy generation rates for use in thermal analysis. ORIGEN2 is an industry standard code which is supplied by Oak Ridge National Laboratory's Radiation Shielding Information Center (ORNL/RSIC).

ANISN

The ANISN code (Reference 4) solves the one-dimensional Boltzmann transport equations for neutrons and/or gamma rays in a slab, spherical, or cylindrical geometry. The source may be fixed, fission, or a subcritical combination of the two. Cross-sections may be weighted using the space and energy dependent flux generated in solving the transport equation.

The ANISN code was designed to solve deep penetration problems in which angle-dependent spectra are calculated in detail. ANISN includes a technique for handling general anisotropic scattering, point-wise convergence criteria, and alternate step function difference equations that effectively remove the oscillating flux distributions sometimes found in discrete ordinates solutions.

ANISN is suitable for parametric studies of spent fuel shipping package geometries. A limitation of ANISN is its inability to model multi-dimensional geometries, especially streaming paths, however, it is well suited for this trade-off study considering the assumptions described in Section 2.3. ANISN is an industry standard code available through ORNL-RSIC.

2.2 Description of Trade-off Study Algorithms

The algorithms for the trade-off study were developed in the form of a LOTUS 123® Release 2.2 worksheet. Two worksheets were developed. The first worksheet called "RADIALTH.WK1" provides a fast and simple method of calculating the radial steady-state temperature distribution of a multi-layered cask containing spent fuel. The worksheet uses a one-dimensional thermal resistance technique to calculate the temperature distribution through the cask wall. The use of the worksheet, the calculation method used with the associated equations, the worksheet program flow, worksheet modification guidelines, sample problems, and the LOTUS 123® cell listing of the worksheet along with the thermal property library for various cask materials is provided in Appendix C.

A second worksheet called "140B-WT.WK1" calculates the weight of the cask. It calculates the maximum weight of the cask on the crane hook and the maximum shipping weight of the cask for different numbers of fuel assembly capacities and different thicknesses of shielding materials. The use of the worksheet, calculation techniques, and the LOTUS 123® worksheet with the formulas used is provided in Appendix D. The user has the option of linking this weight worksheet to the temperature worksheet described in Appendix C. When linked together, the weight worksheet will use the values of various cask layer thicknesses from the temperature worksheet internally without being input by the user. Appendix D describes this option in detail.

2.3 Key Assumptions

The key assumptions used in this trade-off study are described below.

A. The enrichment, burnup, and decay times combinati[on] cases considered are those that were described in the NuPac proposal (Reference 2).

B. Criticality calculations and structural analysis were not a part of this trade-off study (Reference 2).

C. The cask system must meet the requirements of 10CFR71 for shielding criteria.

D. The cask shielding requirements were developed using the cask internal cavity and basket dimensions based on the preliminary design report results (Reference 1). These parameters are used to define the homogenized source region in the cask internal cavity. Since the principal shielding is provided by the shielding layers in the cask, min changes to the basket and internal cavity dimensions will have insignificant impact on the overall results of these trade-off studies.

E. The neutron and gamma source terms are based on the fixed basket diameter, length, and weight from the Reference 1 design. Similar to assumption D above, minor changes to these parameters will have insignificant impact on the overall results of these trade-off studies.

F. The fuel assembly structural material weights and composition are similar to the BWR and PWR fuel assemblies modeled in Reference 5.

G. The modeling methodology for ANISN computer models is the same as Reference 1.

H. The shielding requirements for the cask top and bottom end were not a part of this trade-off study. Based on the results of the PDR (Reference 1), the two meter radial dose was bounding for both axial and radial directions. Although the axial shielding requirements will also increase for higher burnup, lower decay times cases, since they constitute only 15% of the total cask system weights, they will not have major impact on the results of these trade-off studies.

I. The total weight of the cask is calculated assuming constant values for the cask top and the bottom end pieces based on the Reference 1 values. Section 2.4.4 describes the basis for this assumption.

J. The cross-section data set used for the BWR ORIGEN analysis for higher burnup cases is taken from Reference 5, which gives only one cross-section data set for all burnup cases. Additional cross-section data sets under development by the Oak Ridge National Laboratories (ORNL) were not available or approved at the time of this trade-off study.

2.4 Supporting Calculations

This section describes the various calculations performed to support this trade-off study.

2.4.1 Calculation of Neutron and Gamma Source Strengths and Decay Heat Using ORIGEN2 Computer Code

The input to the ORIGEN2 computer code for the PWR fuel source strength calculation was a generic 17x17 Westinghouse standard PWR fuel assembly. The specific power and shutdown periods were the same as those specified in Reference 5. Appendix A.1 shows the fuel assembly material weights used in the ORIGEN2 computer code models. Appendix A.2 shows a typical ORIGEN2 input file prepared using these inputs.

For the BWR fuel source strength calculations, a General Electric 8x8 BWR fuel assembly was used as input to the ORIGEN2 computer code. The specific power and shutdown periods were the same as those specified in Reference 5. Appendix A.1 shows the fuel assembly material weights used in the ORIGEN2 computer code models. Appendix A.2 shows a typical ORIGEN2 input file prepared using these inputs.

The output from the ORIGEN2 code is the neutron and gamma source strengths and decay heat per fuel assembly for the top nozzle, gas plenum, bottom nozzle, and in-core regions of the fuel assembly. Additional output was also obtained including the source strengths and decay heat for the total "WHOLE" fuel region which includes the sum of the individual fuel assembly regions described above. For the cask shielding and thermal analysis, the values for the "WHOLE" regions are conservatively used in the radial shielding and thermal calculations. Section 6.0 summarizes the results of these ORIGEN2 runs in tabular form. Tables 6.1 through 6.4 show the neutron and gamma source terms for one fuel assembly for various burnups, cooling times, and enrichments. The gamma source strength and the decay heat (Tables 6.5 and 6.6) are the sum of activation products, actinides plus daughters, and fission product source terms for each region of the fuel assembly. The neutron source term is the sum of neutrons generated due to (alpha, n) reactions and spontaneous fission neutron sources in the fuel assembly.

Figures 6.1 through 6.3 show typical gamma energy spectrums for BWR fuel assembly with 3% initial U235 enrichment and 30,000 MWD/MTIHM burnup for 5, 10, and 15 year decay times respectively. Figures 6.4 through 6.6 show typical gamma energy spectrum for PWR fuel assembly with 3% initial U235 enrichment and 35,000 MWD/MTIHM burnup for 5, 10, and 15 years decay times respectively. Figures 6.7 and 6.8 show the plots of decay heat per fuel assembly versus decay times for various burnups of BWR and PWR fuel assemblies respectively.

2.4.2 Calculation of Shield Thicknesses Using ANISN Computer Code

Using the neutron and gamma source strengths and the photon spectra from ORIGEN2 outputs, ANISN models are prepared to calculate the neutron and gamma dose rate at the cask surface and two meters from the cask surfaces. The methodology for ANISN modeling is the same as that described in Reference 1. The cross-section data set (DLC-23, Reference 6) was the same as that used in Reference 1. The "CASK" DLC-23 cross-section library data set contains coupled 22 neutron and 18 gamma ray energy groups. The P1S8 quadrature data set was also used with cylindrical geometry in the ANISN models. A sample ANISN input file for PWR and BWR fuel is included in Appendix B. For BWR and PWR fuels the Appendix B input files do not show the entire 14* array (the cross-section data) due to the voluminous nature of the cross-section data. The flux-to-dose conversion factors are the same as those used in Reference 1.

ANISN runs were made with various thicknesses of gamma and neutron shields to determine the optimum shield thicknesses for a given burnup, cooling time, and initial enrichment of the given fuel with various numbers of fuel assemblies per cask. The dose rate of 10 mrem/hr at two meters from the cask surfaces was the limiting criteria for the shielding analysis. The neutron and gamma shield layer thickness were chosen such that the total dose at two meters from the cask surface was less than 10 mrem/hr for the given cask payload. Section 6.0 summarizes the results of these ANISN runs in tabular form. Tables 6.7 and 6.8 show the gamma and neutron shield layer thicknesses required for a given burnup, initial enrichment, cooling time, and cask payload. These shield thicknesses yield a total dose at two meters from the cask surface of less than 10 mrem/hr, thus satisfying the 10CFR71 shielding requirements.

2.4.3 Calculation of Cask Outer Surface and Cask Inner Shell Temperatures

Using the decay heat values from Section 2.4.1 and the cask shielding (neutron and gamma) thicknesses from Section 2.4.2, the algorithms described in Appendix C were used to determine the temperature distribution through the various cask layers.

The ambient temperature was conservatively assumed to be 130°F and the maximum solar heat flux on the cask outside surface was 125 Btu/hr. ft^2 per the requirements of 10CFR71. Section 6.0 summarizes the results of these calculations. Tables 6.9 and 6.10 show the cask outside surface temperature and the cask inner shell temperature for the various combinations of parameters. Figures 6.9 and 6.10 show typical temperature distribution through various cask layers with BWR and PWR baskets respectively. Figures 6.11 and 6.12 show cask outer surface temperature as a function of total cask cavity heat load for BWR basket with 52 fuel assemblies and PWR basket with 21 fuel assemblies respectively.

2.4.4 Calculation of Cask Outside Diameter and Total Hook Weight

The shielding material thicknesses from Section 2.4.2 were used to calculate the cask outside diameter for various configurations. The algorithms described in Appendix D were used to calculate the cask total hook weight. The weights of the cask top and bottom end pieces (i.e. bottom closure plate, bottom neutron shield, bottom inner disk, top closure plate, top neutron shield, top inner disk, basket) lift fixtures and impact limiters which are assumed to be the same as those of Reference 1 values for this trade-off study. Note that when the cask outside diameter is increased to accommodate thicker neutron and/or gamma shields, the weights of some of the components above will change. These changes were not a part of this trade-off study. This will not have a significant impact on the results of this trade-off study because the weights of the top and bottom end pieces only account for approximately 15% of the total cask hook weight. Section 6.0 summarizes the results of these calculations. Tables 6.11 and 6.12 show the cask outside diameter and the total weight of the cask on the hook for various combinations of parameters. Figures 6.13 and 6.14 show a plot of total cask hook weight as a function of total gamma source strength in the cask inner cavity for BWR and PWR baskets respectively.

3.0 DESCRIPTION OF REDESIGNED CASK SYSTEM

The redesigned cask systems are assumed to be the same as the design basis cask system described in Reference 1 for purposes of this study except for the cask shield thicknesses, weight, and outside diameter. The cask internal fuel basket designs are assumed to be the same except for the number of spent fuel cells; i.e., cask payload. The shield thicknesses, weights, and outside diameters for the various combinations of cask capacity, initial enrichment, burnup, and decay time considered in the trade-off studies are presented in Tables 6.7, 6.8 and 6.11 through 6.12.

4.0 CASK CAPACITIES FOR REDESIGN AND DOWNRATED CASES

The design basis cask capacity is 21 fuel assemblies for the PWR basket and 52 fuel assemblies for BWR basket. The cask capacities for the redesign and downrated cases considered in this trade-off study are as follows:

PWR Basket		BWR Basket	
Redesign	Downrated	Redesign	Downrated
26	6	64	24
	12		32
	18		48

5.0 COST AND SCHEDULE IMPACT TO PROCEED WITH REDESIGN

Cost impact evaluations are made for each of the trade-off study cases by estimating the cost savings or burdens which would be imposed by changes in the cask design. The changes considered are limited to changes in cask outside diameter, shield layer weights, and capacity. Cask capacity changes are limited to changes in the number of cells in the fuel basket. Since changes to cask diameter and weight are caused by shield thickness changes, the cost impact of cask diameter, weight, and shield thickness changes are considered a function of shield thickness changes only. Cost impact evaluations were not made for the trade-off study cases where the maximum allowable hook weight of 200,000 pounds is exceeded. Also, since the cask body for the BWR and PWR baskets is assumed to be the same, the BWR and PWR base case cask shield thicknesses are assumed to be the same. Therefore, if the calculated required BWR cask shield thickness is equal to or less than the PWR base case thickness of 3.5 inches, a value of 3.5 inches is assumed for the cost and schedule impact evaluation.

The cost impact evaluations are made using baseline fabrication cost estimates from the preliminary design report (Reference 1) as follows:

Item	PWR	BWR
Cask Body	$1,736K	$1,736K
Fuel Basket	$ 445K	$ 595K

The baseline PWR basket cost is split 80/20 of which 80% is a cost per storage cell which may be factored according to the number of storage locations. The baseline BWR basket cost is split 60/40 of which 60% is a cost per storage cell. Furthermore, it is assumed that a flat amount of $80K in engineering and fabrication set costs would be incurred for any change to the cask.

The baseline BWR and PWR cask body cost is assumed to be 50% materials and 50% labor. The labor costs are considered constant and the shielding material is assumed to represent 20% of the cask body materials costs.

The cost per metric ton of heavy metal which can be shipped in each of the cask designs considered in the trade-off studies was also evaluated. Since this cost varies inversely with the number of storage cells and thus the fabrication costs, such an evaluation provides a more complete picture of the overall cost impact of cask capacity changes.

The results of the cost impact evaluation are included in Tables 6.13 and 6.14 for each of the cases included in the trade-off studies.

Schedule impact evaluations are made for each of the trade-off study cases by estimating the time savings or delays which would be imposed by changes in the cask design. The cask change items considered for the schedule impact evaluations are the same as those used for the cost impact evaluation.

The baseline fabrication schedule estimates from the preliminary design report (Reference 1) are as follows:

Item	PWR	BWR
Cask Fabrication	50.2 Weeks	50.2 Weeks
Basket Fabrication	30.8 Weeks	30.8 Weeks

There would be no schedule impact due to shield thickness changes in the small range required for the redesign cases considered in these trade-off studies. The schedule impact associated with cask capacity changes are estimated, assuming that 80% of the basket fabrication time is directly proportional to the number of storage cells in the basket. Therefore, for the design base case, 24.6 weeks (30.8 weeks x 80%) would represent the variable basket fabrication time associated the number of fuel storage cells in a 21 element basket.

The results of the schedule impact evaluation are included in Tables 6.13 and 6.14 for each of the cases included in the trade-off studies.

6.0 CONCLUSIONS

The conclusions of the trade-off studies are presented in the Tables 6. 1 through 6.14 and Figures 6.1 to 6.18. As discussed earlier, the results are presented in a form which permits each of the combinations of burnup, enrichment, and decay time to be independently considered, which ensures ease of interpretation of the results.

Tables 6.1 through 6.4 present the neutron and gamma source strengths for one fuel assembly for various burnups, cooling times, and enrichments. Tables 6.5 and 6.6 show the decay heat as a function of burnups, cooling times, and enrichments. These tables are the results of the ORIGEN2 computer runs and are the inputs for the shielding, cask outside diameter, and cask weight evaluations.

Tables 6.7, 6.8, 6.11 and 6.12 present the cask shielding thickness, outside diameter, and weight results as a function of burnup, cooling time, and decay heat. Cask shielding thickness and weight results for all cases considered are presented, although a limit of 200,000 pounds is placed on the cask weight by these trade-off studies.

Tables 6.9 and 6.10 present the cask inner shell and outside surface temperature results for the various combinations of burnup, cooling time, and enrichment which were considered in this trade-off study. Since these trade-off studies did not include any constraints on cask surface or inner shell temperature, the results were not compared with any design limits.

Tables 6.13 and 6.14 present the results of the cost and schedule impact evaluation. Results are presented for all cases except those where the cask weight constraint of 200,000 pounds is exceeded.

Review of the results indicates that the most optimum decay time for shipment of both BWR and PWR fuel assemblies in this cask design is 10 years. These trade-off studies also indicate that the optimum number of fuel assemblies per basket is 52 for BWR and 21 for PWR fuel baskets. Although assemblies with higher burnup and smaller decay times can be shipped in this cask design the cost per metric ton increases for these cases.

Review of the results also indicates that the most influential parameter on the fabrication costs for a given burnup and initial enrichment, expressed in terms of cost per metric ton of initial heavy metal (MTIHM) stored, is the cask payload in number of fuel assemblies. This is shown in Figures 6.15 through 6.18 for the base case initial enrichment and burnup BWR and PWR casks. These figures show only very small variations in cost with different decay times, reflecting the small variations in shield thickness and the relatively small influence that shield thickness changes have on the fabrication cost. In fact, for the BWR cask which has no changes in shield thickness for the base case, there is no variation in cost versus decay time for a given cask payload. There is, however, a significant difference in cost versus payload. Similar comparisons for the other initial enrichment and burnup cases provide the information necessary to choose optimized designs based on minimum cost per quantity of spent fuel shipped.

Table 6.1

BWR FUEL - TOTAL GAMMA SOURCE STRENGTH

Total Gamma Source as a Function of
Enrichment, Burnup, and Decay Time
(Photons/Sec/Assembly)

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30	40	50
Decay Times (Years)	5	2.05E15	2.77E15	3.41E15
	10	1.24E15	1.64E15	2.06E15
	15	1.02E15	1.33E15	1.67E15

Table 6.2

PWR FUEL- TOTAL GAMMA SOURCE STRENGTH

Total Gamma Source as a Function of
Enrichment, Burnup, and Decay Time
(Photons/Sec/Assembly)

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35	45	55
Decay Times (Years)	5	6.62E15	8.47E15	1.05E16
	10	3.78E15	4.91E15	5.95E15
	15	3.06E15	3.96E15	4.75E15

Table 6.3

BWR FUEL - TOTAL NEUTRON SOURCE STRENGTH

Neutron Source Strength per Assembly as a Function of
Enrichment, Burnup, and Decay Time
(Neutrons/Sec/Assembly)

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30	40	50
Decay Times (Years)	5	3.454E7	1.263E8	1.704E8
	10	2.883E7	1.048E8	1.413E8
	15	2.414E7	8.715E7	1.175E8

Table 6.4

PWR FUEL - TOTAL NEUTRON SOURCE STRENGTH

Neutron Source Strength Per Assembly as a Function of
Enrichment, Burnup, and Decay Time
(Neutrons/Sec/Assembly)

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35	45	55
Decay Times (Years)	5	1.665E8	2.466E8	6.440E8
	10	1.385E8	2.049E8	5.339E8
	15	1.155E8	1.705E8	4.432E8

Table 6.5

BWR FUEL - DECAY HEAT PER ASSEMBLY

Decay Heat as a Function of
Enrichment, Burnup, and Decay Time
(KWatt/Assembly)

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30	40	50
Decay Times (Years)	5	0.276	0.397	0.495
	10	0.183	0.263	0.334
	15	0.158	0.226	0.286

Table 6.6

PWR FUEL- DECAY HEAT PER ASSEMBLY

Decay Heat as a Function of
Enrichment, Burnup, and Decay Time
(KWatt/Assembly)

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35	45	55
Decay Times (Years)	5	0.907	1.170	1.548
	10	0.573	0.749	0.995
	15	0.488	0.635	0.837

Table 6.7

BWR CASK SHIELDING THICKNESS

Shielding Thickness as a Function of
Enrichment, Burnup, Capacity, and Decay Time
(inch)

Decay Time = 5 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30*	40*	50**
Number of Fuel Assemblies	24	3.13	3.38	3.25/6.38
	32	3.13	3.63	3.50/6.38
	48	3.50	4.00	3.75/6.38
	52	3.50	4.00	3.88/6.38
	64	3.75	4.25	4.00/6.38

Decay Time = 10 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30*	40*	50**
Number of Fuel Assemblies	24	2.50	2.88	2.75/6.38
	32	2.75	3.00	3.00/6.38
	48	2.88	3.38	3.25/6.38
	52	3.00	3.50	3.25/6.38
	64	3.13	3.75	3.50/6.38

Decay Time = 15 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30*	40*	50**
Number of Fuel Assemblies	24	2.25	2.50	2.50/6.38
	32	2.38	2.75	2.75/6.38
	48	2.75	3.00	3.00/6.38
	52	2.75	3.00	3.00/6.38
	64	2.88	3.25	3.13/6.38

* Required lead (gamma shield) thickness in inches. The Borosilicone (neutron shield) thickness is 5.375".

** Required lead/Borosilicone (gamma/neutron shield) thickness in inches.

Table 6.8

PWR CASK SHIELDING THICKNESS

Shielding Thickness as a Function of
Enrichment, Burnup, Capacity, and Decay Time
(inch)

Decay Time = 5 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35*	45*	55**
Number of Fuel Assemblies	6	3.25	3.38	3.38/6.38
	12	3.75	3.88	4.00/6.38
	18	4.00	4.00	4.25/6.38
	21	4.13	4.25	4.38/6.38
	26	4.25	4.38	4.50/6.38

Decay Time = 10 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35*	45*	55**
Number of Fuel Assemblies	6	2.75	2.88	3.00/6.38
	12	3.13	3.25	3.38/6.38
	18	3.38	3.63	3.63/6.38
	21	3.50	3.75	3.75/6.38
	26	3.63	3.88	4.00/6.38

Decay Time = 15 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35*	45*	55**
Number of Fuel Assemblies	6	2.50	2.50	2.63/6.38
	12	2.88	3.00	3.00/6.38
	18	3.13	3.25	3.38/6.38
	21	3.25	3.38	3.50/6.38
	26	3.38	3.50	3.63/6.38

* Required lead (gamma shield) thickness in inches. The Borosilicone (neutron shield) thickness is 5.375".

** Required lead/Borosilicone (gamma/neutron shield) thickness in inches.

Table 6.9

BWR CASK OUTER SURFACE/INNER SHELL TEMPERATURE

Cask Outer Surface/Inner Shell Temperature as a Function of
Enrichment, Burnup, Capacity, and Decay Time
for 130°F Ambient and 125 BTU/hr.ft^2 Solar Heat Flux
(°F)

Decay Time = 5 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30 (1)/(2)	40 (1)/(2)	50 (1)/(2)
Number of Fuel Assemblies	24	233/297	245/336	254/372
	32	243/328	258/377	269/424
	48	260/386	281/456	297/524
	52	265/397	287/470	303/548
	64	277/438	303/525	322/619

Decay Time = 10 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30 (1)/(2)	40 (1)/(2)	50 (1)/(2)
Number of Fuel Assemblies	24	223/267	232/293	238/320
	32	230/288	241/322	249/357
	48	243/328	258/378	270/429
	52	246/338	262/389	275/447
	64	254/367	274/428	289/497

Decay Time = 15 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30 (1)/(2)	40 (1)/(2)	50 (1)/(2)
Number of Fuel Assemblies	24	221/259	228/282	234/304
	32	226/277	236/307	243/337
	48	238/312	251/355	261/399
	52	240/321	254/368	266/415
	64	248/347	265/402	278/460

1. Cask outer surface temperature (°F).
2. Cask inner shell temperature (°F).

Table 6.10

PWR CASK OUTER SURFACE/INNER SHELL TEMPERATURE

Cask Outer Surface/Inner Shell Temperature as a Function of Enrichment, Burnup, Capacity, and Decay Time for 130°F Ambient and 125 BTU/hr.ft^2 Solar Heat Flux (°F)

Decay Time = 5 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35 (1)/(2)	45 (1)/(2)	55 (1)/(2)
Number of Fuel Assemblies	6	228/281	235/302	243/336
	12	250/354	263/394	278/458
	18	271/424	289/482	309/573
	21	281/457	300/523	324/628
	26	295/512	319/591	346/716

Decay Time = 10 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35 (1)/(2)	45 (1)/(2)	55 (1)/(2)
Number of Fuel Assemblies	6	219/253	224/268	230/291
	12	234/301	243/330	254/374
	18	248/348	261/389	276/453
	21	255/371	269/413	287/491
	26	266/408	283/459	303/552

Decay Time = 15 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35 (1)/(2)	45 (1)/(2)	55 (1)/(2)
Number of Fuel Assemblies	6	216/246	221/259	226/278
	12	230/288	237/312	247/349
	18	242/328	253/363	266/417
	21	248/348	261/388	275/450
	26	258/380	273/429	290/503

1. Cask outer surface temperature (°F).
2. Cask inner shell temperature (°F).

Table 6.11

BWR CASK OD AND WEIGHT

Cask Outside Diameter and Weight as a Function of
Enrichment, Burnup, Capacity, and Decay Time

Decay Time = 5 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30 (1)/(2)	40 (1)/(2)	50 (1)/(2)
Number of Fuel Assemblies	24	81.01/167100	81.51/171300	83.26/173100
	32	81.26/174000	82.01/180300	83.76/182100
	48	81.76/187800	82.27/196300	84.26/196000
	52	81.76/190200	82.27/198700	84.51/200500
	64	82.26/201700	83.26/210200	84.76/210000

Decay Time = 10 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30 (1)/(2)	40 (1)/(2)	50 (1)/(2)
Number of Fuel Assemblies	24	79.76/156700	80.51/163000	82.26/164700
	32	80.26/165700	80.76/169800	82.76/173700
	48	80.51/177300	81.51/185700	83.26/187500
	52	80.76/181800	81.76/190200	83.26/189900
	64	81.01/191100	82.26/201700	83.76/201300

Decay Time = 15 years

Enrichment (% U-235)		3.0%		4.0%
Burnup (GWD/MTU)		30 (1)/(2)	40 (1)/(2)	50 (1)/(2)
Number of Fuel Assemblies	24	79.26/152600	79.76/156700	81.76/160600
	32	79.51/159500	80.26/165700	82.26/169500
	48	80.26/175300	80.76/179400	82.76/183300
	52	80.26/177700	80.76/181800	82.76/185700
	64	80.51/186900	81.26/193200	83.01/195000

1. Cask outside diameter (in).
2. Cask system weight (lb).

Table 6.12

PWR CASK OD AND WEIGHT

Cask Outside Diameter and Weight as a Function of Enrichment, Burnup, Capacity, and Decay Time

Decay Time = 5 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35 (1)/(2)	45 (1)/(2)	55 (1)/(2)
Number of Fuel Assemblies	6	81.26/162600	82.01/164700	83.51/168600
	12	82.26/180200	82.51/182300	84.76/188400
	18	82.76/193500	82.76/193500	85.26/201800
	21	83.01/200200	83.26/202400	85.51/208500
	26	83.26/210000	83.51/212100	85.76/218300

Decay Time = 10 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35 (1)/(2)	45 (1)/(2)	55 (1)/(2)
Number of Fuel Assemblies	6	80.26/154300	80.51/156300	82.76/162300
	12	81.01/169600	81.26/171700	83.51/177700
	18	81.51/182900	82.01/187100	84.01/191100
	21	81.76/189600	82.26/193800	84.26/197700
	26	82.01/199200	82.51/203500	84.76/209600

Decay Time = 15 years

Enrichment (% U-235)		3.0%	4.0%	
Burnup (GWD/MTU)		35 (1)/(2)	45 (1)/(2)	55 (1)/(2)
Number of Fuel Assemblies	6	79.76/150100	79.76/150100	82.01/156100
	12	80.51/165400	80.76/167500	82.76/171400
	18	81.01/178700	81.26/180800	83.51/186800
	21	81.26/185300	81.51/187400	83.76/193500
	26	81.51/195000	82.51/197100	84.01/203200

1. Cask outside diameter (in).
2. Cask system weight (lb).

Table 6.13

BWR CASK COST AND SCHEDULE IMPACT

Cost and Schedule Impact as a Function of
Enrichment, Burnup, Capacity, and Decay Time

Decay Time = 5 years

Enrichment (% U-235)		3.0%						4.0%		
Burnup (GWD/MTU)		30			40			50		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Number of Fuel Assemblies	24	2219	68	505	2219	68	505	2256	68	514
	32	2274	72	388	2280	72	389	2323	72	397
	48	2384	79	271	2408	79	274	2446	79	278
	52	2331	81	245	2436	81	256	--	--	--
	64	--	--	--	--	--	--	--	--	--

Decay Time = 10 years

Enrichment (% U-235)		3.0%						4.0%		
Burnup (GWD/MTU)		30			40			50		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Number of Fuel Assemblies	24	2219	68	505	2219	68	505	2231	68	[illegible]8
	32	2274	72	388	2274	72	388	2299	72	[illegible]93
	48	2384	79	271	2384	79	271	2421	79	276
	52	2331	81	245	2331	81	245	2448	81	257
	64	2548	87	218	--	--	--	--	--	--

Decay Time = 15 years

Enrichment (% U-235)		3.0%						4.0%		
Burnup (GWD/MTU)		30			40			50		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Number of Fuel Assemblies	24	2219	68	505	2219	68	505	2219	68	505
	32	2274	72	388	2274	72	388	2286	72	390
	48	2284	79	271	2284	79	271	2408	79	274
	52	2331	81	245	2331	81	245	2436	81	256
	64	2493	87	213	2493	87	213	2524	87	216

1. Fabrication cost (1989 dollars K).

2. Fabrication time in weeks.

3. Fabrication cost per metric ton of initial heavy metal capacity (1989 dollars K).

Table 6.14

PWR CASK COST AND SCHEDULE IMPACT

Cost and Schedule Impact as a Function of
Enrichment, Burnup, Capacity, and Decay Time

Decay Time = 5 years

Enrichment (% U-235)		3.0%			4.0%					
Burnup (GWD/MTU)		35			45			55		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Number of Fuel Assemblies	6	1994	63	717	2001	63	719	2050	63	737
	12	2121	70	381	2127	70	382	2183	70	392
	18	2235	78	268	2235	78	268	2297	78	275
	21	--	--	--	--	--	--	--	--	--
	26	--	--	--	--	--	--	--	--	--

Decay Time = 10 years

Enrichment (% U-235)		3.0%			4.0%					
Burnup (GWD/MTU)		35			45			55		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Number of Fuel Assemblies	6	1970	63	708	1976	63	710	2032	63	730
	12	2090	70	376	2096	70	377	2152	70	387
	18	2204	78	264	2216	78	266	2266	78	272
	21	2181	81	224	2273	81	234	2323	81	239
	26	--	--	--	--	--	--	--	--	--

Decay Time = 15 years

Enrichment (% U-235)		3.0%			4.0%,					
Burnup (GWD/MTU)		35			45			55		
		(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Number of Fuel Assemblies	6	1957	63	704	1957	63	704	2013	63	724
	12	2077	70	373	2084	70	375	2133	70	384
	18	2192	78	263	2198	78	263	2254	78	270
	21	2249	81	231	2255	81	232	2311	81	237
	26	2340	87	194	--	--	--	--	--	--

1. Fabrication cost (1989 dollars K).
2. Fabrication time in weeks.
3. Fabrication cost per metric ton of initial heavy metal capacity (1989 dollars K).

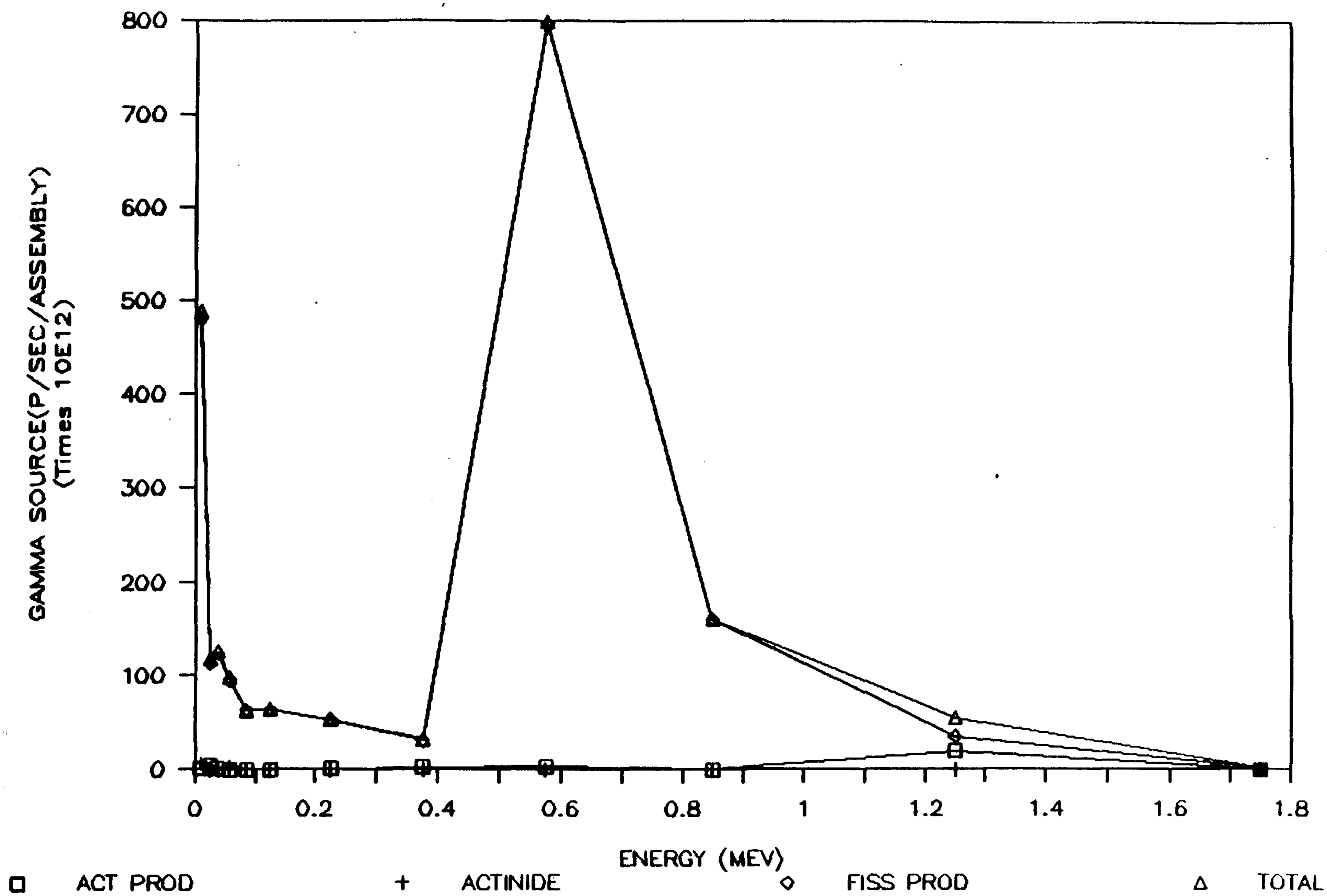

Figure 6.1

BWR FUEL ASSEMBLY 3% U235, 30 GWD/MTIHM

GAMMA SOURCE PER ASSEMBLY 5 YEAR DECAY

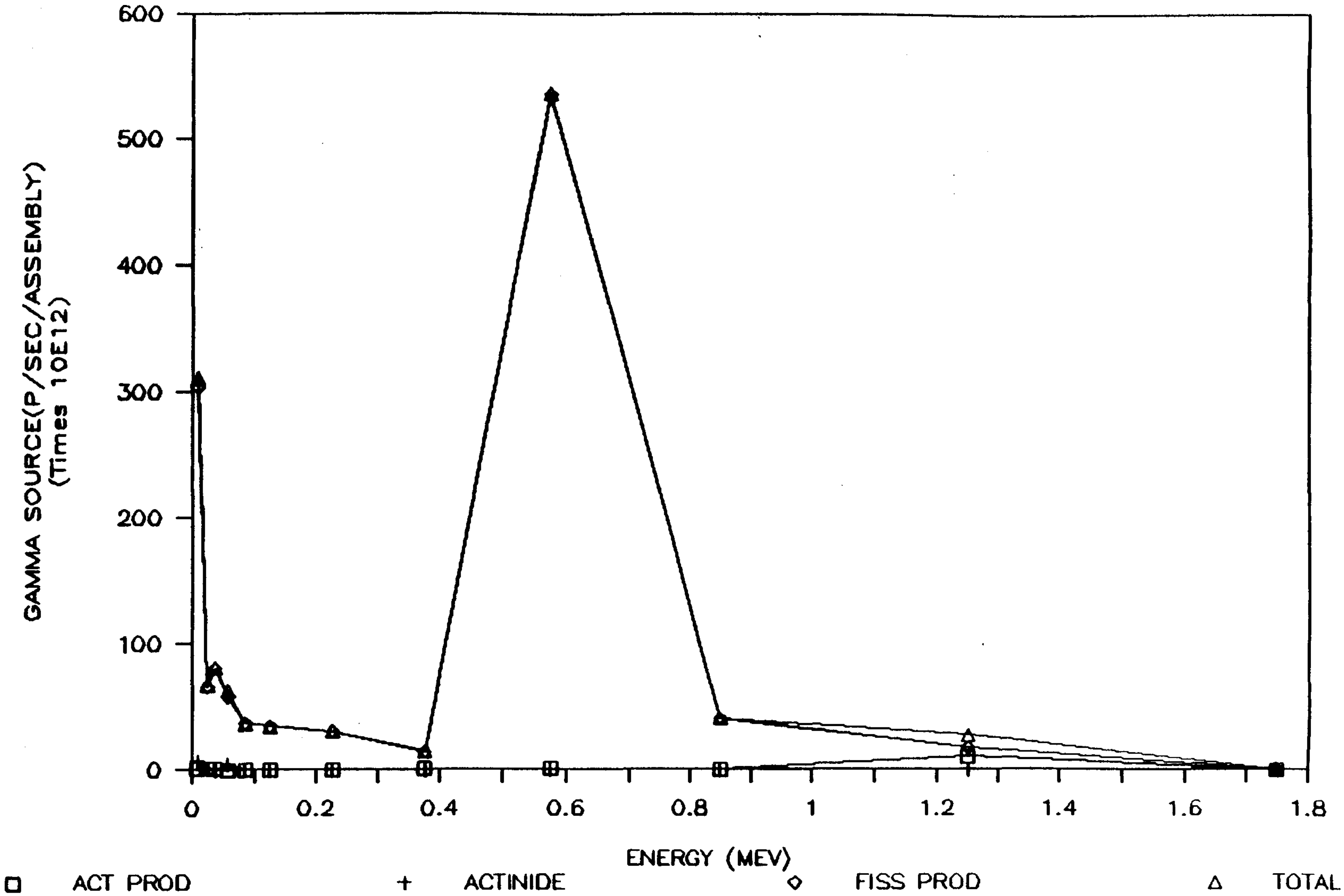

Figure 6.2

BWR FUEL ASSEMBLY 3% U235, 30 GWD/MTIHM

GAMMA SOURCE PER ASSEMBLY 10 YEAR DECAY

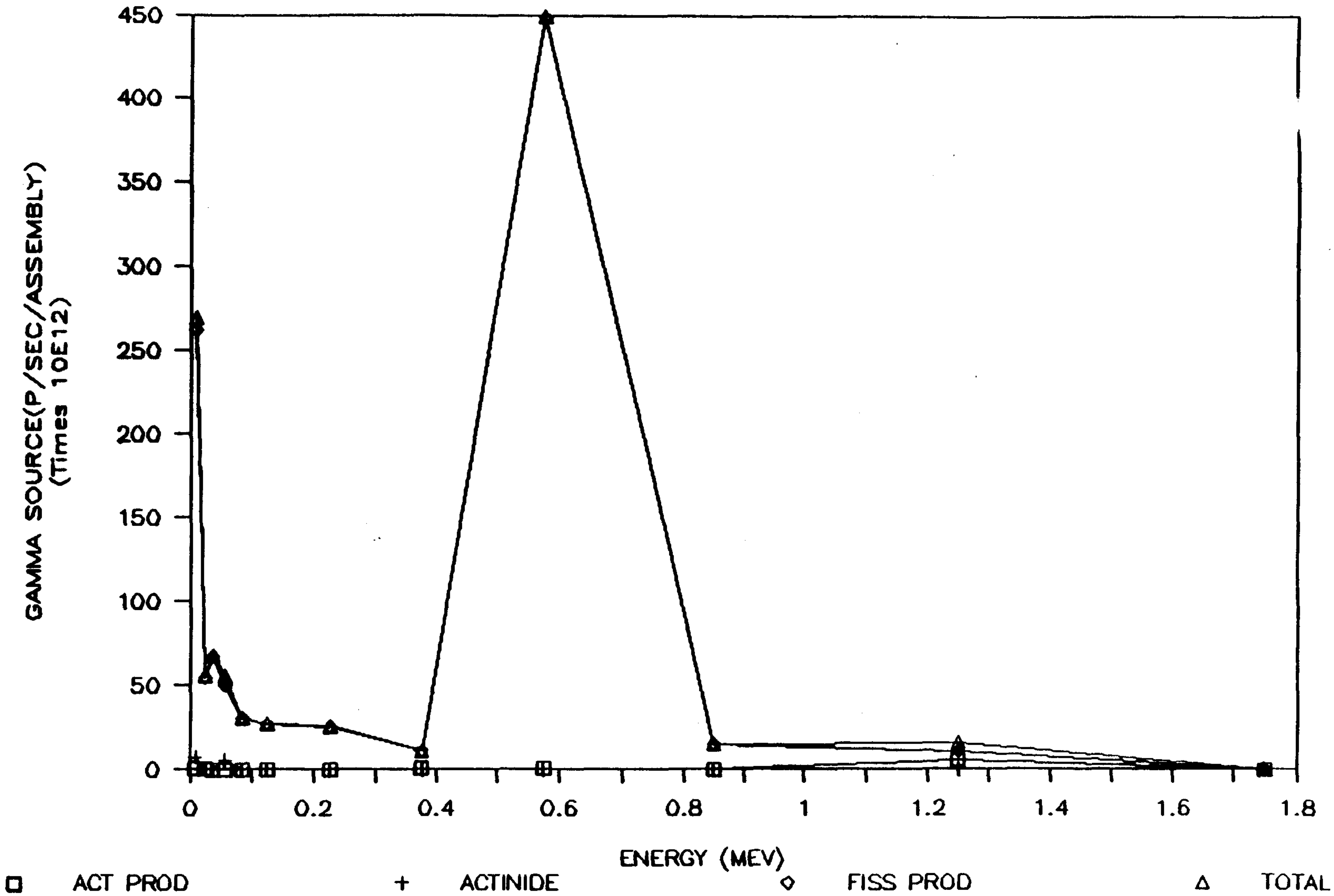

Figure 6.3

BWR FUEL ASSEMBLY 3% U235, 30 GWD/MTIHM

GAMMA SOURCE PER ASSEMBLY 15 YEAR DECAY

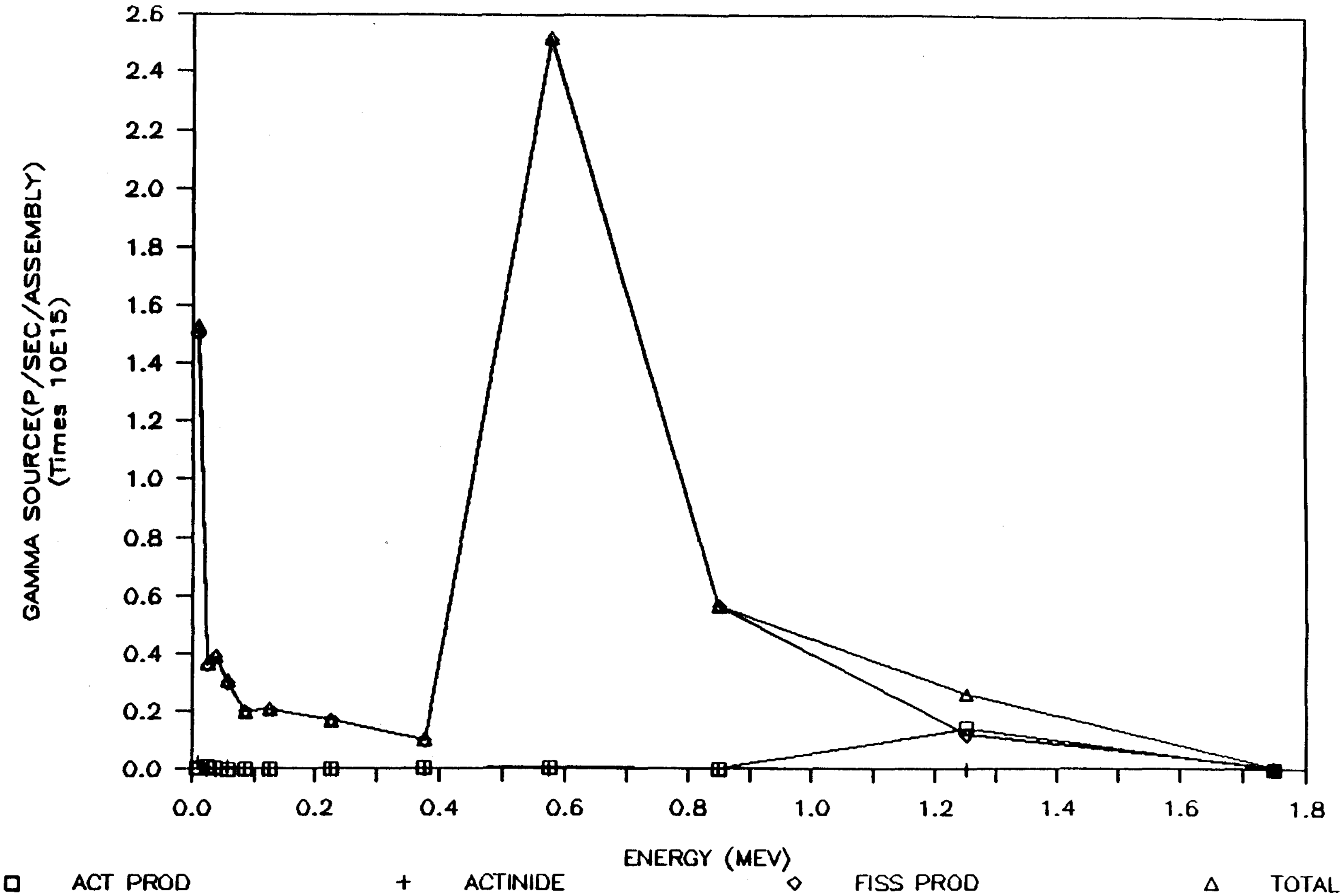

Figure 6.4

PWR FUEL ASSEMBLY 3% U235, 35 GWD/MTIHM

GAMMA SOURCE PER ASSEMBLY 5 YEAR DECAY

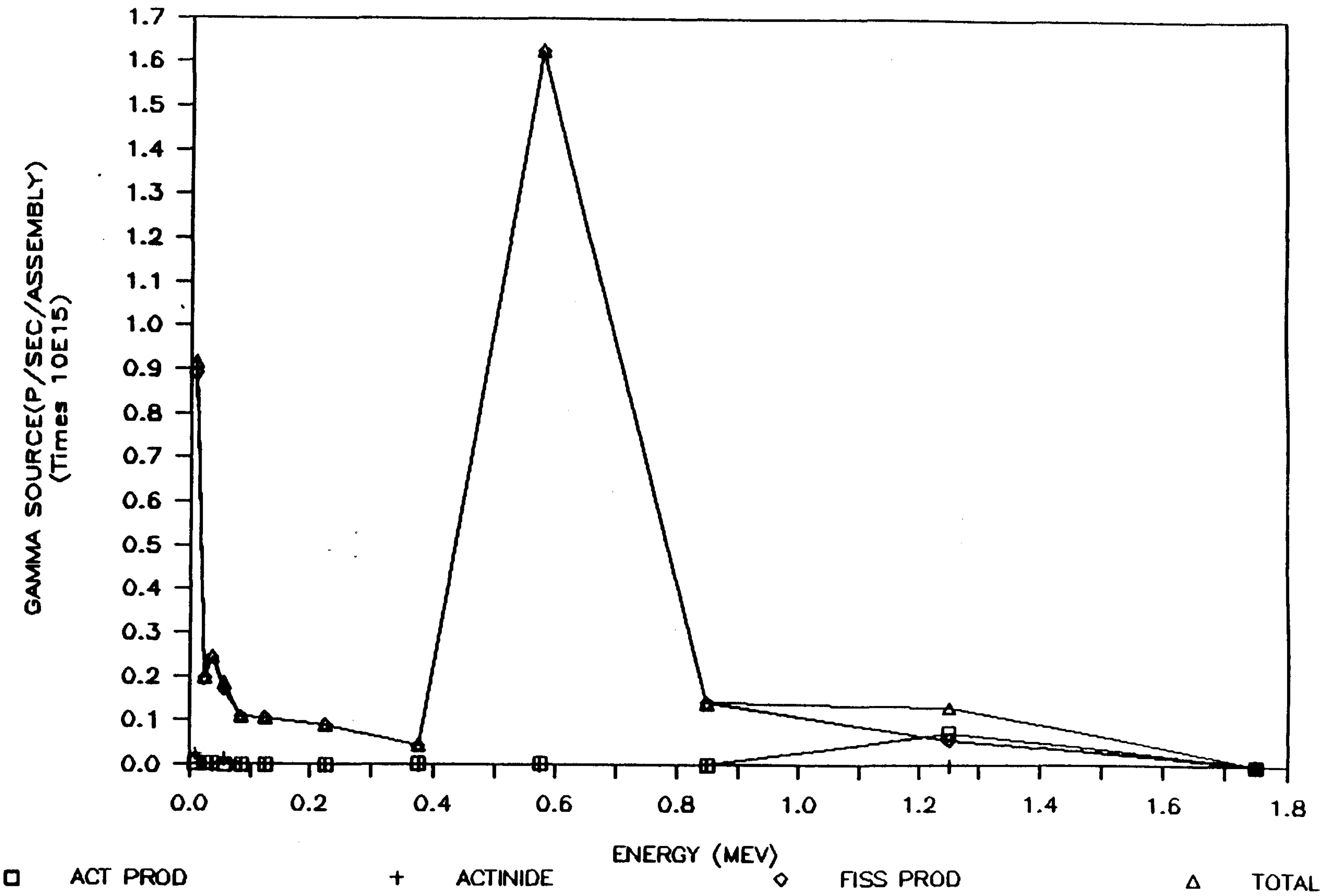

Figure 6.5

PWR FUEL ASSEMBLY 3% U235, 35 GWD/MTIHM

GAMMA SOURCE PER ASSEMBLY 10 YEAR DECAY

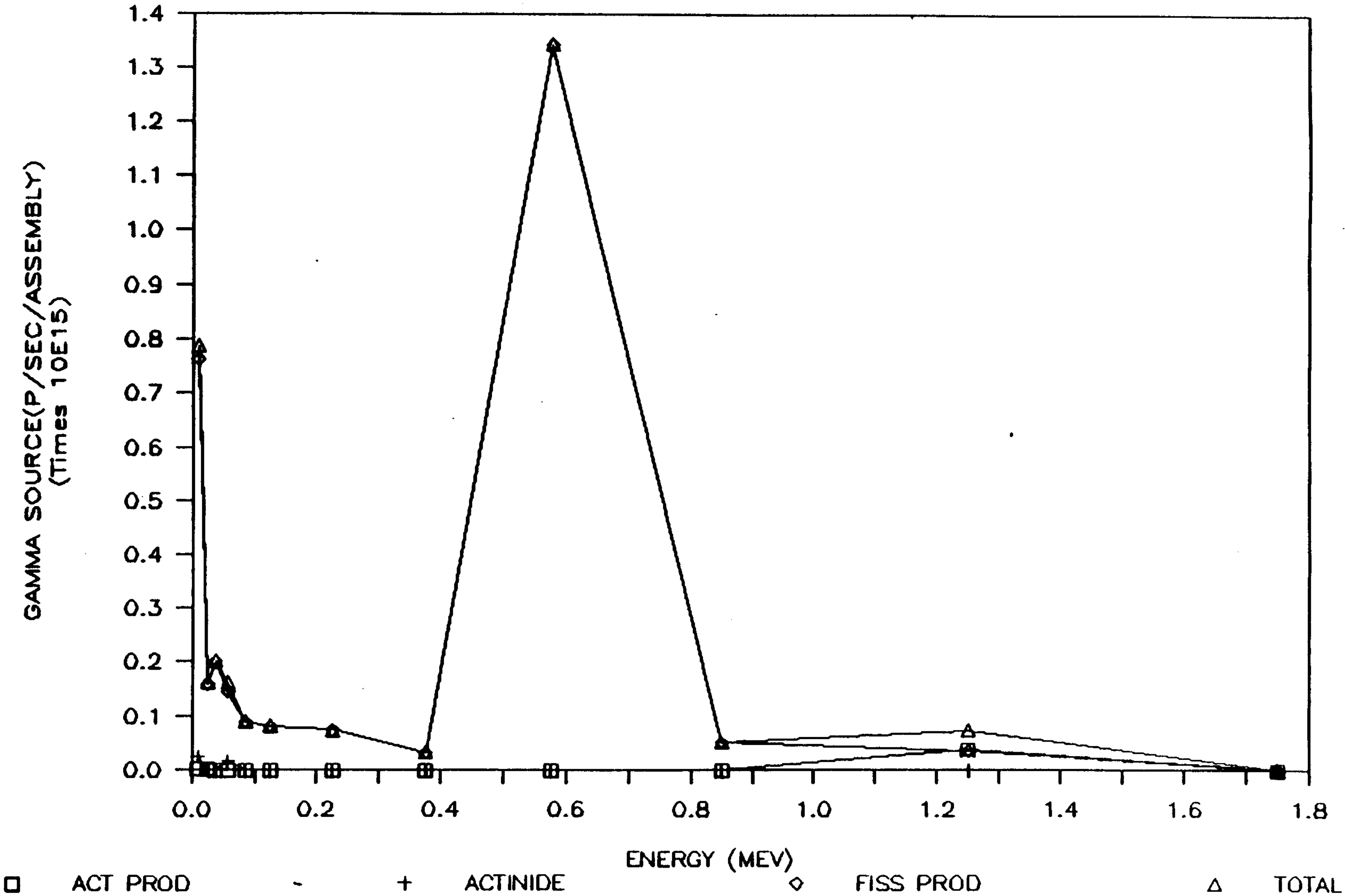

Figure 6.6

PWR FUEL ASSEMBLY 3% U235, 35 GWD/MTIHM

GAMMA SOURCE PER ASSEMBLY 15 YEAR DECAY

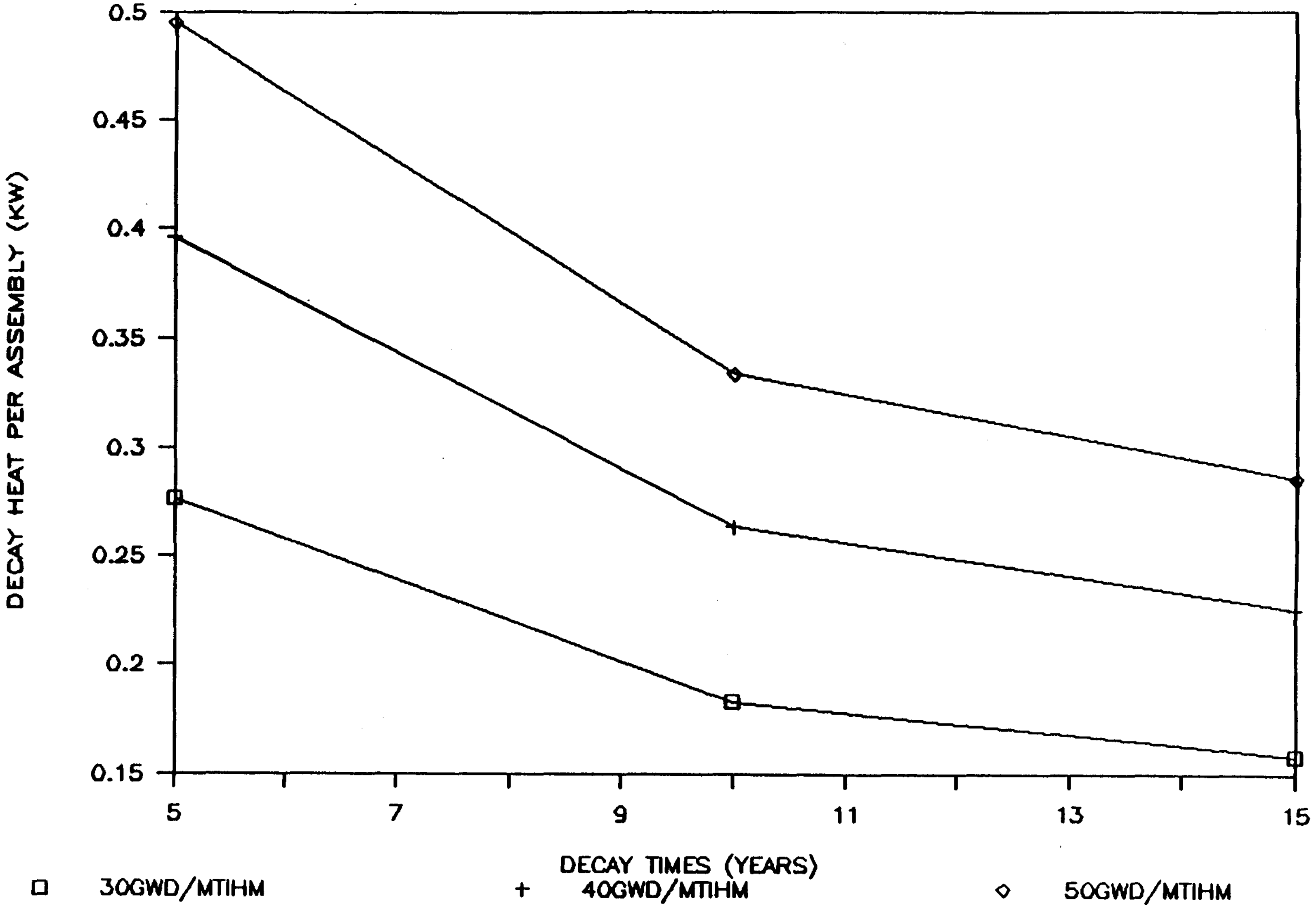

Figure 6.7

DECAY HEAT VERSUS COOLING TIME AND BURNUP

BWR FUEL ASSEMBLY

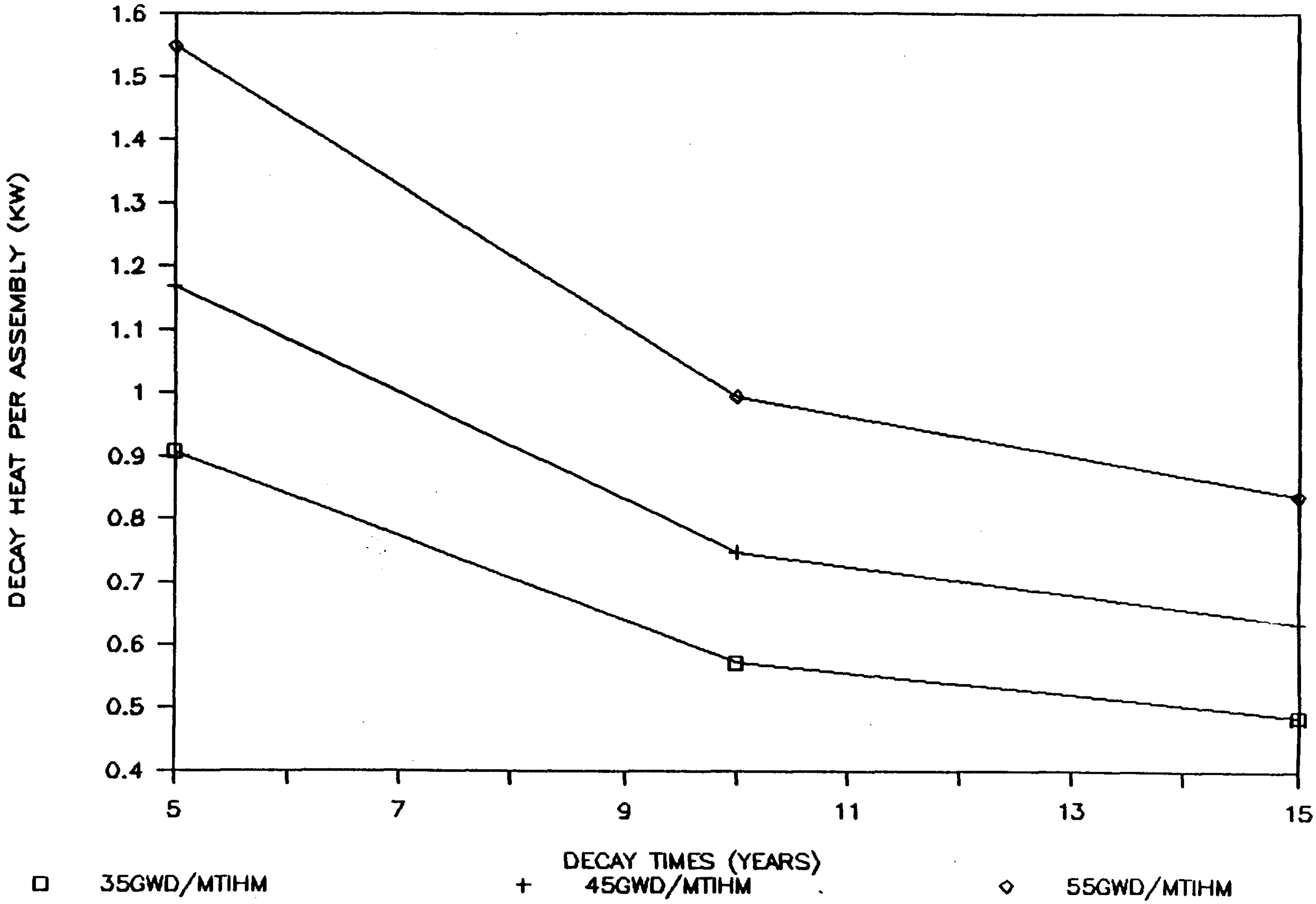

Figure 6.8

DECAY HEAT VERSUS COOLING TIME AND BURNUP

PWR FUEL ASSEMBLY

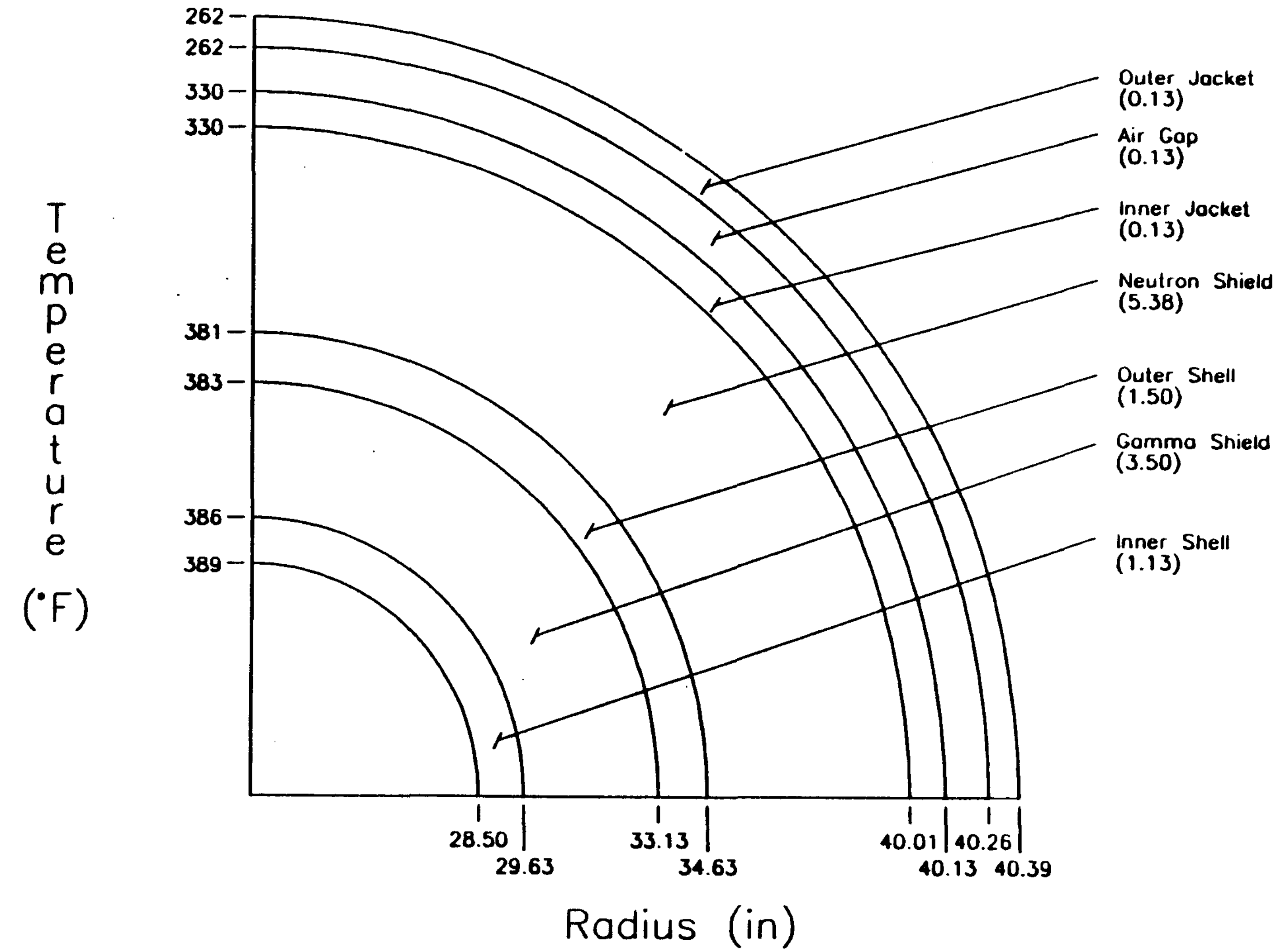

Figure 6.9

TEMPERATURE DISTRIBUTION THROUGH VARIOUS CASK LAYERS WITH BWR BASKET CONTAINING 52 ASSEMBLIES WITH 40 GWD[illegible]IHM BURNUP AND 10 YEAR DECAY

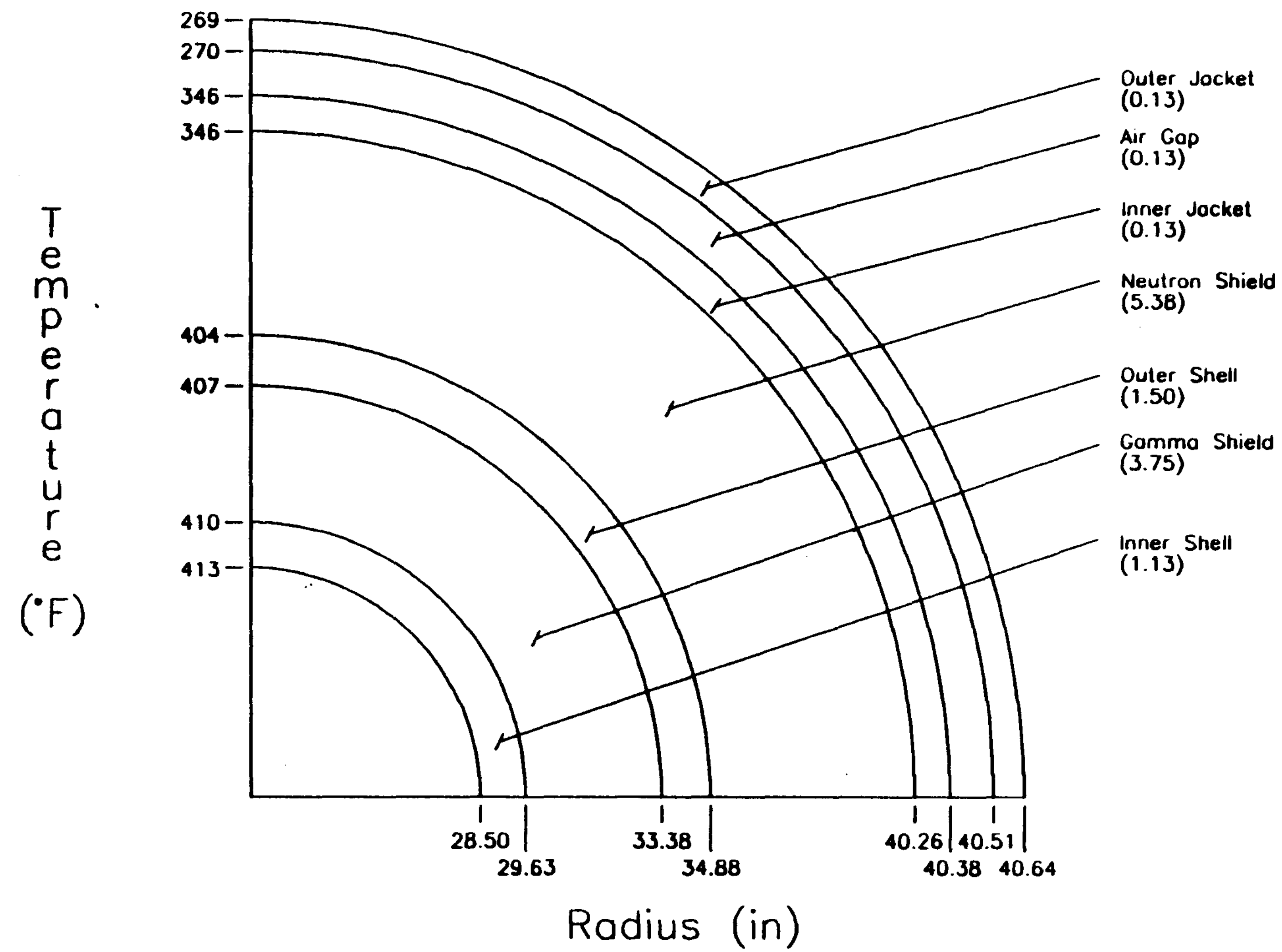

Figure 6.10

TEMPERATURE DISTRIBUTION THROUGH VARIOUS CASK LAYERS WITH PWR BASKET CONTAINING 21 ASSEMBLIES WITH 45 GWD/MTIHM BURNUP AND 10 YEAR DECAY

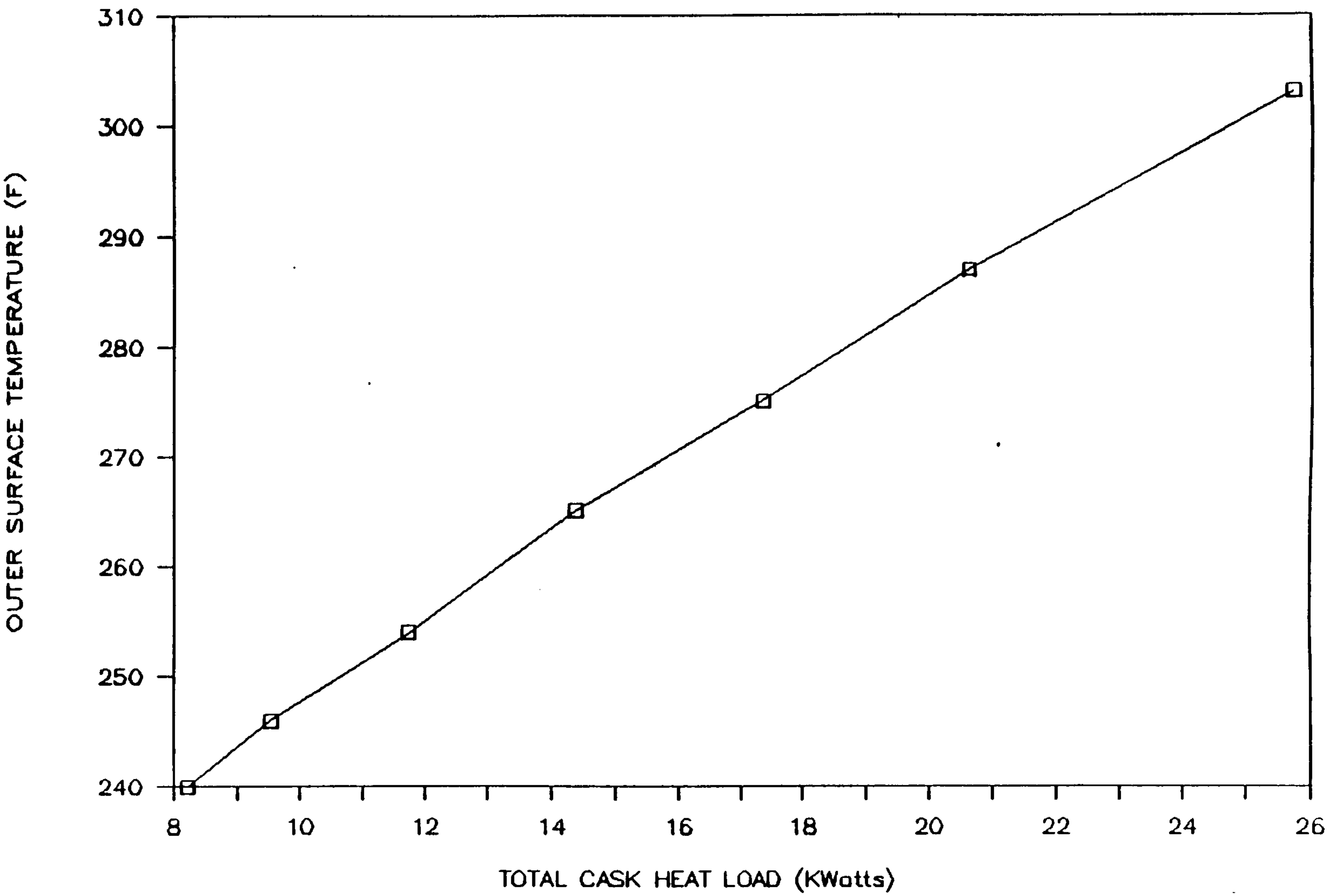

Figure 6.11

BWR CASK BASKET WITH 52 FUEL ASSEMBLY

TOTAL DECAY HEAT VERSUS CASK SURFACE TEMPERATURE

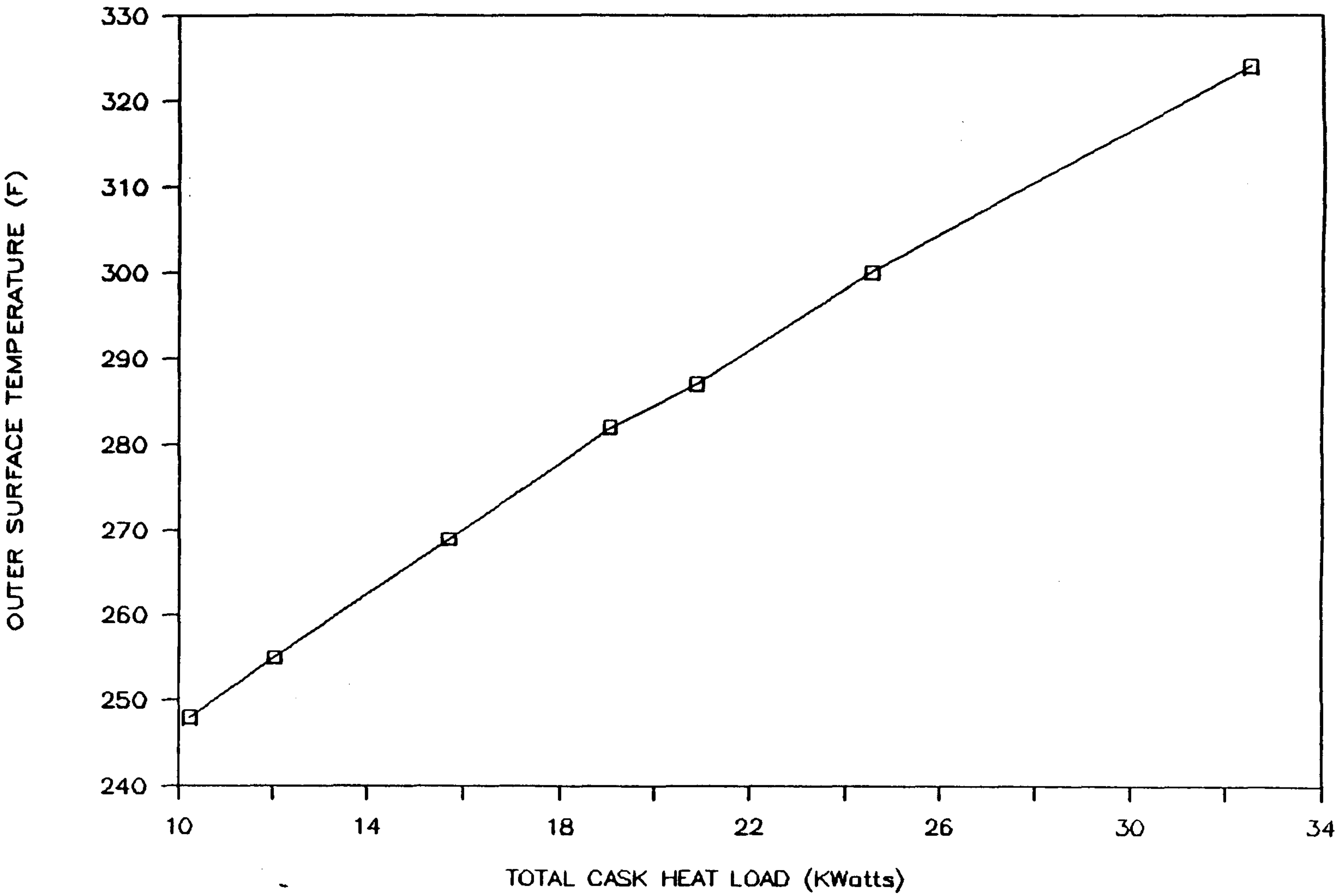

Figure 6.12

PWR CASK BASKET WITH 21 FUEL ASSEMBLY

TOTAL DECAY HEAT VERSUS CASK SURFACE TEMPERATURE

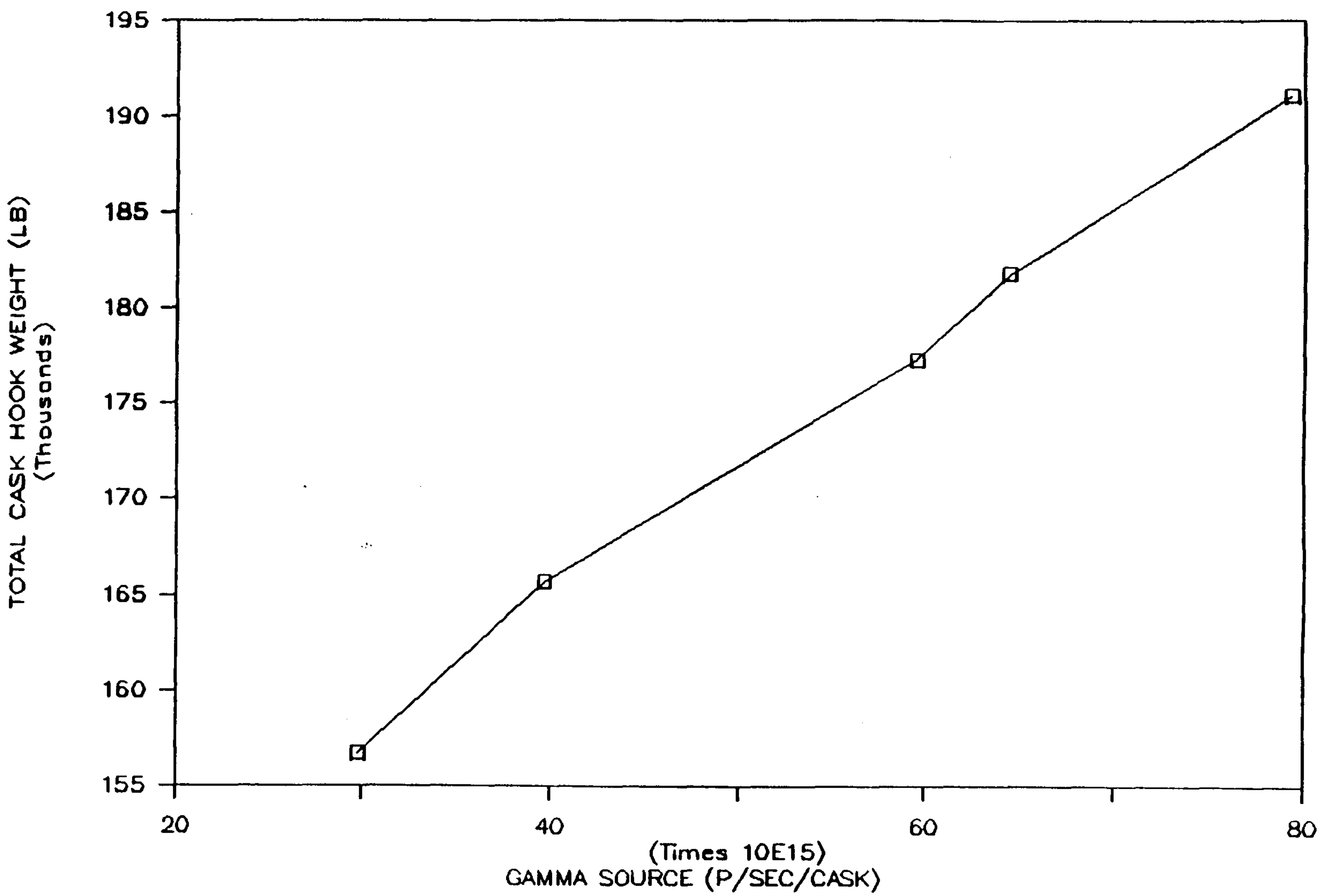

Figure 6.13

CASK WEIGHT VERSUS TOTAL GAMMA SOURCE

BWR BASKET 30 GWD/MTIHM, 10 YEAR DECAY

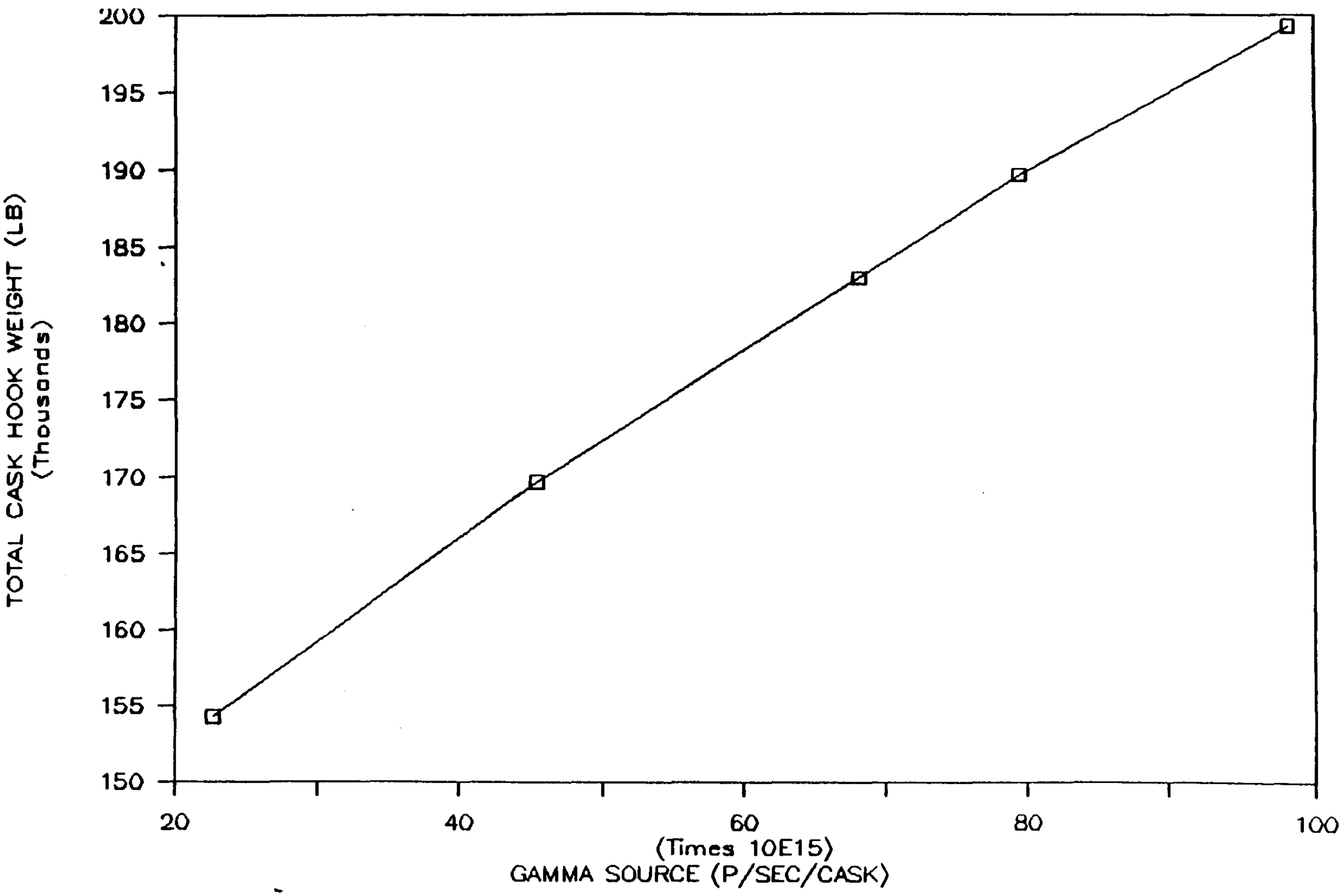

Figure 6.14

CASK WEIGHT VERSUS TOTAL GAMMA SOURCE

PWR BASKET 35 GWD/MTIHM, 10 YEAR DECAY

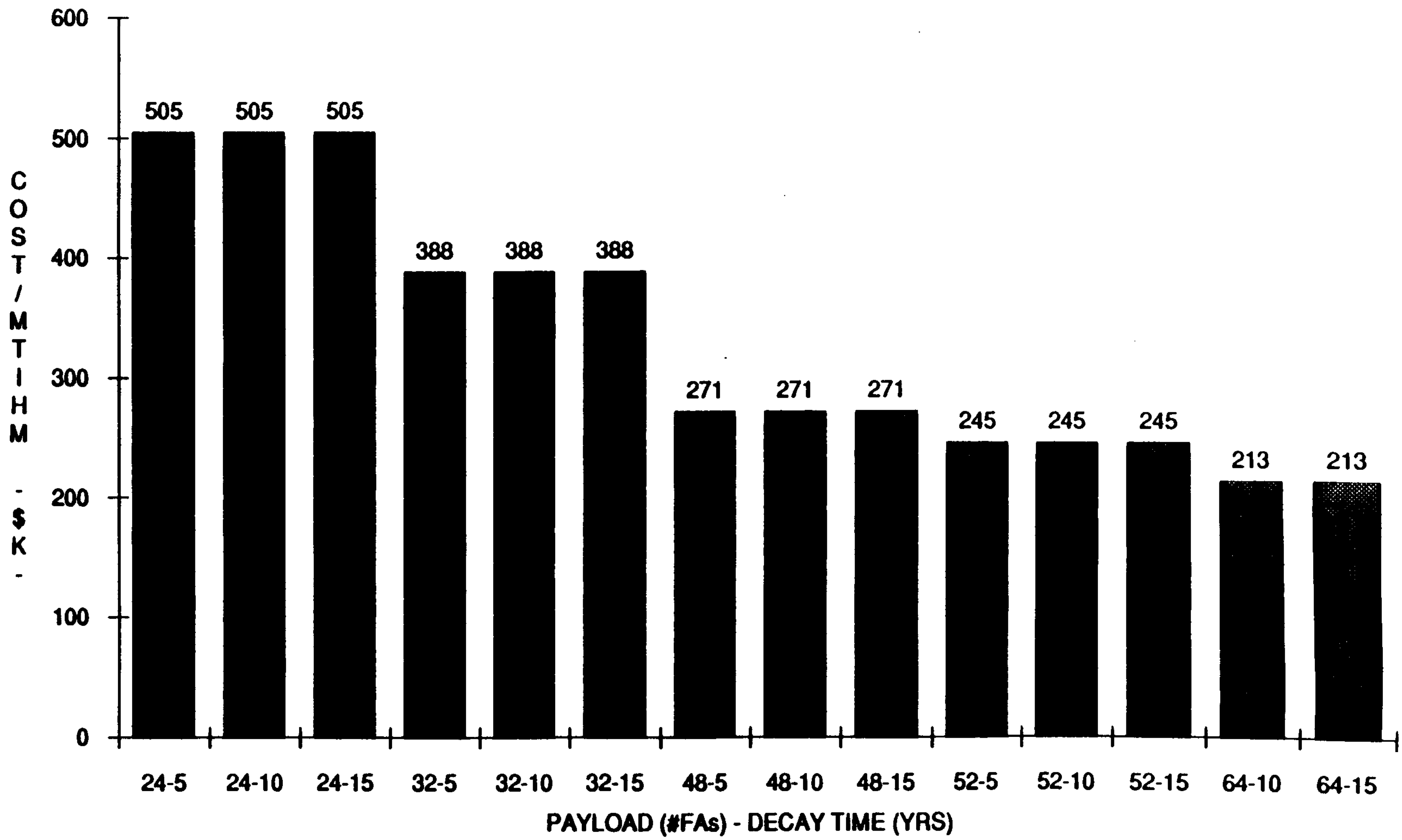

Figure 6.15

FABRICATION COST PER MTIHM VERSUS BWR CASK PAYLOAD AND DECAY TIME

(GROUPED BY PAYLOAD)

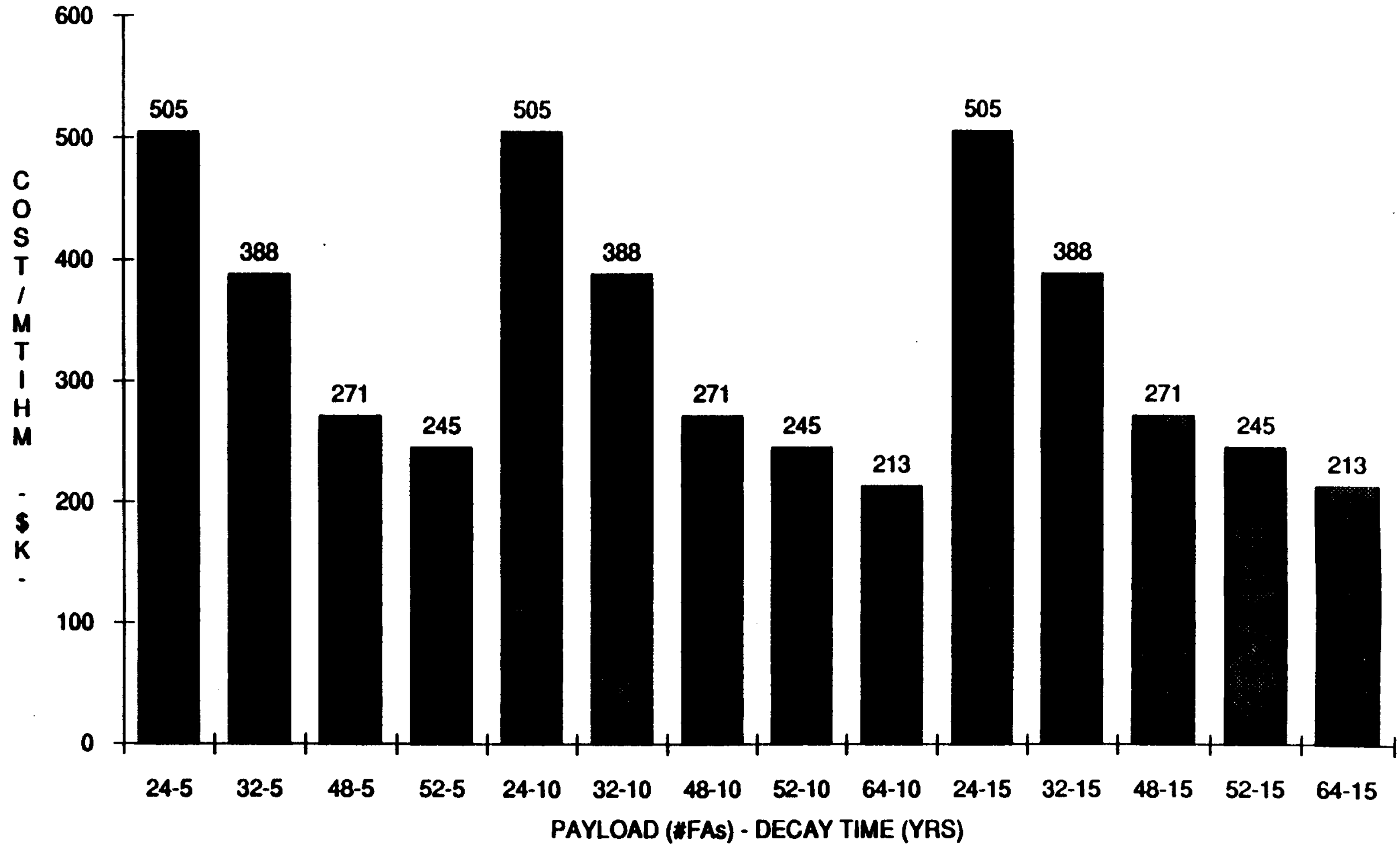

Figure 6.16

FABRICATION COST PER MTIHM VERSUS BWR CASK PAYLOAD AND DECAY TIME

(GROUPED BY DECAY TIME)

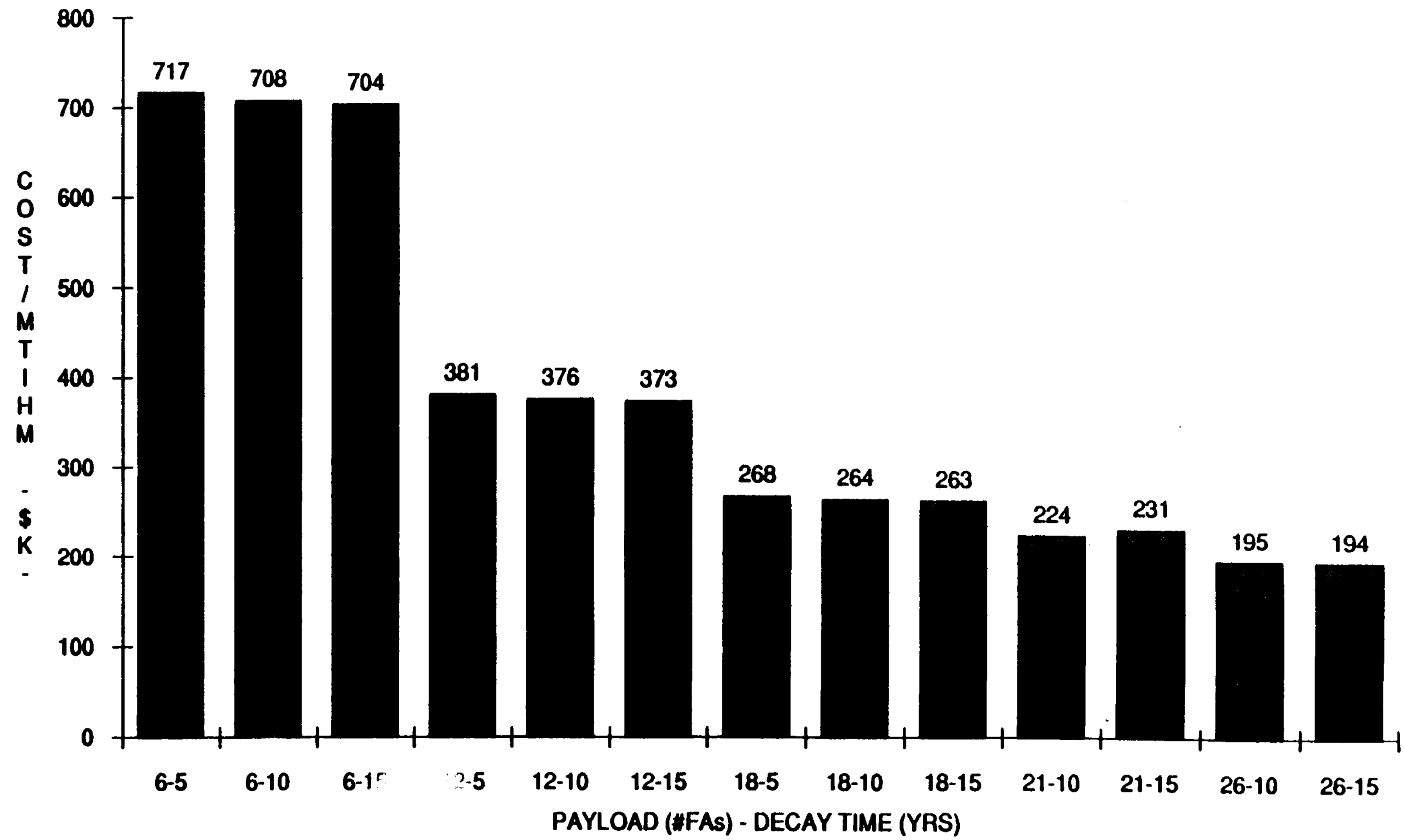

Figure 6.17

FABRICATION COST PER MTIHM VERSUS PWR CASK PAYLOAD AND DECAY TIME

(GROUPED BY PAYLOAD)

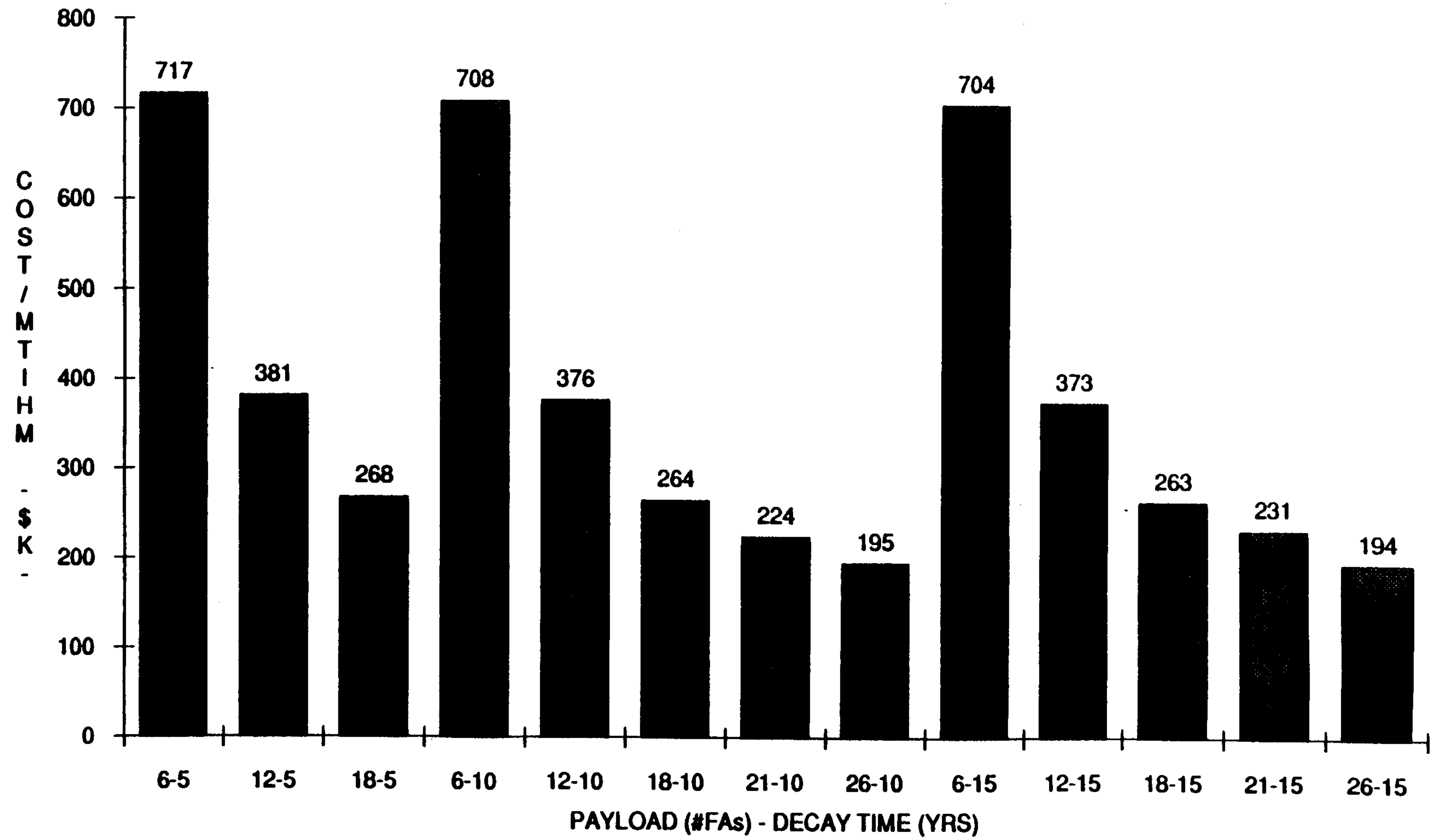

Figure 6.18

FABRICATION COST PER MTIHM VERSUS PWR CASK PAYLOAD AND DECAY TIME

(GROUPED BY DECAY TIME)

7.0 REFERENCES

1. "NUPAC 140-B Rail/Barge Cask Preliminary Design Report," DOE Contract Number DE-AC07-88ID12700, Revision 0, 1989.

2. NUPAC Proposal to Perform Additional Trade-Off Studies, Proposal Number P-04360-2, Revision 2, Dated September 20, 1989 under DOE Contract Number DE-AC07-III12700.

3. Croff, A.G., "A User's Manual for the ORIGEN2 Computer Code," ORNL/TM-7175, Oak Ridge National Laboratory, 1980.

4. RSIC Computer Code Collection, "ANISN/PC," Oak Ridge National Laboratory, CCC-514 Micro, 1988.

5. U.S. Department of Energy, "Characteristics of Spent Fuel, High Level Waste, and Other Radioactive Wastes which may Require Long Term Isolation," Office of Civilian Radioactive Waste Management, DOE/RW-0184, December 1987.

6. RSIC Data Library Collection, "CASK-81," Oak Ridge National Laboratory, DLC-23, 1987.

APPENDIX A.1

Weights of the PWR and BWR Fuel Assemblies

APPENDIX A.1

WEIGHTS OF THE PWR AND BWR FUEL ASSEMBLIES

	kg Per PWR Fuel Assembly				
Material	Top	Plenum	In-Core	Bottom	Total
SS302	0.000	2.990	0.000	0.000	2.990
SS304	6.890	0.091	0.540	5.900	13.421
Inconel-718	2.517	0.714	4.900	1.802	9.932
Nicrobraze-5	0.000	0.079	0.000	0.000	0.079
UO2	0.000	0.000	525.954	0.000	525.954
Zircaloy-4	0.000	5.853	119.983	0.000	125.836
Totals-->	9.407	9.727	651.377	7.702	678.212

	kg Per BWR Fuel Assembly				
Material	Top	Plenum	In-Core	Bottom	Total
SS302	0.000	1.100	0.000	0.000	1.100
SS304	3.206	0.000	0.000	6.006	9.211
Inconel-X750	0.000	0.000	0.300	0.400	0.700
UO2	0.000	0.000	207.954	0.000	207.954
Zircaloy-2	0.000	4.700	51.200	0.000	55.900
Zircaloy-4	0.000	3.800	43.600	0.000	47.400
Totals-->	3.206	9.600	303.054	6.406	322.265

APPENDIX A.2

Typical Origen Input Files for PWR and BWR Fuel Assemblies

```
-1
-1
-1
RDA     ##########################################################
RDA     ##                                                      ##
RDA     ##    NuPac OCRWM Cask Add'l Tradeoff Studies           ##
RDA     ##    PNFS Project 420-0810                             ##
RDA     ##    Input Filename:        PWR3-35.U5                 ##
RDA     ##    Creation Date:         1/25/90, 11:38             ##
RDA     ##    Fuel Type:             3.0% W17x17 Std.           ##
RDA     ##    Burnup:                35000 MWd/MTIHM            ##
RDA     ##                                                      ##
RDA     ##########################################################
RDA
LIP     0  0  0
LIB     -1 1 2 3      204      205      206    9  3  0  1  1
PHO     101  102  103  10
RDA    READ UNIT AMOUNTS OF FUEL AND FUEL ASSEMBLY MATERIALS
INP          -1  1  -1  -1  1  1  ONE MTIHM UO2
INP          -2  1  -1  -1  1  1  ONE KG ZIRCALOY-4
INP          -3  1  -1  -1  1  1  ONE KG INCONEL-718
INP          -4  1  -1  -1  1  1  ONE KG SS 302
INP          -5  1  -1  -1  1  1  ONE KG SS 304
INP          -6  1  -1  -1  1  1  ONE KG NICROBRAZE-50
RDA     MIX TOP, PLENUM, IN-CORE, AND BOTTOM MIXTURES
RDA     MIX TOP ZONE
MOV          -2        -7        0     0.000 ZIRCALOY-4
ADD          -3        -7        0     2.517 INCONEL-718
ADD          -4        -7        0     0.000 SS302
ADD          -5        -7        0     6.890 SS304
ADD          -6        -7        0     0.000 NICROBRAZE-50
RDA     MIX PLENUM ZONE
MOV          -2        -8        0     5.853 ZIRCALOY-4
ADD          -3        -8        0     0.714 INCONEL-718
ADD          -4        -8        0     2.990 SS302
ADD          -5        -8        0     0.091 SS304
ADD          -6        -8        0     0.079 NICROBRAZE-50
RDA     MIX IN-CORE ZONE - SANS UO2
MOV          -2        -9        0   119.983 ZIRCALOY-4
ADD          -3        -9        0     4.900 INCONEL-718
ADD          -4        -9        0     0.000 SS302
ADD          -5        -9        0     0.540 SS304
ADD          -6        -9        0     0.000 NICROBRAZE-50
RDA     MIX BOTTOM ZONE
MOV          -2       -10        0     0.000 ZIRCALOY-4
ADD          -3       -10        0     1.802 INCONEL-718
ADD          -4       -10        0     0.000 SS302
ADD          -5       -10        0     5.900 SS304
ADD          -6       -10        0     0.000 NICROBRAZE-50
RDA     IRRADIATE ONE MTIHM OF UO2 AT 100% POWER
BUP
IRP       103.70      37.5       -1        1    4    2  BURNUP = 3889 MWD/MTIHM
IRP       207.41      37.5        1        1    4    0  BURNUP = 7778 MWD/MTIHM
IRP       311.11      37.5        1        1    4    0  BURNUP = 11667 MWD/MTIHM
DEC       417.11                  1        1    4    0  106 DAY OUTAGE
IRP       520.81      37.5        1        1    4    0  BURNUP = 15556 MWD/MTIHM
IRP       624.52      37.5        1        1    4    0  BURNUP = 19444 MWD/MTIHM
IRP       728.22      37.5        1        1    4    0  BURNUP = 23333 MWD/MTIHM
DEC       834.22                  1        1    4    0  106 DAY OUTAGE
IRP       937.93      37.5        1        1    4    0  BURNUP = 27222 MWD/MTIHM
IRP      1041.63      37.5        1        1    4    0  BURNUP = 31111 MWD/MTIHM
IRP      1145.33      37.5        1        1    4    0  BURNUP = 35000 MWD/MTIHM
BUP
RDA
RDA     IRRADIATE TOP ZONE MATERIAL AT 10% FLUX
IRF       103.70      -0.1       -7        7        4        2
IRF       207.41      -0.1        7        7        4        0
IRF       311.11      -0.1        7        7        4        0
DEC       417.11                  7        7        4        0
IRF       520.81      -0.1        7        7        4        0
IRF       624.52      -0.1        7        7        4        0
IRF       728.22      -0.1        7        7        4        0
DEC       834.22                  7        7        4        0
IRF       937.93      -0.1        7        7        4        0
IRF      1041.63      -0.1        7        7        4        0
```

```
IRF         1145.33      -0.1          7           7          4          0
RDA
RDA         IRRADIATE PLENUM ZONE MATERIAL AT 20% FLUX
IRF          103.70      -0.2         -8           8          4          2
IRF          207.41      -0.2          8           8          4          0
IRF          311.11      -0.2          8           8          4          0
DEC          417.11                    8           8          4          0
IRF          520.81      -0.2          8           8          4          0
IRF          624.52      -0.2          8           8          4          0
IRF          728.22      -0.2          8           8          4          0
DEC          834.22                    8           8          4          0
IRF          937.93      -0.2          8           8          4          0
IRF         1041.63      -0.2          8           8          4          0
IRF         1145.33      -0.2          8           8          4          0
RDA         IRRADIATE CORE ZONE (SANS UO2) AT 100% FLUX
IRF          103.70      -1.0         -9           9          4          2
IRF          207.41      -1.0          9           9          4          0
IRF          311.11      -1.0          9           9          4          0
DEC          417.11                    9           9          4          0
IRF          520.81      -1.0          9           9          4          0
IRF          624.52      -1.0          9           9          4          0
IRF          728.22      -1.0          9           9          4          0
DEC          834.22                    9           9          4          0
IRF          937.93      -1.0          9           9          4          0
IRF         1041.63      -1.0          9           9          4          0
IRF         1145.33      -1.0          9           9          4          0
RDA
RDA         IRRADIATE BOTTOM ZONE MATERIAL AT 20% FLUX
IRF          103.70      -0.2        -10          10          4          2
IRF          207.41      -0.2         10          10          4          0
IRF          311.11      -0.2         10          10          4          0
DEC          417.11                   10          10          4          0
IRF          520.81      -0.2         10          10          4          0
IRF          624.52      -0.2         10          10          4          0
IRF          728.22      -0.2         10          10          4          0
DEC          834.22                   10          10          4          0
IRF          937.93      -0.2         10          10          4          0
IRF         1041.63      -0.2         10          10          4          0
IRF         1145.33      -0.2         10          10          4          0
RDA
RDA         MIX A COMBINED IN-CORE ZONE
MOV               9          11          0          1.0
ADD               1          11          0     0.4636
RDA         MIX A WHOLE ASSEMBLY OUT OF THE PARTS
MOV               7          12          0          1.0 TOP ZONE
ADD               8          12          0          1.0 PLENUM ZONE
ADD              10          12          0          1.0 BOTTOM ZONE
ADD              11          12          0          1.0 (COMBINED) IN-CORE ZONE
RDA         MOVE ASSEMBLY PARTS TO SCRATCH VECTORS
MOV               7          -1          0          1.0 TOP ZONE
MOV               8          -2          0          1.0 PLENUM ZONE
MOV              11          -3          0          1.0 (COMBINED) IN-CORE ZONE
MOV              10          -4          0          1.0 BOTTOM ZONE
MOV              12          -5          0          1.0 WHOLE ASSEMBLY
TIT         SOURCE CHARACTERISTICS OF 3.0%, 35.0 GWD/MTIHM FUEL AT DISCHARGE
BAS         ONE W17X17 STD. FUEL ASSEMBLY
OPTL        8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
OPTA        8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
OPTF        8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
CUT         9 .01  25 .01  26 .01  27 .01      -1
RDA         MOVE VECTORS -1 THRU -5 TO POSITIVE VECTORS FOR OUTPUT
MOV              -1           1          0          1.0
MOV              -2           2          0          1.0
MOV              -3           3          0          1.0
MOV              -4           4          0          1.0
MOV              -5           5          0          1.0
HED               1 TOP
HED               2 PLENUM
HED               3 IN-CORE
HED               4 BOTTOM
HED               5 WHOLE
OUT         -5   1   -1   0
TIT         SOURCE CHARACTERISTICS OF 3.0%, 35.0 GWD/MTIHM FUEL AFTER 5 YRS
DEC               5          -1          1           5          4
DEC               5          -2          2           5          4
DEC               5          -3          3           5          4
```

```
DEC             5         -4         4         5         4
DEC             5         -5         5         5         4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT       -5   1    -1   0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 35.0 GWD/MTIHM FUEL AFTER 10 YRS
DEC            10         -1         1         5         4
DEC            10         -2         2         5         4
DEC            10         -3         3         5         4
DEC            10         -4         4         5         4
DEC            10         -5         5         5         4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT       -5   1    -1   0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 35.0 GWD/MTIHM FUEL AFTER 15 YRS
DEC            15         -1         1         5         4
DEC            15         -2         2         5         4
DEC            15         -3         3         5         4
DEC            15         -4         4         5         4
DEC            15         -5         5         5         4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT       -5   1    -1   0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 35.0 GWD/MTIHM FUEL AFTER 20 YRS
DEC            20         -1         1         5         4
DEC            20         -2         2         5         4
DEC            20         -3         3         5         4
DEC            20         -4         4         5         4
DEC            20         -5         5         5         4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT       -5   1    -1   0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 35.0 GWD/MTIHM FUEL AFTER 50 YRS
DEC            50         -1         1         5         4
DEC            50         -2         2         5         4
DEC            50         -3         3         5         4
DEC            50         -4         4         5         4
DEC            50         -5         5         5         4
HED             1 TOP
HED             2 PLENUM
HED             3 IN-CORE
HED             4 BOTTOM
HED             5 WHOLE
OUT       -5   1    -1   0
END
        2   922340      53.1    922350   30000.0    922380 969946.9         0       0.0 ONE MTIHM FUEL
ACTINIDES
        4    30000       1.0    50000       1.0    60000       89.4    80000 118600.0 ONE MTIHM FUEL IMPUR
        4    90000      10.7   110000      15.0   130000       16.7   140000      12.1 ONE MTIHM FUEL IMPUR
        4   150000      35.0   200000       2.0   220000        1.0   240000       3.0 ONE MTIHM FUEL IMPUR
        4   250000       1.7   260000      18.0   270000        1.0   290000       1.0 ONE MTIHM FUEL IMPUR
        4   300000      40.3   420000      10.0   480000       25.0   490000       2.0 ONE MTIHM FUEL IMPUR
        4   500000       4.0   740000       2.0   820000        1.0   830000       0.4 ONE MTIHM FUEL IMPUR
        0
        4    10000 1.30E-02    50000 3.30E-04    60000 1.20E-01    70000 8.00E-02 ONE KG ZIRC-4
        4    80000 9.50E-01   130000 2.40E-02   160000 3.50E-02   220000 2.00E-02 ONE KG ZIRC-4
        4   230000 2.00E-02   240000 1.25E+00   250000 2.00E-02   260000 2.25E+00 ONE KG ZIRC-4
        4   270000 1.00E-02   280000 2.00E-02   290000 2.00E-02   400000 9.80E+02 ONE KG ZIRC-4
        4   410000 1.20E-01   480000 2.50E-04   500000 1.60E+01   720000 7.80E-02 ONE KG ZIRC-4
        4   740000 2.00E-02   922340 2.00E-04        0      0.0        0      0.0 ONE KG ZIRC-4
        0
        4    60000 4.00E-01    70000 1.30E+00   130000 6.00E+00   140000 2.00E+00 ONE KG INC-718
        4   160000 7.00E-02   220000 8.00E+00   240000 1.90E+02   250000 2.00E+00 ONE KG INC-718
        4   260000 1.80E+02   270000 4.70E+00   280000 5.20E+02   290000 1.00E+00 ONE KG INC-718
```

```
4    410000 5.55E+01    420000 3.00E+01         0       0.0         0       0.0 ONE KG INC-718
0
4     60000 1.50E+00     70000 1.30E+00    140000 1.00E+01    150000 4.50E-01 ONE KG SS-302
4    160000 3.00E-01    240000 1.80E+02    250000 2.00E+01    260000 6.98E+02 ONE KG SS-302
4    270000 8.00E-01    280000 8.92E+01    410000 1.00E-01         0       0.0 ONE KG SS-302
0
4     60000 8.00E-01     70000 1.30E+00    140000 1.00E+01    150000 4.50E-01 ONE KG SS-304
4    160000 3.00E-01    240000 1.90E+02    250000 2.00E+01    260000 6.88E+02 ONE KG SS-304
4    270000 8.00E-01    280000 8.92E+01    410000 1.00E-01         0       0.0 ONE KG SS-304
0
4     50000 5.00E-02     60000 1.00E-01     70000 6.60E-02     80000 4.30E-02 ONE KG NBRAZE-50
4    130000 1.00E-01    140000 5.11E-01    150000 1.03E+02    160000 1.00E-01 ONE KG NBRAZE-50
4    220000 1.00E-01    240000 1.50E+02    250000 1.00E-01    260000 4.71E-01 ONE KG NBRAZE-50
4    270000 3.81E-01    280000 7.44E+02    400000 1.00E-01    740000 1.00E-01 ONE KG NBRAZE-50
0
```

```
-1
-1
-1
RDA     ############################################################
RDA     ##                                                        ##
RDA     ##   NuPac OCRWM Cask Add'l Tradeoff Studies              ##
RDA     ##   PNFS Project 420-0810                                ##
RDA     ##   Input Filename:        BWR3-30.U5                    ##
RDA     ##   Creation Date:         1/26/90, 10:34                ##
RDA     ##   Fuel Type:             3.0% GE8x8                    ##
RDA     ##   Burnup:                30000 MWd/MTIHM               ##
RDA     ##                                                        ##
RDA     ############################################################
RDA
LIP      0  0  0
LIB      -1 1 2 3      251      252      253   9  3  0  1  1
PHO      101  102  103  10
RDA     READ UNIT AMOUNTS OF FUEL AND FUEL ASSEMBLY MATERIALS
INP          -1  1  -1  -1  1  1  ONE MTIHM UO2
INP          -2  1  -1  -1  1  1  ONE KG ZIRCALOY-4
INP          -3  1  -1  -1  1  1  ONE KG ZIRCALOY-2
INP          -4  1  -1  -1  1  1  ONE KG INCONEL-X750
INP          -5  1  -1  -1  1  1  ONE KG SS 302
INP          -6  1  -1  -1  1  1  ONE KG SS 304
RDA      MIX TOP, PLENUM, IN-CORE, AND BOTTOM MIXTURES
RDA      MIX TOP ZONE
MOV          -2        -7        0     0.000 ZIRCALOY-4
ADD          -3        -7        0     0.000 ZIRCALOY-2
ADD          -4        -7        0     0.000 INCONEL-X750
ADD          -5        -7        0     0.000 SS302
ADD          -6        -7        0     3.206 SS304
RDA      MIX PLENUM ZONE
MOV          -2        -8        0     3.800 ZIRCALOY-4
ADD          -3        -8        0     4.700 ZIRCALOY-2
ADD          -4        -8        0     0.000 INCONEL-X750
ADD          -5        -8        0     1.100 SS302
ADD          -6        -8        0     0.000 SS304
RDA      MIX IN-CORE ZONE - SANS UO2
MOV          -2        -9        0    43.600 ZIRCALOY-4
ADD          -3        -9        0    51.200 ZIRCALOY-2
ADD          -4        -9        0     0.300 INCONEL-X750
ADD          -5        -9        0     0.000 SS302
ADD          -6        -9        0     0.000 SS304
RDA      MIX BOTTOM ZONE
MOV          -2       -10        0     0.000 ZIRCALOY-4
ADD          -3       -10        0     0.000 ZIRCALOY-2
ADD          -4       -10        0     0.400 INCONEL-X750
ADD          -5       -10        0     0.000 SS302
ADD          -6       -10        0     6.006 SS304
RDA      IRRADIATE ONE MTIHM OF UO2 AT 100% POWER
BUP
IRP        96.53      25.9       -1        1    4    2  BURNUP = 2500 MWD/MTIHM
IRP       193.05      25.9        1        1    4    0  BURNUP = 5000 MWD/MTIHM
IRP       289.58      25.9        1        1    4    0  BURNUP = 7500 MWD/MTIHM
DEC       395.58                  1        1    4    0  106 DAY OUTAGE
IRP       492.10      25.9        1        1    4    0  BURNUP = 10000 MWD/MTIHM
IRP       588.63      25.9        1        1    4    0  BURNUP = 12500 MWD/MTIHM
IRP       685.15      25.9        1        1    4    0  BURNUP = 15000 MWD/MTIHM
DEC       791.15                  1        1    4    0  106 DAY OUTAGE
IRP       887.68      25.9        1        1    4    0  BURNUP = 17500 MWD/MTIHM
IRP       984.20      25.9        1        1    4    0  BURNUP = 20000 MWD/MTIHM
IRP      1080.73      25.9        1        1    4    0  BURNUP = 22500 MWD/MTIHM
DEC      1186.73                  1        1    4    0  106 DAY OUTAGE
IRP      1283.25      25.9        1        1    4    0  BURNUP = 25000 MWD/MTIHM
IRP      1379.78      25.9        1        1    4    0  BURNUP = 27500 MWD/MTIHM
IRP      1476.30      25.9        1        1    4    0  BURNUP = 30000 MWD/MTIHM
BUP
RDA
RDA      IRRADIATE TOP ZONE MATERIAL AT 10% FLUX
IRF        96.53      -0.1       -7        7         4        2
IRF       193.05      -0.1        7        7         4        0
IRF       289.58      -0.1        7        7         4        0
DEC       395.58                  7        7         4        0
IRF       492.10      -0.1        7        7         4        0
IRF       588.63      -0.1        7        7         4        0
```

```
IRF      685.15    -0.1       7        7        4        0
DEC      791.15               7        7        4        0
IRF      887.68    -0.1       7        7        4        0
IRF      984.20    -0.1       7        7        4        0
IRF     1080.73    -0.1       7        7        4        0
DEC     1186.73               7        7        4        0
IRF     1283.25    -0.1       7        7        4        0
IRF     1379.78    -0.1       7        7        4        0
IRF     1476.30    -0.1       7        7        4        0
RDA
RDA     IRRADIATE PLENUM ZONE MATERIAL AT 20% FLUX
IRF      140.48    -0.2      -8        8        4        2
IRF      280.96    -0.2       8        8        4        0
IRF      421.43    -0.2       8        8        4        0
DEC      527.43               8        8        4        0
IRF      667.91    -0.2       8        8        4        0
IRF      808.39    -0.2       8        8        4        0
IRF      948.87    -0.2       8        8        4        0
DEC     1054.87               8        8        4        0
IRF     1195.35    -0.2       8        8        4        0
IRF     1335.82    -0.2       8        8        4        0
IRF     1476.30    -0.2       8        8        4        0
RDA
RDA     IRRADIATE CORE ZONE (SANS UO2) AT 100% FLUX
IRF       96.53    -1.0      -9        9        4        2
IRF      193.05    -1.0       9        9        4        0
IRF      289.58    -1.0       9        9        4        0
DEC      395.58               9        9        4        0
IRF      492.10    -1.0       9        9        4        0
IRF      588.63    -1.0       9        9        4        0
IRF      685.15    -1.0       9        9        4        0
DEC      791.15               9        9        4        0
IRF      887.68    -1.0       9        9        4        0
IRF      984.20    -1.0       9        9        4        0
IRF     1080.73    -1.0       9        9        4        0
DEC     1186.73               9        9        4        0
IRF     1283.25    -1.0       9        9        4        0
IRF     1379.78    -1.0       9        9        4        0
IRF     1476.30    -1.0       9        9        4        0
RDA
RDA     IRRADIATE BOTTOM ZONE MATERIAL AT 15% FLUX
IRF       96.53    -0.2     -10       10        4        2
IRF      193.05    -0.2      10       10        4        0
IRF      289.58    -0.2      10       10        4        0
DEC      395.58              10       10        4        0
IRF      492.10    -0.2      10       10        4        0
IRF      588.63    -0.2      10       10        4        0
IRF      685.15    -0.2      10       10        4        0
DEC      791.15              10       10        4        0
IRF      887.68    -0.2      10       10        4        0
IRF      984.20    -0.2      10       10        4        0
IRF     1080.73    -0.2      10       10        4        0
DEC     1186.73              10       10        4        0
IRF     1283.25    -0.2      10       10        4        0
IRF     1379.78    -0.2      10       10        4        0
IRF     1476.30    -0.2      10       10        4        0
RDA
RDA     MIX A COMBINED IN-CORE ZONE
MOV          9        11      0      1.0
ADD          1        11      0    0.183
RDA     MIX A WHOLE ASSEMBLY OUT OF THE PARTS
MOV          7        12      0      1.0 TOP ZONE
ADD          8        12      0      1.0 PLENUM ZONE
ADD         10        12      0      1.0 BOTTOM ZONE
ADD         11        12      0      1.0 (COMBINED) IN-CORE ZONE
RDA     MOVE ASSEMBLY PARTS TO SCRATCH VECTORS
MOV          7        -1      0      1.0 TOP ZONE
MOV          8        -2      0      1.0 PLENUM ZONE
MOV         11        -3      0      1.0 (COMBINED) IN-CORE ZONE
MOV         10        -4      0      1.0 BOTTOM ZONE
MOV         12        -5      0      1.0 WHOLE ASSEMBLY
TIT     SOURCE CHARACTERISTICS OF 3.0%, 30.0 GWD/MTIHM FUEL AT DISCHARGE
BAS     ONE GE8X8 FUEL ASSEMBLY
OPTL    8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
OPTA    8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
OPTF    8 8 8 8 8   8 8 8 7 8   8 8 8 8 8   8 8 8 8 8   8 8 8 8
```

```
CUT       9 .01  25 .01  26 .01  27 .01       -1
RDA       MOVE VECTORS -1 THRU -5 TO POSITIVE VECTORS FOR OUTPUT
MOV             -1          1          0        1.0
MOV             -2          2          0        1.0
MOV             -3          3          0        1.0
MOV             -4          4          0        1.0
MOV             -5          5          0        1.0
HED              1 TOP
HED              2 PLENUM
HED              3 IN-CORE
HED              4 BOTTOM
HED              5 WHOLE
OUT       -5   1    -1    0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 30.0 GWD/MTIHM FUEL AFTER 5 YRS
DEC              5          -1         1         5          4
DEC              5          -2         2         5          4
DEC              5          -3         3         5          4
DEC              5          -4         4         5          4
DEC              5          -5         5         5          4
HED              1 TOP
HED              2 PLENUM
HED              3 IN-CORE
HED              4 BOTTOM
HED              5 WHOLE
OUT       -5   1    -1    0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 30.0 GWD/MTIHM FUEL AFTER 10 YRS
DEC             10          -1         1         5          4
DEC             10          -2         2         5          4
DEC             10          -3         3         5          4
DEC             10          -4         4         5          4
DEC             10          -5         5         5          4
HED              1 TOP
HED              2 PLENUM
HED              3 IN-CORE
HED              4 BOTTOM
HED              5 WHOLE
OUT       -5   1    -1    0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 30.0 GWD/MTIHM FUEL AFTER 15 YRS
DEC             15          -1         1         5          4
DEC             15          -2         2         5          4
DEC             15          -3         3         5          4
DEC             15          -4         4         5          4
DEC             15          -5         5         5          4
HED              1 TOP
HED              2 PLENUM
HED              3 IN-CORE
HED              4 BOTTOM
HED              5 WHOLE
OUT       -5   1    -1    0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 30.0 GWD/MTIHM FUEL AFTER 20 YRS
DEC             20          -1         1         5          4
DEC             20          -2         2         5          4
DEC             20          -3         3         5          4
DEC             20          -4         4         5          4
DEC             20          -5         5         5          4
HED              1 TOP
HED              2 PLENUM
HED              3 IN-CORE
HED              4 BOTTOM
HED              5 WHOLE
OUT       -5   1    -1    0
TIT       SOURCE CHARACTERISTICS OF 3.0%, 30.0 GWD/MTIHM FUEL AFTER 50 YRS
DEC             50          -1         1         5          4
DEC             50          -2         2         5          4
DEC             50          -3         3         5          4
DEC             50          -4         4         5          4
DEC             50          -5         5         5          4
HED              1 TOP
HED              2 PLENUM
HED              3 IN-CORE
HED              4 BOTTOM
HED              5 WHOLE
OUT       -5   1    -1    0
END
         2    922340     53.12    922350   30000.0    922380 969946.8        0 0.00E+00      1 MTIHM FUEL
ACTINIDES
```

```
      4    30000 1.00E+00     50000 1.00E+00     60000 8.94E+01     80000 1.19E+05     1 MTIHM FUEL
IMPUR
      4    90000 1.07E+01    110000 1.50E+01    130000 1.67E+01    140000 1.21E+01     1 MTIHM FU
IMPUR
      4   150000 3.50E+01    200000 2.00E+00    220000 1.00E+00    240000 3.00E+00     1 MTIHM FUE
IMPUR
      4   250000 1.70E+00    260000 1.80E+01    270000 1.00E+00    290000 1.00E+00     1 MTIHM FUEL
IMPUR
      4   300000 4.03E+01    420000 1.00E+01    480000 2.50E+01    490000 2.00E+00     1 MTIHM FUEL
IMPUR
      4   500000 4.00E+00    740000 2.00E+00    820000 1.00E+00    830000 4.00E-01     1 MTIHM FUEL
IMPUR
      0
      4    10000 1.30E-02     50000 3.30E-04     60000 1.20E-01     70000 8.00E-02     1 KG ZIRC-4
      4    80000 9.50E-01    130000 2.40E-02    160000 3.50E-02    220000 2.00E-02     1 KG ZIRC-4
      4   230000 2.00E-02    240000 1.25E+00    250000 2.00E-02    260000 2.25E+00     1 KG ZIRC-4
      4   270000 1.00E-02    280000 2.00E-02    290000 2.00E-02    400000 9.80E+02     1 KG ZIRC-4
      4   410000 1.20E-01    480000 2.50E-04    500000 1.60E+01    720000 7.80E-02     1 KG ZIRC-4
      4   740000 2.00E-02    922340 2.00E-04         0 0.00E+00         0 0.00E+00     1 KG ZIRC-4
      0
      4    10000 1.30E-02     50000 3.30E-04     60000 1.20E-01     70000 8.00E-02     1 KG ZIRC-2
      4    80000 9.50E-01    130000 2.40E-02    160000 3.50E-02    220000 2.00E-02     1 KG ZIRC-2
      4   230000 2.00E-02    240000 1.00E+00    250000 2.00E-02    260000 1.50E+00     1 KG ZIRC-2
      4   270000 1.00E-02    280000 5.00E-01    290000 2.00E-02    400000 9.80E+02     1 KG ZIRC-2
      4   410000 1.20E-01    480000 2.50E-04    500000 1.60E+01    720000 7.80E-02     1 KG ZIRC-2
      4   740000 2.00E-02         0 0.00E+00         0 0.00E+00         0 0.00E+00     1 KG ZIRC-2
      0
      4    60000 4.00E-01     70000 1.30E+00    130000 8.00E+00    140000 3.00E+00     1 KG INC-X750
      4   160000 7.00E-02    220000 2.49E+01    240000 1.50E+02    250000 7.00E+01     1 KG INC-X750
      4   260000 6.78E+01    270000 6.49E+00    280000 7.22E+02    290000 5.00E-01     1 KG INC-X750
      4   410000 9.00E+00         0 0.00E+00         0 0.00E+00         0 0.00E+00     1 KG INC-X750
      0
      4    60000 1.50E+00     70000 1.30E+00    140000 1.00E+01    150000 4.50E-01     1 KG SS-302
      4   160000 3.00E-01    240000 1.80E+02    250000 2.00E+01    260000 6.98E+02     1 KG SS-302
      4   270000 8.00E-01    280000 8.92E+01    410000 1.00E-01         0 0.00E+00     1 KG SS-302
      0
      4    60000 8.00E-01     70000 1.30E+00    140000 1.00E+01    150000 4.50E-01     1 KG SS-304
      4   160000 3.00E-01    240000 1.90E+02    250000 2.00E+01    260000 6.88E+02     1 KG SS-304
      4   270000 8.00E-01    280000 8.92E+01    410000 1.00E-01         0 0.00E+00     1 KG SS-304
      0
```

APPENDIX B

Typical ANISN Input Files for PWR and BWR Fuel Assemblies

```
[B50Y101.INP]OCRWM BWR 10 YR,4%,50K BURNUP,52 FA,2.75 IN LEAD
15$$    1     0     1     8     2     1     0     8    80     0
       40     3     4    43    44    32     0    44     0     0
        1     0     0    20     0     0     0     0     5     1
        0     0     0     1     1     0
16**    2R0.0     0.0001    1.420892 368.91
        4R0.0     0.5000    0.0002    F0.0
        T
14*
 T
17**     33R0.1048                 47R0.0
         33R0.4241                 47R0.0
         33R1.296                  47R0.0
         33R4.333                  47R0.0
         33R9.009                  47R0.0
         33R11.65                  47R0.0
         33R24.64                  47R0.0
         33R19.83                  47R0.0
         33R4.703                  47R0.0
         33R26.04                  47R0.0
         33R47.05                  47R0.0
         33R43.24                  47R0.0
         33R29.89                  47R0.0
         33R3.029                  47R0.0
                          640R0.0
         33R0.703                  47R0.0
         33R6.12                   47R0.0
         33R0.0                    47R0.0
         33R53.1                   47R0.0
         33R1.09E+03               47R0.0
         33R8.440E+03              47R0.0
         33R1.020E+05              47R0.0
         33R0.00                   47R0.0
         33R8.860E+06              47R0.0
         33R4.290E+08              47R0.0
         33R7.290E+08              47R0.0
         33R0.0                    47R0.0
         33R7.750E+09              47R0.0
         33R2.000E+08              47R0.0
         33R4.270E+08              47R0.0
         33R5.310E+08              47R0.0
         33R1.390E+09              47R0.0
         33R6.450E+09              47R0.0
        T
3**     33R1.0     47R0.0    39Q80      T
1**     F0.0
4**     32I0.0  3I72.390  9I75.250  3I82.245  10I86.055  2I99.705
        2I101.295  1I101.935  9I103.205   303.205
5**     F1.0
6**     0.0  .0604938 .0453704 .0453704 .0604938 .0604938 .0453704
        .0453704 .0604938 0.00 .0453704 .0462962 .0453704 .0453704
        .0462962 .0453704 0.00 .0453704 .0453704 .0453704 .0453704
        0.00 .0604938 .0604938
7**    -.9759000 -.9511897 -.7867958 -.5773503 -.2182179 +.2182179
```

```
         +.5773503 +.7867958 +.9511897 -.8164965 -.7867958 -.5773503
         -.2182179 +.2182179 +.5773503 +.7867958 -.6172134 -.5773503
         -.2182179 +.2182179 +.5773503 -.3086067 -.2182179 +.2182179
8$$      33R1      4R2       10R3      4R4       11R5      3R6   3R7
         12R8
9$$      33        35        39        35        41        43    35
         37

/  MAT   1, 2  = H
/  MAT   3, 4  = B
/  MAT   5, 6  = C
/  MAT   7, 8  = N
/  MAT   9, 10 = O
/  MAT  11, 12 = Na
/  MAT  13, 14 = AL
/  MAT  15, 16 = SI
/  MAT  17, 18 = CR
/  MAT  19, 20 = FE
/  MAT  21, 22 = NI
/  MAT  23, 24 = CU
/  MAT  25, 26 = ZR
/  MAT  27, 28 = PB
/  MAT  29, 30 = U235
/  MAT  31, 32 = U238
/
/ MIXTURE  33, 34 = FUEL
/ MIXTURE  35, 36 = STEEL
/ MIXTURE  37, 38 = AIR
/ MIXTURE  39, 40 = LEAD
/ MIXTURE  41, 42 = B-SI
/ MIXTURE  43, 44 = CU
/

10$$
/FUEL-
     33  34
     33  34
     33  34
     33  34
     33  34
     33  34
     33  34
     33  34

/STEEL-
     35  36
     35  36
     35  36

/AIR-
     37  38
     37  38

/LEAD-
```

```
     39  40

/B-SI
     41  42
     41  42
     41  42
     41  42
     41  42
     41  42
     41  42

/COPPER
     43  44

11$$
/ FUEL-
     9   10
     17  18
     19  20
     21  22
     23  24
     25  26
     29  30
     31  32
/ STEEL-
     17  18
     19  20
     21  22
/ AIR-
      7   8
      9  10
/LEAD-
     27  28
/B-SI
      1   2
      3   4
      5   6
      9  10
     11  12
     13  14
     15  16
/COPPER
     23  24
12**
/ FUEL
       2R7.691E-3
       2R1.744E-3
       2R6.153E-3
       2R7.316E-4
       2R1.502E-3
       2R2.834E-3
       2R1.168E-4
       2R3.729E-3
/ STEEL
```

```
        2R1.721E-2
        2R6.071E-2
        2R7.218E-3
/ AIR
        2R1.98E-5
        2R5.28E-6
/LEAD
        2R3.296E-2
/B-SI
        2R4.494E-2
        2R9.400E-4
        2R8.600E-3
        2R2.810E-2
        2R2.500E-5
        2R6.690E-3
        2R5.980E-3
/COPPER
        2R8.493E-2
19$$     F1
         T          T
```

```
[P455Y16.INP]PWR 15YR,4%,55K 21 FA,2.50 IN LEAD,NEW N,+1.0BSI
15$$    1     0     1     8     2     1     0     8    80     0
       40     3     4    43    44    32     0    44     0     0
        1     0     0    20     0     0     0     0     5     1
        0     0     0     1     1     0
16**    2R0.0     0.0001    1.420892 347.22
        4R0.0     0.5000    0.0002   F0.0
        T
14*
  T
17**     33R0.7796                 47R0.0
         33R3.155                  47R0.0
         33R9.644                  47R0.0
         33R32.24                  47R0.0
         33R67.02                  47R0.0
         33R86.69                  47R0.0
         33R183.3                  47R0.0
         33R147.5                  47R0.0
         33R34.98                  47R0.0
         33R193.7                  47R0.0
         33R350.0                  47R0.0
         33R321.7                  47R0.0
         33R222.3                  47R0.0
         33R22.53                  47R0.0
                         640R0.0
         33R0.957                  47R0.0
         33R8.33                   47R0.0
         33R0.0                    47R0.0
         33R72.20                  47R0.0
         33R2.170E+02              47R0.0
         33R2.320E+03              47R0.0
         33R4.780E+03              47R0.0
         33R0.00                   47R0.0
         33R7.660E+06              47R0.0
         33R4.250E+08              47R0.0
         33R3.650E+08              47R0.0
         33R0.0                    47R0.0
         33R7.890E+09              47R0.0
         33R1.860E+08              47R0.0
         33R4.350E+08              47R0.0
         33R5.070E+08              47R0.0
         33R1.440E+09              47R0.0
         33R6.690E+09              47R0.0
        T
3**     33R1.0     47R0.0    39Q80     T
1**     F0.0
4**     32I0.0  3I72.390  9I75.250  3I81.610  10I85.420  2I101.610
        2I103.200 1I103.840 9I105.110   305.110
5**     F1.0
6**     0.0  .0604938 .0453704 .0453704 .0604938 .0604938 .0453704
        .0453704 .0604938 0.00 .0453704 .0462962 .0453704 .0453704
        .0462962 .0453704 0.00 .0453704 .0453704 .0453704 .0453704
        0.00 .0604938 .0604938
```

```
7**     -.9759000 -.9511897 -.7867958 -.5773503 -.2182179 +.2182179
         +.5773503 +.7867958 +.9511897 -.8164965 -.7867958 -.5773503
         -.2182179 +.2182179 +.5773503 +.7867958 -.6172134 -.5773503
         -.2182179 +.2182179 +.5773503 -.3086067 -.2182179 +.2182179
8$$      33R1      4R2      10R3      4R4      11R5      3R6   3R7
         12R8
9$$      33        35        39        35        41        43    35
         37

/  MAT    1, 2  = H
/  MAT    3, 4  = B
/  MAT    5, 6  = C
/  MAT    7, 8  = N
/  MAT    9, 10 = O
/  MAT   11, 12 = Na
/  MAT   13, 14 = AL
/  MAT   15, 16 = SI
/  MAT   17, 18 = CR
/  MAT   19, 20 = FE
/  MAT   21, 22 = NI
/  MAT   23, 24 = CU
/  MAT   25, 26 = ZR
/  MAT   27, 28 = PB
/  MAT   29, 30 = U235
/  MAT   31, 32 = U238
/
/ MIXTURE  33, 34 = FUEL
/ MIXTURE  35, 36 = STEEL
/ MIXTURE  37, 38 = AIR
/ MIXTURE  39, 40 = LEAD
/ MIXTURE  41, 42 = B-SI
/ MIXTURE  43, 44 = CU
/

10$$
/FUEL-
     33  34
     33  34
     33  34
     33  34
     33  34
     33  34
     33  34
     33  34

/STEEL-
     35  36
     35  36
     35  36

/AIR-
     37  38
     37  38
```

```
/LEAD-
     39  40

/B-SI
     41  42
     41  42
     41  42
     41  42
     41  42
     41  42
     41  42

/COPPER
     43  44

11$$
/ FUEL-
     9   10
     17  18
     19  20
     21  22
     23  24
     25  26
     29  30
     31  32
/ STEEL-
     17  18
     19  20
     21  22
/ AIR-
      7   8
      9  10
/LEAD-
     27  28
/B-SI
      1   2
      3   4
      5   6
      9  10
     11  12
     13  14
     15  16
/COPPER
     23  24
12**
/ FUEL
       2R6.436E-3
       2R1.374E-3
       2R4.848E-3
       2R5.766E-4
       2R1.819E-3
       2R2.599E-3
       2R1.303E-4
       2R3.088E-3
```

```
/ STEEL
        2R1.721E-2
        2R6.071E-2
        2R7.218E-3
/ AIR
        2R1.98E-5
        2R5.28E-6
/LEAD
        2R3.296E-2
/B-SI
        2R4.494E-2
        2R9.400E-4
        2R8.600E-3
        2R2.810E-2
        2R2.500E-5
        2R6.690E-3
        2R5.980E-3
/COPPER
        2R8.493E-2
19$$     F1
         T         T
```

APPENDIX C

Radialth.wk1: A Lotus 123® Worksheet to Calculate Cask Radial Temperature Distributions

Contents

1.0 Introduction

This report documents a Lotus 123® Release 2.2 worksheet, radialth.wk1, that provides a fast, simple method of calculating the radial steady-state temperature distribution of a multilayered cask containing spent nuclear fuel. The worksheet uses a 1-dimensional thermal resistance technique to calculate the temperature distribution through the cask.

The worksheet uses built in tables to define temperature dependent thermal properties for up to seven cask layers. A materials library is provided in the worksheet which contains thermal conductivities for twenty materials commonly used in cask designs. The user can specify any number of fuel assemblies, decay heat per assembly, and solar heat loads for use in the analysis, as well as one layer through which heat transfer by thermal radiation is applied. The worksheet accounts for convection in a cask gap or liquid neutron shield by including effective thermal conductivities for both air and water in the material library. The Wooton-Epstein correlation is used to estimate the maximum fuel pin temperatures.

Inputs to the worksheet are entered and modified by typing over highlighted cells in the worksheet summary. A quick recalculation option checks the effects of changing geometry or heat loads, and a full recalculation option pulls material properties out of the material library, sets up internal radiation equations, and interpolates the thermal conductivities. At the conclusion of the full recalculation, a plot of temperature versus location in the cask layers is shown on the screen and can be plotted by the user.

The use of the worksheet is described in Section 2. The worksheet calculation method and program flow are described in Sections 3 and 4. Instructions for modifying the worksheet to include additional materials or different calculation methods are provided in Section 5.

2.0 Use of Worksheet

The input screen/results summary for the worksheet is shown below. **Values which can be modified are shown in boldface below and are highlighted in the worksheet itself.** It is highly recommended that the installation of Lotus 123® in which the worksheet is used be configured with the small type display option (ex. EGA 80x43) in order to see the whole input screen at once. To change a worksheet parameter, the new value is simply input over the old. The input parameters are discussed below.

Number of Assemblies	21		Internal Radiation	
Decay Heat per Assembly	0.66 Kw			
Ambient Temperature	125 °F		hr	0.394624
Solar Heat Load	127 Btu/hr-ft^2		ei	0.15
Emissivity of Outer Surface	0.587		eo	0.587
Cask Inner Radius	28.500 in			
Cask Cavity Length	180.500 in			
Convection Coefficient	0.921 Btu/hr-ft^2-°F)			
Radiation Coefficient	1.125 Btu/hr-ft^2-°F)			

Cask Layer	Material	Thickness (in)	k (Btu/hr-ft-°F)	Ti (°F)	To (°F)
Inner Shell	SS304	1.130	8.700	391.226	388.988
Gamma Shield	Lead	3.500	18.228	388.988	385.921
Outer Shell	SS304	1.500	8.700	385.921	383.373
Neutron Shield	Bsilicone	5.880	1.400	383.373	327.281
Inner Jacket	Copper	0.125	225.360	327.281	327.274
Air Gap	Air	0.134	0.020	327.274	259.093
Outer Jacket	SS304	0.125	8.700	259.093	258.917

Internal Radiation? Yes   Layer Air Gap
Cask Orientation   Horizontal

Number of Rows in Assembly   15 (15x15 assembly)
Height of Assumed Array (P/4)   4.01 ft
Length of Bundle   12.00 ft
Maximum Fuel Temperature   649.64 °F (Wooton-Epstein)

Press alt-c to update conductivities and recalculate.
Press F9 to recalculate using the present conductivities.
Press F10 to display current graph.

The materials library includes:

ss304	duranium	air	argon	void
lead	copper	airconv	helium	balsa
csteel	ns3	water	nitrogen	redwood
ns3stif	bsilicone	h20conv	aluminum	purethan

Number of Assemblies: (value) This value is the number of fuel assemblies in the cask. It is multiplied by the decay heat per assembly to determine the total decay heat load (cask payload) in the cask.

Decay Heat Per Assembly: (value, kW) The decay heat of an individual fuel assembly. In order to specify simply a cask heat load, enter "1" for the number of assemblies and enter the cask heat load in this cell.

Ambient Temperature: (value, °F) The bulk air temperature around the cask outer surface.

Solar Heat Load: (value, Btu/hr·ft^2) The solar heat flux on the cask surface.

Emissivity of Outer Surface: (value) The emissivity of the cask outer surface.

Cask Inner Radius: (value, in) The inside radius of the cas k (layer 1).

Cask Cavity Length: (value, in) The length of the cask internal cavity. Used in calculating the area over which the cask internal heat load is applied for determining the heat flux.

Cask Layer: (label) The names of each of the up to seven layers. The layer at the top of the list is the cask inside layer (layer 1). The layer name may be entered as "n/a" for layers which are not involved in the calculation. Layers through which radiation heat transfer is applied must have layers on each side which are included in the calculation. An example of a cask model is shown in Figure 1.

Material: (label) The name of the materials comprising each layer. The material names must all be included in the material library and must exactly match the name in the material library. Material names may be entered in upper, lower, or mixed case (as can any entry in both worksheets). The materials "airconv" and "h20conv" include the effects of convection in the layer. Every layer must have a material associated with it. Materials for layers not included in the analysis can be labelled "n/a".

Thickness: (value, in) The thickness of each layer. Layers which are not used should have a thickness of 0. Layers through which radiation heat transfer is applied must have a non-zero thickness to avoid a division by zero error.

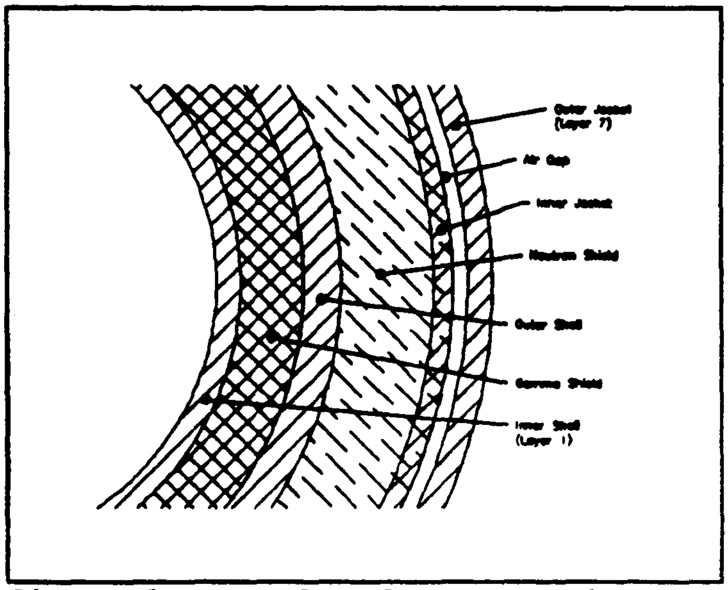

Figure 1: Example of Cask Model

Internal Radiation?: (label, "yes" or "no") Tells the worksheet whether to include thermal radiation between two layers in the calculation. Internal radiation cannot be applied on either the inside or outside layers, and both neighboring materials must have emissivities in their library entries (any of the metals).

Layer: (label) Tells the worksheet which layer is to include the thermal radiation heat transfer mode. If more than one layer needs to have thermal radiation, the worksheet must be modified as discussed in Section 5. The layer name must exactly match (except in case) one of the layers in the geometry list.

Cask Orientation: (label, "horizontal" or "vertical") Tells the worksheet whether the cask is standing on one end (vertical) or lying on its side (horizontal). This parameter allows the worksheet to adjust the heat transfer coefficient used on the cask outer boundary.

Number of Rows in Assembly: (value) The number of fuel pins in each row of a fuel bundle. For a 15x15 PWR assembly the value would be 15.

Height of Assumed Array: (value, ft) The height of one side of a fuel bundle. For a multi-assembly cask this value is equal to the perimeter around the fuel bundle array in the basket divided by four [2].

Length of Bundle: (value, ft) The length of the active fuel region in the fuel assembly.

After the geometry, heat load, and radiation parameters have been entered, the key sequence alt-c (hold down the {alt} key while pressing {c}) begins a full worksheet recalculation. This includes loading the material properties for the correct materials into the worksheet, adjusting the heat transfer equations to include (or remove) thermal radiation, interpolating the temperature dependent thermal properties, forcing 123® to recalculate the spreadsheet, and plotting a chart of the layer temperatures versus radius.

A fast recalculation which does not update the material properties or internal radiation can be started by pressing the F9 {calc} key. This forces 123® to iterate the values in the spreadsheet forty times and is useful when only a layer thickness or a heat load has been changed and the effect on the thermal conductivities is expected to be negligible. Pressing alt-k will perform one interpolation of the thermal conductivity tables (rather than the four performed by pressing alt-c). This is useful for quickly updating the thermal conductivities and using F9 to recalculate the worksheet. Pressing the F10 {graph} key will display the current cask radial temperature profile, including any changes made by recalculating the worksheet.

3.0 Calculation Method

The cask outside surface temperature is calculated first, and then the temperature drops across each layer are determined, working inward. Forty iterations are made for each calculation before the material properties are linearly interpolated from the temperature dependent material library tables. This is repeated four times during each recalculation.

All of the temperature drops, including the cask outer surface temperature, are calculated using the thermal resistance concept,

$$Q = \frac{T_i - T_o}{\Sigma R_n} \qquad (1)$$

where Q is the total cask cavity heat load (Btu/hr), T_i is the inside temperature, T_o is the outside temperature, and R_n is the total thermal resistance for heat transfer mode n. Heat transfer modes used in this worksheet are conduction, convection, and radiation. A detailed description of the equations used in the worksheet is given below.

3.1 Ambient to Outer Surface

The cask outer surface temperature is calculated assuming that heat is transferred from the cask outer surface to the air by convection and radiation. The contribution due to radiation is included in the convection term by superposing their effects as shown below.

$$Q = h_c A(T_o - T_\infty) + \varepsilon\sigma A(T_o^4 - T_\infty^4) \qquad (2)$$

where Q is the total cask cavity heat load (Btu/hr), ε is the cask outside surface emissivity, σ is the Stefan-Boltzmann constant, h_c is the convective heat transfer coefficient, and A is the cask surface area for heat transfer. For a horizontal cylinder, h_c is equal to [4],

$$h_c = 0.18(T_o - T_\infty)^{1/3} \qquad (3)$$

For a vertical cylinder h_c is assumed to be that of a vertical plate, and is equal to the value given by Equation 3 after replacing the coefficient 0.18 with 0.19 [4]. The total heat load on the cask outer surface, Q, is the sum of the total cask decay heat and the solar heat flux,

$$Q = Q_{fuel} + 2\pi r_o l q_{solar} \tag{4}$$

where r_o is the cask outside radius, l is the cask inner cavity length, Q_{fuel} is the total cask cavity heat load, and q_{solar} is the solar heat flux.

By defining a radiation coefficient h_r as,

$$h_r = \varepsilon\sigma(T_o+T_\infty)(T_o^2+T_\infty^2) \tag{5}$$

Equation 2 can be rearranged into the form,

$$T_o = \frac{Q}{A(h_c+h_r)} + T_\infty \tag{6}$$

This relation gives the outside cask temperature in terms of the total cask heat load, ambient temperature, cask area, and the sum of the heat transfer coefficients. Because the heat transfer coefficients are in turn dependent on the cask surface temperature, iterations are necessary to determine the cask surface temperature. The radial worksheet iterates forty times for each calculation step.

3.2 Internal Temperature Drops

The only mode of heat transfer assumed to occur in the internal cask layers is conduction. The thermal resistance for conduction across concentric cylinders is equal to,

$$R_c = \frac{\ln\left(\frac{r_o}{r_i}\right)}{2\pi k l} \tag{7}$$

where r_o is the outside radius, r_i is the inside radius, and k is the thermal conductivity of the layer material. Substituting into Equation 1 and rearranging gives,

$$T_i = \frac{Q \cdot \ln\left(\frac{r_o}{r_i}\right)}{2\pi k l} + T_o \tag{8}$$

where Q in this case is equal to the total decay heat generation rate of the fuel assemblies.

3.2.1 Internal Thermal Radiation

Layers through which there is thermal radiation heat transfer are modelled as having two thermal resistances in parallel, radiation and convection. The total thermal resistance for two resistances in parallel is given by,

$$R_{total} = \frac{1}{\frac{1}{R_c} + \frac{1}{R_r}} \tag{9}$$

The resistance due to conduction, R_c is identical to that in Equation 7, and the resistance due to radiation is given by,

$$R_r = \frac{1}{2\pi h_r r_i l} \tag{10}$$

where the radiation coefficient h_r for two concentric cylinders is given by,

$$h_r = \frac{\sigma(T_i+T_o)(T_i^2+T_o^2)}{\frac{1}{\varepsilon_i} + \frac{r_i}{r_o}\left(\frac{1}{\varepsilon_o}-1\right)} \tag{11}$$

where ε_i and ε_o are the emissivities of the inside and outside surfaces respectively. Substituting Equations 7, 9, and 10 into Equation 1 and rearranging gives the temperature on the inside surface,

$$T_i = \frac{Q}{2\pi h_r r_i l + \frac{2\pi k l}{\ln\left(\frac{r_o}{r_i}\right)}} + T_o \tag{12}$$

Equation 12 is inserted by the worksheet into the cell corresponding to the layer specified for internal radiation in the input/output screen. The emissivities of the adjacent layers are taken from the material library. The radiation coefficient h_r is calculated by assuming temperatures for Equation 11 and iterating 40 times when the worksheet is recalculated.

3.3 Internal Convection

Internal convection is handled in the worksheet by substituting the thermal conductivity with an effective thermal conductivity which includes the effects of convection. Effective conductivities are provided in the material library for air and water (airconv and h20conv). Prior to inserting either of these tables into the worksheet, the user should verify that taking credit for convection in that layer is reasonable. This can be done by calculating the Grashof number for the annular region,

$$Gr_\delta = \frac{g\beta (T_i - T_o)(r_o - r_i)^3}{\nu^2} \tag{13}$$

where ß is the thermal coefficient of volume expansion, g is the gravitational constant, and nu is the kinematic viscosity. The fluid flow in the annulus must be in the turbulent regime in order for the convection corrected conductivities to be used. Turbulent flow occurs when the product of the Grashof and the Prandtl numbers ($Gr_\delta Pr$) is greater than 10^7 [1].

3.4 Maximum Fuel Bundle Temperature

The maximum fuel bundle temperature is estimated using the Wooton-Epstein correlation in the same manner as described in Reference 2. The temperature is given by the relation [2],

$$Q = \sigma C_1 F_1 A_1 (T_e^4 - T_c^4) + C_2 A_1 (T_e - T_c)^{\left(\frac{4}{3}\right)} \tag{14}$$

Where C_1 is a geometric constant equal to $4N/(N+1)^2$ (N odd) or $4/(N+2)$ (N even), N is the number of rod rows in a fuel bundle, F_1 is an exchange factor (0.539 [2]), A_1 is the bundle surface area, H is the height of one side of a bundle (ft), T_e is the hottest rod cladding temperature, T_c is the cavity wall temperature, C_2 is a convection constant (0.118 [2]), and σ is the Stefan-Boltzmann constant. For multi-assembly casks, H is equal to one fourth of the perimeter of the basket fuel bundle array. The bundle surface area is equal to 4 times the assembly height times the assembly length, L [2].

Equation 14 is solved for T_e, resulting in an equation which gives T_e as a function of itself. An initial value is assumed and the equation is iterated until it converges. Because the appearance of T_e for which the equation must be solved in order to allow convergence changes with the values of the other parameters in Equation 14, both appearances of T_e are solved for. The relation which converges is then displayed in the input/output screen.

4.0 Worksheet Program Flow

The recalculation macros for the worksheet consists of a main macro and several subroutines. A description of the program flow for the radial worksheet is given below.

The worksheet is organized in the following manner. The worksheet calculations are carried out in the area around cell A1. The input/output screen is located starting at cell V1. The main and interpolation macros are located below the main worksheet calculation area, starting at A65. The material library is located below the macros starting at cell A213 and extending to the right. The macros which handle internal radiation are then located below the material library, starting at cell A242.

The controlling macro is "\c" which updates the material properties and forces the worksheet to be recalculated. The controlling macro does the following,

1) Recalculates the worksheet, updating all formulas and references.
2) Copies the thermal conductivities of each of the materials specified in the input screen to the appropriate table.
3) Checks for a yes response to the internal radiation prompt. Calls subroutine "intrad" if internal radiation is required. Otherwise it calls "nintrad".
4) Recalculates the worksheet and calls subroutine "\k" to interpolate the thermal conductivities. These is repeated 4 times.
5) Recalculates the worksheet a final time.

6) Moves the cellpointer to the input/output screen.
7) Plots the current graph of the cask radial temperature distribution.

Subroutine "\k" calls the seven subroutines that interpolate the thermal conductivities for each of the seven layers. These are \i, \g, \s, \n, \ijacket, \mjacket, and \ojacket. Each of these subroutines is identical with only the cell addresses changed.

An example of an interpolation macro is \i:

1) Deletes the range "inner", goes to location "table1" (the top of the temperature list of the material properties for the inside layer), and creates the range "inner" which includes all of the temperature entries.
2) Sets "number1" to the number of rows in "inner"
3) If there is only one entry, "number1" will be a large number. If "number1" is greater than or equal to 24 then the thermal conductivity of the inside layer is set equal to the conductivity entry.
4) Checks to see if the largest temperature is less than the average of the layer inside and outside temperatures, and sets the thermal conductivity equal to the corresponding entry if it is.
5) Sets the conductivity equal to the entry corresponding to the lowest temperature if the average layer temperature is less than the lowest table temperature.
6) Sets "tm" equal to the average layer temperature.
7) Begins a loop which calls the subroutine "interp".
8) Sets the thermal conductivity equal to the value obtained in "interp."

The subroutine "interp" performs the following tasks,

1) Moves the cellpointer down one row.
2) Checks to see if the current cell is greater than the average layer temperature. If it is the subroutine performs a linear interpolation between the current cell temperature and the next lower cell's temperature, and breaks out of the for loop. If the cell temperature is not greater than the current cell temperature it repeats the for loop.

The subroutine "nintrad" is called by "\c" if internal radiation is not included in the model. Nintrad replaces cells F12..F17 with the conduction only equation for T_1 (Equation 8). Nintrad then erases the internal radiation coefficient and emissivities from the input/output screen.

Subroutine "intrad" is called by "\c" when internal radiation is included in the model. The @vlookup function is used to copy the correct temperature, material, and geometry parameters for the layer in question into the cells referenced by h_r. Intrad then does the following,

1) Calls "nintrad" to clear the worksheet of any previous internal radiation.
2) Checks if the affected layer is either the innermost or outermost cask layer. If it is the innermost or outermost layer then the internal radiation switch in the input screen is changed to "no", the worksheet is recalculated, and execution is terminated because internal radiation is not applicable to these layers.
3) Copies the emissivities of the surrounding layers into cells C288 and C290.
4) Copies the emissivities and radiation coefficients to the input/output screen.
5) Copies the value of T_i from B303 to the T_i of the affected layer in the main calculation area.

5.0 Worksheet Modifications

The worksheets can be modified to model different geometries. For example, an axial worksheet can be created by modifying the radial worksheet. Modifications which can be made include adding layers to the model, adding materials to the library, allowing two or more layers with internal radiation, and changing the heat transfer coefficients.

5.1 Adding Layers

Adding layers to the radial worksheet is a complicated modification which involves reorganizing the worksheet and creating and editing macros. It is recommended that casks with more than seven layers be modelled by using two worksheets. One unmodified worksheet would model the outside layers and one (or more) modified worksheet(s) would model the inside layers. The modification required in the internal worksheets is to replace the contents of the cell that calculates the cask surface temperature with the inner temperature calculated in the outer worksheet. This is done in the following manner.

1) Copy the radial worksheet file to two new files (ex. outside.wk1 and inside.wk1).

2) Enter the proper geometry for both worksheets. The cask inside radius for the outer worksheet should be equal to the outside radius of the inner worksheet. Recalculate the outside worksheet.

3) Load the inside worksheet (inside.wk1) and replace the contents of cell G18 with the formula +<<*drive:\path\file.wk1*>>F12 (ex. +<<c:\123\outside.wk1>>F12).

4) If both the inside and outside worksheets are in the current 123® directory then the drive and path name can be omitted from the function.

5) If dynamic linking of the two worksheets is not desired, the contents of cell G18 can simply be replaced with the desired temperature for the outside layer in that worksheet. This method also works to provide a constant temperature boundary condition on the outside of the cask.

5.2 Adding Materials

Materials are added to the worksheet material library by creating a range which contains the temperatures and corresponding thermal conductivities in a blank portion of the worksheet. The range name is the name that is entered in the worksheet input screen to select a material for a layer. The material library is organized in groups of three columns. The first column contains the temperatures, the second column contains the thermal conductivities, and the third column is blank. Emissivities are placed in the first column below the temperatures. The contents of the material library are listed in Appendix C. A detailed example of adding a material is given below.

1) Goto cell AW212. Enter the name of the material by which it will be called by the worksheet (ex. lithium).

2) Goto cell AW213. Enter a description of the material.

3) Goto cell AW214 (optional). Enter the name of the reference for the material properties.

4) Enter the label T in cell AW216 and the label k in cell AX216.

5) Create a range with the same name that is entered in cell AW212. The range must include twenty rows and two columns. In this case the range will include AW217..AX236. Example:
/rnclithium{return}aw217{return}ax236{return}

6) Enter the thermal properties with the temperatures in °F in cells AW217, AW218,... and the thermal conductivities in cells AX217, AX218,... Up to 19 entries can be made in the table. Entries in any material table can be changed at any time simply by replacing the old entries with new ones.

7) If the material will ever be used as a surface for internal radiation, enter the label Emissivity in cell

AW237, and enter the value of the emissivity in cell AW238.

8) To delete a material from the library use the /rnd command to delete the range from the worksheet.

5.3 Additional Layers With Internal Radiation

To model a cask with more than one layer through which heat is transferred by radiation requires disabling the automatic internal radiation macros and "hardwiring" internal radiation heat transfer into the layer temperature calculations. It is recommended that casks with more than one internal radiation layer be modelled using two linked worksheets as discussed above. Each linked worksheet would contain one layer with internal radiation. If this is not an acceptable solution, an outline of how to modify the worksheet is given below.

1) Goto range \c and erase the cells {if @left(@... } and {nintrad} from the macro (B192 and B193). Move the remaining lines up two rows to fill the in the blanks.

2) Enter the formulas for all required h_r's (Equation 11) into blank cells in the worksheet, referencing columns F and G for the inner and outer temperatures.

3) Enter the formulas for the T_i's (Equation 12) into the proper rows in column F.

5.4 Changing Coefficients

Natural convection and radiation heat transfer coefficients used in the worksheet can be modified to model different geometries. It is in this manner that an axial worksheet can be created from the radial worksheet. The equations which calculate the T_i's are in column F and can be modified for different geometries. The cells containing the natural convection and the radiation heat transfer coefficients for the outer surface are B25 and B26 respectively. The cell containing the radiation heat transfer coefficient for internal radiation is A300 and the cell that calculates T_i for internal radiation is A303. The cell that calculates the cask surface temperature is G18.

Appendix A Examples

Two sample problems are included in this report to document the correct operation of the worksheet. The worksheet models the prefire case of the HTAS1 sample problem 1 and the fire case of the HTAS1 sample problem 2 in the radial direction [5]. The results are then compared to those listed in the HTAS1 manual. The first case models the cask with an ambient temperature of 100 °F and no solar heat load. Due to the differences between the worksheet and HTAS1, the cavity heat load was reduced from 11.5 kW to 11.08 kW. The worksheet output summary is shown below.

Number of Assemblies	1	
Decay Heat per Assembly	11.08	kW
Ambient Temperature	100	°F
Solar Heat Load	0	Btu/hr-ft^2
Emissivity of Outer Surface	0.500	
Cask Inner Radius	6.750	in
Cask Cavity Length	178.000	in
Convection Coefficient	0.931	Btu/hr-ft^2-°F)
Radiation Coefficient	0.863	Btu/hr-ft^2-°F)

Cask Layer	Material	Thickness (in)	k (Btu/hr-ft-°F)	Ti (°F)	To (°F)
Cavity	Air	0.000	0.019	264.875	264.875
Inner Shell	SS304	0.310	8.700	264.875	262.780
Shield	Lead	6.630	19.033	262.780	248.657
Outer Shell	SS304	1.250	8.700	248.657	244.580
Neutron Shield	H20Conv	4.500	18.850	244.580	238.910
Water Jacket	SS304	0.160	8.700	238.910	238.528
N/A	N/A	0.000	8.700	238.528	238.528

Internal Radiation? No Layer N/A
Cask Orientation Horizontal

Number of Rows in Assembly	15	(15x15 assembly)
Height of Assumed Array (P/4)	0.73	ft
Length of Bundle	12.00	ft
Maximum Fuel Temperature	827.03	°F (Wooton-Epstein)

Example 1 Input/Output Summary

The second case models the same geometry with an ambient temperature of 130 °F, an emissivity of 0.8 and an internal void in the neutron shield. The worksheet output summary is shown below.

Number of Assemblies	1		Internal Radiation		
Decay Heat per Assembly	11.08 kW				
Ambient Temperature	130 °F		hr	1.577821	
Solar Heat Load	0 Btu/hr-ft^2		ei	0.587	
Emissivity of Outer Surface	0.800		eo	0.587	
Cask Inner Radius	6.750 in				
Cask Cavity Length	178.000 in				
Convection Coefficient	0.855 Btu/hr-ft^2-°F)				
Radiation Coefficient	1.468 Btu/hr-ft^2-°F)				

Cask Layer	Material	Thickness (in)	k (Btu/hr-ft-°F)	Ti (°F)	To (°F)
Cavity	Air	0.000	0.023	463.571	463.571
Inner Shell	Csteel	0.310	23.605	463.571	462.799
Shield	Lead	6.630	17.849	462.799	447.738
Outer Shell	SS304	1.250	8.909	447.738	443.757
Neutron Shield	Void	4.500	0.000	443.757	237.118
Water Jacket	Csteel	0.160	24.861	237.118	236.985
N/A	N/A	0.000	8.700	236.985	236.985

Internal Radiation? Yes   Layer Neutron Shield
Cask Orientation   Horizontal

Number of Rows in Assembly	15 (15x15 assembly)
Height of Assumed Array (P/4)	0.73 ft
Length of Bundle	12.00 ft
Maximum Fuel Temperature	931.21 °F (Wooton-Epstein)

Example 2 Input/Output Summary

The results of the worksheet calculations compared to those of Reference 5 are shown below.

Layer	Worksheet Example 1 °F	Ref 5 Problem 1 °F	Worksheet Example 2 °F	Ref 5 Problem 2 °F
Cavity	264.87	264.55	463.6	451.4
Inner	262.78	262.46	462.8	450.6
Shield	248.66	248.36	447.7	435.7
Outer	244.58	244.28	443.7	432.1
Neutron	238.91	238.61	237.1	234.4
Jacket	238.53	238.22	237.0	234.3

Appendix B Radial Worksheet Listing

B.1 Cell Listing

```
A1: [W23] 'Cask Radial Temperature Worksheet
D1: [W13] 'by Kyle Jones 1/9/89
V1: [W20] 'Number of Assemblies
X1: (F0) U [W11] 1
A2: [W23] 'Decay Heat per Assy
B2: [W11] (X2)
C2: 'kW
D2: (F1) [W13] 3414.43*B2
E2: [W15] 'Btu/hr
V2: [W20] 'Decay Heat per Assembly
X2: (F2) U [W11] 11.08
Y2: [W14] 'kW
A3: [W23] 'No. of Assys
B3: [W11] (X1)
D3: [W13] (B3)
V3: [W20] 'Ambient Temperature
X3: (F0) U [W11] 100
Y3: [W14] '°F
A4: [W23] 'Solar Heat Load
B4: [W11] (X4)
C4: 'Btu/hr-ft2
D4: [W13] (B4)
E4: [W15] 'Btu/hr-ft2
V4: [W20] 'Solar Heat Load
X4: (F0) U [W11] 0
Y4: [W14] 'Btu/hr-ft^2
A5: [W23] 'Ambient Temperature
B5: [W11] (X3)
C5: '°F
D5: [W13] (B5)
E5: [W15] '°F
V5: [W20] 'Emissivity of Outer Surface
X5: (F3) U [W11] 0.5
A6: [W23] 'Cask I.R.
B6: [W11] (X6)
C6: 'in
D6: (F3) [W13] (B6/12)
E6: [W15] 'ft
V6: [W20] 'Cask Inner Radius
X6: (F3) U [W11] 6.75
Y6: [W14] 'in
A7: [W23] 'Cask Length
B7: [W11] (X7)
C7: 'in
D7: (F3) [W13] (B7/12)
E7: [W15] 'ft
V7: [W20] 'Cask Cavity Length
X7: (F3) U [W11] 178
Y7: [W14] 'in
A8: [W23] 'Shell Emissivity
B8: [W11] (X5)
D8: [W13] (B8)
V8: [W20] 'Convection Coefficient
X8: (F3) [W11] (B25)
Y8: [W14] 'Btu/hr-ft^2-°F)
V9: [W20] 'Radiation Coefficient
X9: (F3) [W11] (B26)
Y9: [W14] 'Btu/hr-ft^2-°F)
A10: [W23] 'Layer
B10: [W11] ^Thickness
C10: ^I.R.
D10: [W13] ^O.R.
E10: [W15] ^k
F10: ^Ti
G10: [W13] ^To
H10: 'Material
B11: [W11] ^(in)
C11: ^(ft)
D11: [W13] ^(ft)
E11: [W15] ^(Btu/hr-ft-°F)
F11: ^(°F)
G11: [W13] ^(°F)
V11: [W20] 'Cask Layer
W11: ^Material
X11: [W11] ^Thickness
Y11: [W14] ^k
Z11: ^Ti
AA11: ^To
A12: [W23] @PROPER(V13)
B12: [W11] (X13)
C12: (F3) ($B$6)/12
D12: (F3) [W13] (B12/12+C12)
E12: (F3) [W15] 0.0191919099
F12: (F2) ($B$21*@LN(D12/C12))/(2*3.1416*[illegible]*$D$7)+G12
G12: (F2) [W13] (T12)
H12: @LOWER(W13)
I12: 1
X12: [W11] ^(in)
Y12: (F3) [W14] ^(Btu/hr-ft-°F)
Z12: ^(°F)
AA12: ^(°F)
A13: [W23] @PROPER(V14)
B13: [W11] (X14)
C13: (F3) (D12)
D13: (F3) [W13] (B13/12+C13)
E13: (F3) [W15] 8.7
```

```
F13: (F2) ($B$21*@LN(D13/C13))/(2*3.1416*KGAMMA*$D$7)+G13
G13: (F2) [W13] (TI3)
H13: @LOWER(W14)
I13: 2
V13: U [W20] 'Cavity
W13: U 'Air
X13: (F3) U [W11] 0
Y13: (F3) [W14] (KINNER)
Z13: (F3) (TI1)
AA13: (F3) (G12)
AB13: 1
A14: [W23] @PROPER(V15)
B14: [W11] (X15)
C14: (F3) (D13)
D14: (F3) [W13] (B14/12+C14)
E14: (F3) [W15] 19.032031472
F14: (F2) ($B$21*@LN(D14/C14))/(2*3.1416*KOUTER*$D$7)+G14
G14: (F2) [W13] (TI4)
H14: @LOWER(W15)
I14: 3
V14: U [W20] 'Inner Shell
W14: U 'SS304
X14: (F3) U [W11] 0.31
Y14: (F3) [W14] (KGAMMA)
Z14: (F3) (TI2)
AA14: (F3) (G13)
AB14: 2
A15: [W23] @PROPER(V16)
B15: [W11] (X16)
C15: (F3) (D14)
D15: (F3) [W13] (B15/12+C15)
E15: (F3) [W15] 0.7
F15: (F2) ($B$21*@LN(D15/C15))/(2*3.1416*KNEUTRON*$D$7)+G15
G15: (F2) [W13] (TI5)
H15: @LOWER(W16)
I15: 4
V15: U [W20] 'Shield
W15: U 'Lead
X15: (F3) U [W11] 6.63
Y15: (F3) [W14] (KOUTER)
Z15: (F3) (TI3)
AA15: (F3) (G14)
AB15: 3
A16: [W23] @PROPER(V17)
B16: [W11] (X17)
C16: (F3) (D15)
D16: (F3) [W13] (B16/12+C16)
E16: (F3) [W15] 10.049822687
F16: (F2) ($B$21*@LN(D16/C16))/(2*3.1416*KIJACKET*$D$7)+G16
G16: (F2) [W13] (TI6)
H16: @LOWER(W17)
I16: 5
V16: U [W20] 'Outer Shell
W16: U 'SS304
X16: (F3) U [W11] 1.25
Y16: (F3) [W14] (KNEUTRON)
Z16: (F3) (TI4)
AA16: (F3) (G15)
AB16: 4
A17: [W23] @PROPER(V18)
B17: [W11] (X18)
C17: (F3) (D16)
D17: (F3) [W13] (B17/12+C17)
E17: (F3) [W15] 0.7
F17: (F2) ($B$21*@LN(D17/C17))/(2*3.1416*KWJACKET*$D$7)+G17
G17: (F2) [W13] (TI7)
H17: @LOWER(W18)
I17: 6
V17: U [W20] 'Neutron Shield
W17: U 'H20Conv
X17: (F3) U [W11] 4.5
Y17: (F3) [W14] (KIJACKET)
Z17: (F3) (TI5)
AA17: (F3) (G16)
AB17: 5
A18: [W23] @PROPER(V19)
B18: [W11] (X19)
C18: (F3) (D17)
D18: (F3) [W13] (B18/12+C18)
E18: (F3) [W15] 0.7
F18: (F2) ($B$21*@LN(D18/C18))/(2*3.1416*KOJACKET*$D$7)+G18
G18: (F2) [W13] (B83/(B87*B84)+D8)
H18: @LOWER(W19)
I18: 7
V18: U [W20] 'Water Jacket
W18: U 'SS304
X18: (F3) U [W11] 0.16
Y18: (F3) [W14] (KWJACKET)
Z18: (F3) (TI6)
AA18: (F3) (G17)
AB18: 6
V19: U [W20] 'N/A
W19: U 'N/A
X19: (F3) U [W11] 0
Y19: (F3) [W14] (KOJACKET)
Z19: (F3) (TI7)
AA19: (F3) (G18)
AB19: 7
A21: [W23] 'Total Decay Heat
B21: (F2) [W11] ($D$2*$D$3)
C21: 'Btu/hr
V21: [W20] 'Internal Radiation?
W21: U 'No
X21: [W11] "Layer
```

```
Y21: U [W14] 'N/A
A22: [W23] 'Total Solar Load
B22: (F2) [W11] ($D$4)*(2*3.1416*$D$10*$D$7)
C22: 'Btu/hr
E22: [W15] 'Wooten-Epstein
V22: [W20] 'Cask Orientation
W22: U 'Horizontal
A23: [W23] 'Total Shell Heat Load
B23: (F2) [W11] (B21+B22)
C23: 'Btu/hr
E23: [W15] 'C1
F23: (F4) @IF($F$24/2=@INT($F$24/2),4/($F$24+2),4*$F$24/($F$24+1)^2)
H23: 'Tguess
A24: [W23] 'Cask Outer Area
B24: (F2) [W11] 2*3.1416*$D$10*$D$7
C24: 'ft^2
E24: [W15] 'N
F24: @INT((X24^2*X1)^0.5+0.5)
H24: @IF(FLAG=0,1000,(H27))
I24: '°R
V24: [W20] 'Number of Rows in Assembly
X24: (F0) U [W11] 15
Y24: [W14] +"("&@STRING(X24,0)&"x"&@STRING(X24,0)&" assembly)"
A25: [W23] 'Convection Coefficient
B25: (F2) [W11] @IF(@UPPER(@LEFT(W22,1))="V",0.19*($G$10-$B$5)^(1/3),0.18*($G$10-$B$5)^(1/3))
C25: 'Btu/hr-ft2-°F
E25: [W15] 'H (ft)
F25: +$X$25
H25: @IF(FLAG=0,1000,(H28))
V25: [W20] 'Height of Assumed Array (P/4)
X25: (F2) U [W11] 0.7292
Y25: [W14] 'ft
A26: [W23] 'Radiation Coefficient
B26: (F2) [W11] (0.0000000017)*$D$8*($D$5+$G$10+919.34)*(($D$5+459.67)^2+($G$10+459.67)^2)
C26: 'Btu/hr-ft2-°F
E26: [W15] 'A1 (ft^2)
F26: 4*F25*X26
H26: 'Tcalc
V26: [W20] 'Length of Bundle
X26: (F2) U [W11] 12
Y26: [W14] 'ft
A27: [W23] 'Shell Heat Xfer Coeff
B27: (F2) [W11] (B25+B26)
C27: 'Btu/hr-ft2-°F
E27: [W15] 'To (°R)
F27: (Z21+459.67)
G27: [W13] "calc 1
H27: ((F29-F31*F23*F30*F26*(H24^4-F27^4))/(F28*F26))^0.75+F27
I27: '°R
V27: [W20] 'Maximum Fuel Temperature
X27: (F2) [W11] @IF(@ISERR(H27),(H28-459.67),(H27-459.67))
Y27: [W14] '°F (Wooten-Epstein)
E28: [W15] 'C2
F28: 0.118
G28: [W13] "calc 2
H28: ((F29-F28*F26*(H25-F27)^1.3333)/(F31*F23*F30*F26)+F27^4)^0.25
I28: '°R
E29: [W15] 'Q
F29: (B21)
V29: [W20] 'Press alt-c to update conductivities and recalculate.
E30: [W15] 'F1
F30: 0.539
H30: 'Flag
V30: [W20] 'Press F9 to recalculate using the present conductivities.
E31: [W15] 'sigma
F31: (S2) 0.0000000017
H31: 1
V31: [W20] 'Press F10 to display current graph.
V33: [W20] 'The materials library includes:
A35: [W23] 'Temperature Dependent Thermal Properties
V35: [W20] ^ss304
W35: ^duranium
X35: [W11] ^air
Y35: [W14] ^argon
Z35: ^void
V36: [W20] ^lead
W36: ^copper
X36: [W11] ^airconv
Y36: [W14] ^helium
Z36: ^balsa
A37: [W23] (LAYER1)
B37: [W11] (W13)
D37: [W13] (LAYER2)
E37: [W15] (W14)
G37: [W13] (LAYER3)
H37: (W15)
J37: [W16] (LAYER4)
K37: [W14] (W16)
M37: [W19] (LAYER5)
N37: (W17)
P37: [W16] (LAYER6)
Q37: (W18)
S37: [W19] (LAYER7)
T37: (W19)
V37: [W20] ^csteel
W37: ^ns3
X37: [W11] ^water
Y37: [W14] ^nitrogen
Z37: ^redwood
A38: [W23] 'No. Entries
B38: [W11] 6
D38: [W13] 'No. Entries
E38: [W15] 7
G38: [W13] 'No. Entries
```

```
H38: 9
J38: [W16] 'No. Entries
K38: [W14] 7
M38: [W19] 'No. Entries
N38: 5
P38: [W16] 'No. Entries
Q38: 7
S38: [W19] 'No. Entries
T38: 2
V38: [W20] ^ns3stif
W38: ^bsilicone
X38: [W11] ^h2Oconv
Y38: [W14] ^aluminum
Z38: ^purethan
V39: [W20] 'Graph Settings
A40: [W23] ^T (°F)
B40: [W11] ^k (Btu/hr-ft-°F)
D40: [W13] ^T (°F)
E40: [W15] ^k (Btu/hr-ft-°F)
G40: [W13] ^T (°F)
H40: ^k (Btu/hr-ft-°F)
J40: [W16] ^T (°F)
K40: [W14] ^k (Btu/hr-ft-°F)
M40: [W19] ^T (°F)
N40: ^k (Btu/hr-ft-°F)
P40: [W16] ^T (°F)
Q40: ^k (Btu/hr-ft-°F)
S40: [W19] ^T (°F)
T40: ^k (Btu/hr-ft-°F)
V41: [W20] 'Distance (in)
W41: 'Temperature (°F)
A42: [W23] 80.8
B42: [W11] 0.0151
D42: [W13] 32
E42: [W15] 8.1
G42: [W13] 32
H42: 20.3
J42: [W16] 32
K42: [W14] 8.1
M42: [W19] 150
N42: 14.75
P42: [W16] 32
Q42: 8.1
T42: 8.1
A43: [W23] 170
B43: [W11] 0.0172
D43: [W13] 212
E43: [W15] 8.7
G43: [W13] 212
H43: 19.3
J43: [W16] 212
K43: [W14] 8.7
M43: [W19] 200
N43: 17.33
P43: [W16] 212
Q43: 8.7
S43: [W19] 212
T43: 8.7
V43: [W20] (X6)
W43: (Z13)
A44: [W23] 261
B44: [W11] 0.0191
D44: [W13] 392
E44: [W15] 8.7
G44: [W13] 392
H44: 18.2
J44: [W16] 392
K44: [W14] 8.7
M44: [W19] 250
N44: 19.15
P44: [W16] 392
Q44: 8.7
S44: [W19] 392
T44: 8.7
V44: [W20] (V43+X13)
W44: (AA13)
A45: [W23] 351
B45: [W11] 0.021
D45: [W13] 572
E45: [W15] 9.4
G45: [W13] 572
H45: 17.2
J45: [W16] 572
K45: [W14] 9.4
M45: [W19] 300
N45: 20.83
P45: [W16] 572
Q45: 9.4
S45: [W19] 572
T45: 9.4
V45: [W20] (V44+X14)
W45: (AA14)
A46: [W23] 441
B46: [W11] 0.0228
D46: [W13] 752
E46: [W15] 10
G46: [W13] 630
H46: 12.1
J46: [W16] 752
K46: [W14] 10
M46: [W19] 400
N46: 23.38
P46: [W16] 752
Q46: 10
```

```
S46: [W19] 752
T46: 10
V46: [W20] (V45+X15)
W46: (AA15)
A47: [W23] 531
B47: [W11] 0.0246
D47: [W13] 1112
E47: [W15] 11
G47: [W13] 717
H47: 9.7
J47: [W16] 1112
K47: [W14] 11
P47: [W16] 1112
Q47: 11
S47: [W19] 1112
T47: 11
V47: [W20] (V46+X16)
W47: (AA16)
A48: [W23] 621
B48: [W11] 0.0263
D48: [W13] 1472
E48: [W15] 13
G48: [W13] 800
H48: 9
J48: [W16] 1472
K48: [W14] 13
P48: [W16] 1472
Q48: 13
S48: [W19] 1472
T48: 13
V48: [W20] (V47+X17)
W48: (AA17)
A49: [W23] 711
B49: [W11] 0.028
G49: [W13] 900
H49: 8.7
V49: [W20] (V48+X18)
W49: (AA18)
G50: [W13] 1276
H50: 8.66
V50: [W20] (V49+X19)
W50: (AA19)
A65: [W23] 'Interpolation Macros
A67: [W23] (LAYER1)
A68: [W23] '\i
B68: [W11] '/rndinner~{goto}table1~/rncinner~.{end}{down}~
A69: [W23] ^counter
B69: [W11] '{let number1,@rows(inner)}~
A70: [W23] 2
B70: [W11] '{if number1>=24}{right}{let kinner,@cellpointer("contents")}{return}
B71: [W11] '{down number1-1}
B72: [W11] '{if @cellpointer("contents")<=@avg(tminner)}{right}{let kinner,@cellpointer("contents")}{return}
A73: [W23] ^Tm
B73: [W11] '{end}{up}
A74: [W23] 238.71897196
B74: [W11] '{if @cellpointer("contents")>=@avg(tminner)}{right}{let kinner,@cellpointer("contents")}{return}
A75: [W23] ^Ki
B75: [W11] '{let tm,@avg(tminner)}
A76: [W23] 8.7
B76: [W11] '{for counter,1,number1-1,1,interp}
B77: [W11] '{let kinner,@avg(ki)}
A80: [W23] '\interp
B80: [W11] '{down}
B81: [W11] '{if @cellpointer("contents")>=tm}{branch b83}
B82: [W11] '{branch B93}
B83: [W11] '/rndthigh~
B84: [W11] '/rndtlow~
B85: [W11] '/rndkhigh~
B86: [W11] '/rndklow~
B87: [W11]'/rncthigh~~
B88: [W11] '{up}/rnctlow~~
B89: [W11] '{right}/rncklow~~
B90: [W11] '{down}/rnckhigh~~
B91: [W11] '{let ki,((((@avg(tm)-@avg(tlow))/(@avg(thigh)-@avg(tlow)))*(@avg(khigh)-@avg(klow)))+@avg(klow))}
B92: [W11] '{forbreak}
A95: [W23] (LAYER2)
A96: [W23] '\g
B96: [W11] '/rndgamma~{goto}table2~/rncgamma~.{end}{down}~
B97: [W11] '{let number2,@rows(gamma)}~
B98: [W11] '{if number2>=24}{right}{let kgamma,@cellpointer("contents")}{return}
B99: [W11] '{down number2-1}
B100: [W11] '{if @cellpointer("contents")<=@avg(tmgamma)}{right}{let kgamma,@cellpointer("contents")}{return}
B101: [W11] '{end}{up}
B102: [W11] '{if @cellpointer("contents")>=@avg(tmgamma)}{right}{let kgamma,@cellpointer("contents")}{return}
B103: [W11] '{let tm,@avg(tmgamma)}
B104: [W11] '{for counter,1,number2-1,1,interp}
B105: [W11] '{let kgamma,@avg(ki)}
A108: [W23] (LAYER3)
A109: [W23] '\s
B109: [W11] '/rndouter~{goto}table3~/rncouter~.{end}{down}~
B110: [W11] '{let number3,@rows(outer)}~
B111: [W11] '{if number3>=24}{right}{let kouter,@cellpointer("contents")}{return}
B112: [W11] '{down number3-1}
B113: [W11] '{if @cellpointer("contents")<=@avg(tmouter)}{right}{let kouter,@cellpointer("contents")}{return}
B114: [W11] '{end}{up}
B115: [W11] '{if @cellpointer("contents")>=@avg(tmouter)}{right}{let kouter,@cellpointer("contents")}{return}
B116: [W11] '{let tm,@avg(tmouter)}
B117: [W11] '{for counter,1,number3-1,1,interp}
B118: [W11] '{let kouter,@avg(ki)}
A121: [W23] (LAYER4)
A122: [W23] '\n
B122: [W11] '/rndneutron~{goto}table4~/rncneutron~.{end}{down}~
B123: [W11] '{let number4,@rows(neutron)}~
B124: [W11] '{if number4>=24}{right}{let kneutron,@cellpointer("contents")}{return}
```

```
B125: [W11] '{down number4-1}
B126: [W11] '{if @cellpointer("contents")<=@avg(tmneutron)}{right}{let kneutron,@cellpointer("contents")}{return}
B127: [W11] '{end}{up}
B128: [W11] '{if @cellpointer("contents")>=@avg(tmneutron)}{right}{let kneutron,@cellpointer("contents")}{return}
B129: [W11] '{let tm,@avg(tmneutron)}
B130: [W11] '{for counter,1,number4-1,1,interp}
B131: [W11] '{let kneutron,@avg(ki)}
A134: [W23] (LAYER5)
A135: [W23] '\ijacket
B135: [W11] '/rndijacket~{goto}table5~/rncijacket~.{end}{down}~
B136: [W11] '{let number5,@rows(ijacket)}~
B137: [W11] '{if number5>=24}{right}{let kijacket,@cellpointer("contents")}{return}
B138: [W11] '{down number5-1}
B139: [W11] '{if @cellpointer("contents")<=@avg(tmijacket)}{right}{let kijacket,@cellpointer("contents")}{return}
B140: [W11] '{end}{up}
B141: [W11] '{if @cellpointer("contents")>=@avg(tmijacket)}{right}{let kijacket,@cellpointer("contents")}{return}
B142: [W11] '{let tm,@avg(tmijacket)}
B143: [W11] '{for counter,1,number5-1,1,interp}
B144: [W11] '{let kijacket,@avg(ki)}
A147: [W23] (LAYER6)
A148: [W23] '\mjacket
B148: [W11] '/rndmjacket~{goto}table6~/rncmjacket~.{end}{down}~
B149: [W11] '{let number6,@rows(mjacket)}~
B150: [W11] '{if number6>=24}{right}{let kmjacket,@cellpointer("contents")}{return}
B151: [W11] '{down number6-1}
B152: [W11] '{if @cellpointer("contents")<=@avg(tmmjacket)}{right}{let kmjacket,@cellpointer("contents")}{return}
B153: [W11] '{end}{up}
B154: [W11] '{if @cellpointer("contents")>=@avg(tmmjacket)}{right}{let kmjacket,@cellpointer("contents")}{return}
B155: [W11] '{let tm,@avg(tmmjacket)}
B156: [W11] '{for counter,1,number6-1,1,interp}
B157: [W11] '{let kmjacket,@avg(ki)}
A160: [W23] (LAYER7)
A161: [W23] '\ojacket
B161: [W11] '/rndojacket~{goto}table7~/rncojacket~.{end}{down}~
B162: [W11] '{let number7,@rows(ojacket)}~
B163: [W11] '{if number7>=24}{right}{let kojacket,@cellpointer("contents")}{return}
B164: [W11] '{down number7-1}
B165: [W11] '{if @cellpointer("contents")<=@avg(tmojacket)}{right}{let kojacket,@cellpointer("contents")}{return}
B166: [W11] '{end}{up}
B167: [W11] '{if @cellpointer("contents")>=@avg(tmojacket)}{right}{let kojacket,@cellpointer("contents")}{return}
B168: [W11] '{let tm,@avg(tmojacket)}
B169: [W11] '{for counter,1,number7-1,1,interp}
B170: [W11] '{let kojacket,@avg(ki)}
A173: [W23] 'Calculate K's
A174: [W23] '\k
B174: [W11] '{\i}
B175: [W11] '{\g}
B176: [W11] '{\s}
B177: [W11] '{\n}
B178: [W11] '{\ijacket}
B179: [W11] '{\mjacket}
B180: [W11] '{\ojacket}
A183: [W23] 'Main Worksheet Calculation
A184: [W23] '\c
B184: [W11] '{calc}
B185: [W11] +"/c"&B37&"~table1~"
B186: [W11] +"/c"&E37&"~table2~"
B187: [W11] +"/c"&H37&"~table3~"
B188: [W11] +"/c"&K37&"~table4~"
B189: [W11] +"/c"&N37&"~table5~"
B190: [W11] +"/c"&Q37&"~table6~"
B191: [W11] +"/c"&T37&"~table7~"
B192: [W11] '{if @left(@lower(@s(rad)),1)="y"}{intrad}{branch b194}
B193: [W11] '{nintrad}
B194: [W11] '{calc}{\k}
B195: [W11] '{calc}{\k}
B196: [W11] '{calc}{\k}
B197: [W11] '{calc}{\k}
B198: [W11] '{let flag,0}
B199: [W11] '{calc}
B200: [W11] '{let flag,1}
B201: [W11] '{calc}
B202: [W11] '{goto}report~
B203: [W11] '{graph}
A205: [W23] '\0
B205: [W11] '{home}
B206: [W11] '{goto}report~
A208: [W23] '\r
B208: [W11] '{home}{goto}report~
A210: [W23] 'Material Library
A212: [W23] 'ss304
D212: [W13] 'lead
G212: [W13] 'bsilicone
J212: [W16] 'copper
M212: [W19] 'air
P212: [W16] 'NS3
S212: [W19] 'CSteel
V212: [W20] 'DUranium
Y212: [W14] 'Airconv
AB212: 'N20conv
AE212: 'water
AH212: 'argon
AK212: 'helium
AN212: 'nitrogen
AQ212: 'ns3stif
AT212: 'aluminum
AW212: 'void
AZ212: 'balsa
BC212: 'redwood
BF212: 'purethan
A213: [W23] '304 Stainless Steel
D213: [W13] 'Lead
G213: [W13] 'Boro Silicone
J213: [W16] 'Pure Copper
```

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M213: [W19] 'Standard Atmosphere
P213: [W16] 'HS3
S213: [W19] 'Carbon Steel
V213: [W20] 'Depleted Uranium
Y213: [W14] 'Air with natural conv.
AB213: 'Water with natural conv.
AE213: 'Pure Water
AH213: 'Pure Argon Gas
AK213: 'Pure Helium Gas
AN213: 'Pure Nitrogen Gas
AQ213: 'HS3 with Stiffeners
AT213: 'Pure Aluminum
AW213: 'Internal Void
AZ213: 'Balsa Wood (across grain)
BC213: 'Redwood (across grain)
BF213: 'Polyurethane Foam
A214: [W23] 'Ref: STAS1
D214: [W13] 'Ref: STAS1
G214: [W13] 'Ref: Manufacturer
J214: [W16] 'Ref: Lienhard
M214: [W19] 'Ref: Lienhard
P214: [W16] 'Ref: Manufacturer
S214: [W19] 'Ref: STAS1
V214: [W20] 'Ref: STAS1
Y214: [W14] 'Ref: STAS1
AB214: 'Ref: STAS1
AE214: 'Ref: Lienhard
AH214: 'Ref: Lienhard
AK214: 'Ref: Lienhard
AN214: 'Ref: Lienhard
AT214: 'Ref: Lienhard
AZ214: 'Ref: STAS1
BC214: 'Ref: STAS1
BF214: 'Ref: STAS1
A216: [W23] 'T
B216: [W11] 'k
D216: [W13] 'T
E216: [W15] 'k
G216: [W13] 'T
H216: 'k
J216: [W16] 'T
K216: [W14] 'k
M216: [W19] 'T
N216: 'k
P216: [W16] 'T
Q216: 'k
S216: [W19] 'T
T216: 'k
V216: [W20] 'T
W216: 'k
Y216: [W14] 'T
Z216: 'k
AB216: 'T
AC216: 'k
AE216: 'T
AF216: 'k
AH216: 'T
AI216: 'k
AK216: 'T
AL216: 'k
AN216: 'T
AO216: 'k
AQ216: 'T
AR216: 'k
AT216: 'T
AU216: 'k
AW216: 'T
AX216: 'k
AZ216: 'T
BA216: 'k
BC216: 'T
BD216: 'k
BF216: 'T
BG216: 'k
A217: [W23] 32
B217: [W11] 6.1
D217: [W13] 32
E217: [W15] 20.3
G217: [W13] 100
H217: 1.4
J217: [W16] 32
K217: [W14] 232
M217: [W19] 80.6
N217: 0.0151
P217: [W16] 150
Q217: 0.4002
S217: [W19] 32
T217: 25
V217: [W20] 32
W217: 15
Y217: [W14] 150
Z217: 0.1
AB217: 150
AC217: 14.75
AE217: 32
AF217: 0.332
AH217: 0
AI217: 0.00891
AK217: 0
AL217: 0.0784
AN217: 80.6
AO217: 0.018
AQ217: 150
AR217: 0.949
```

AT217: 32
AU217: 136.4
AW217: 200
AX217: 0
AZ217: 200
BA217: 0.0484
BC217: 200
BD217: 0.0636
BF217: 200
BG217: 0.0242
A218: [W23] 212
B218: [W11] 6.7
D218: [W13] 212
E218: [W15] 19.3
J218: [W16] 68
K218: [W14] 230
M218: [W19] 170
N218: 0.0172
S218: [W19] 212
T218: 25
V218: [W20] 752
W218: 20.1
AB218: 200
AC218: 17.33
AE218: 44.6
AF218: 0.336
AH218: 100.4
AI218: 0.0108
AK218: 200
AL218: 0.0977
AN218: 260.6
AO218: 0.0189
AT218: 212
AU218: 138.7
A219: [W23] 392
B219: [W11] 6.7
D219: [W13] 392
E219: [W15] 18.2
J219: [W16] 212
K219: [W14] 226
M219: [W19] 261
N219: 0.0191
S219: [W19] 392
T219: 24
V219: [W20] 1472
W219: 27.6
AB219: 250
AC219: 19.18
AE219: 80.6
AF219: 0.382
AH219: 200.3
AI219: 0.012
AK219: 400
AL219: 0.113
AN219: 440.6
AO219: 0.0228
AT219: 392
AU219: 137.5
A220: [W23] 572
B220: [W11] 9.4
D220: [W13] 572
E220: [W15] 17.2
J220: [W16] 392
K220: [W14] 225
M220: [W19] 351
N220: 0.021
S220: [W19] 572
T220: 23
V220: [W20] 1652
W220: 30.2
AB220: 300
AC220: 20.83
AE220: 116.6
AF220: 0.388
AH220: 300.2
AI220: 0.0134
AK220: 600
AL220: 0.13
AN220: 620.6
AO220: 0.0258
AT220: 572
AU220: 135.2
A221: [W23] 752
B221: [W11] 10
D221: [W13] 630
E221: [W15] 12.1
J221: [W16] 572
K221: [W14] 222
M221: [W19] 441
N221: 0.0228
S221: [W19] 752
T221: 21
AB221: 400
AC221: 23.38
AE221: 152.6
AF221: 0.381
AH221: 400.3
AI221: 0.0148
AK221: 800
AL221: 0.148
AN221: 800.6
AO221: 0.0288
AT221: 752
AU221: 131.7

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A222: [W23] 1112
B222: [W11] 11
D222: [W13] 717
E222: [W15] 9.7
J222: [W16] 792
K222: [W14] 218
M222: [W19] 531
N222: 0.0246
S222: [W19] 1112
T222: 19
AE222: 168.6
AF222: 0.39
AH222: 500
AI222: 0.016
AT222: 1112
AU222: 124.2
A223: [W23] 1472
B223: [W11] 13
D223: [W13] 800
E223: [W15] 9
M223: [W19] 621
N223: 0.0263
S223: [W19] 1472
T223: 17
AE223: 212
AF223: 0.394
AH223: 1000
AI223: 0.0218
D224: [W13] 900
E224: [W15] 8.7
M224: [W19] 711
N224: 0.028
S224: [W19] 1832
T224: 16
AE224: 260.6
AF224: 0.397
D225: [W13] 1276
E225: [W15] 8.66
AE225: 296.6
AF225: 0.398
AE226: 332.6
AF226: 0.391
AE227: 368.6
AF227: 0.386
AE228: 404.6
AF228: 0.377
AE229: 440.6
AF229: 0.367
AE230: 476.6
AF230: 0.354
AE231: 512.6
AF231: 0.338
AE232: 548.6
AF232: 0.321
AE233: 584.6
AF233: 0.3
AE234: 620.6
AF234: 0.278
A237: [W23] 'Emmisivity
D237: [W13] 'Emmisivity
J237: [W16] 'Emmisivity
S237: [W19] 'Emmisivity
AT237: 'Emmisivity
A238: [W23] 0.587
D238: [W13] 0.63
J238: [W16] 0.15
S238: [W19] 0.587
AT238: 0.2
A242: [W23] 'Internal Radiation Macros and Worksheets
A247: [W23] 'nintrad
B247: [W11] '/cf18~f12.f17~/rcrad1~
B248: [W11] '/res1~
B249: [W11] '/crad1~s3~
A252: [W23] 'intrad
B252: [W11] '{nintrad}
B253: [W11] +"{if "&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8),0)&"=7}{home}{goto}report~{let rad,no}{calc}{quit}"
B254: [W11] +"{if "&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8),0)&"=1}{home}{goto}report~{let rad,no}{calc}{quit}"
B255: [W11] +"{goto}"&B288&"~"
B256: [W11] '{let c288,@cellpointer("contents")}{calc}
B257: [W11] +"{goto}"&C288&"~{end}{down}{end}{down}{down}"
B258: [W11] '{let a294,@cellpointer("contents")}
B259: [W11] +"{goto}"&B288&"~"
B260: [W11] '{let c298,@cellpointer("contents")}{calc}
B261: [W11] +"{goto}"&C288&"~{end}{down}{end}{down}{down}"
B262: [W11] '{let a297,@cellpointer("contents")}{calc}
B263: [W11] '/crad2~rad1~
B264: [W11] +"/cm303~ti"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8),0)&"~"
B265: [W11] '/crad1~s3~
B266: [W11] '/cm308~s1~
A270: [W23] 'No
A273: [W23] 'ir
A274: [W23] @VLOOKUP(@PROPER(LAYER),CALC,2)
A275: [W23] 'or
A276: [W23] @VLOOKUP(@PROPER(LAYER),CALC,3)
A277: [W23] 'k
A278: [W23] @VLOOKUP(@PROPER(LAYER),CALC,4)
A279: [W23] 'ti
A280: [W23] @VLOOKUP(@PROPER(LAYER),CALC,5)
A281: [W23] 'to
A282: [W23] @VLOOKUP(@PROPER(LAYER),CALC,6)
A283: [W23] 'material
A284: [W23] @VLOOKUP(@PROPER(LAYER),CALC,7)
A286: [W23] +"layer"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8)-1,0)
B286: [W11] +"MAT"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8)-1,0)
```

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C288: 'copper
A289: [W23] +"layer"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8),0)
B289: [W11] +"MAT"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,9),0)
A290: [W23] +"layer"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8)+1,0)
B290: [W11] +"MAT"&@STRING(@VLOOKUP(@PROPER(LAYER),CALC,8)+1,0)
C290: 'ss304
A293: [W23] 'ei
A294: [W23] 0.15
A296: [W23] 'eo
A297: [W23] 0.587
A299: [W23] 'hr
A300: [W23] (0.0000000017*(A280+A282+919.34)*((A280+459.67)^2+(A282+459.67)^2))/(1/A294+(A274/A276)*(1/A297-1))
A302: [W23] 'ti
A303: [W23] ($B$21/(A300*2*@PI*A274*$D$7+2*@PI*A278*$D$7/(@LN(A276/A274))))+A282
B303: [W11] +$A$303
A305: [W23] 'Internal Radiation Parameters
A306: [W23] 'hr
B306: [W11] +$A$300
A307: [W23] 'ei
B307: [W11] +$A$294
A308: [W23] 'eo
B308: [W11] +$A$297
A499: [W23] 'Range Names in Radial Worksheet
A501: [W23] 'AIR
B501: [W11] 'M217..N236
A502: [W23] 'AIRCONV
B502: [W11] 'Y217..Z236
A503: [W23] 'ALUMINUM
B503: [W11] 'AT217..AU236
A504: [W23] 'ARGON
B504: [W11] 'AH217..AI236
A505: [W23] 'BALSA
B505: [W11] 'AZ217..BA236
A506: [W23] 'BSILICONE
B506: [W11] 'G217..H236
A507: [W23] 'CALC
B507: [W11] 'A12..I18
A508: [W23] 'COPPER
B508: [W11] 'J217..K236
A509: [W23] 'COUNTER
B509: [W11] 'A70
A510: [W23] 'CSTEEL
B510: [W11] 'S217..T236
A511: [W23] 'DURANIUM
B511: [W11] 'V217..W236
A512: [W23] 'EI
B512: [W11] 'B29
A513: [W23] 'EO
B513: [W11] 'B30
A514: [W23] 'FLAG
B514: [W11] 'E31
A515: [W23] 'GAMMA
B515: [W11] 'D42..D48
A516: [W23] 'H2OCONV
B516: [W11] 'AB217..AC236
A517: [W23] 'HELIUM
B517: [W11] 'AK217..AL236
A518: [W23] 'IJACKET
B518: [W11] 'M42..M46
A519: [W23] 'INNER
B519: [W11] 'A42..A49
A520: [W23] 'INTERP
B520: [W11] 'B80
A521: [W23] 'INTRAD
B521: [W11] 'B252
A522: [W23] 'KGAMMA
B522: [W11] 'E13
A523: [W23] 'KHIGH
B523: [W11] 'Q44
A524: [W23] 'KI
B524: [W11] 'A76
A525: [W23] 'KIJACKET
B525: [W11] 'E16
A526: [W23] 'KINNER
B526: [W11] 'E12
A527: [W23] 'KLOW
B527: [W11] 'Q43
A528: [W23] 'KMJACKET
B528: [W11] 'E17
A529: [W23] 'KNEUTRON
B529: [W11] 'E18
A530: [W23] 'KOJACKET
B530: [W11] 'E10
A531: [W23] 'KOUTER
B531: [W11] 'E14
A532: [W23] 'LAYER
B532: [W11] 'Y21
A533: [W23] 'LAYER1
B533: [W11] 'A12
A534: [W23] 'LAYER2
B534: [W11] 'A13
A535: [W23] 'LAYER3
B535: [W11] 'A14
A536: [W23] 'LAYER4
B536: [W11] 'A15
A537: [W23] 'LAYER5
B537: [W11] 'A16
A538: [W23] 'LAYER6
B538: [W11] 'A17
A539: [W23] 'LAYER7
B539: [W11] 'A18
A540: [W23] 'LEAD
B540: [W11] 'D217..E236
A541: [W23] 'MAT1
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B541: [W11] 'E12
A542: [W23] 'MAT2
B542: [W11] 'E13
A543: [W23] 'MAT3
B543: [W11] 'E14
A544: [W23] 'MAT4
B544: [W11] 'E15
A545: [W23] 'MAT5
B545: [W11] 'E16
A546: [W23] 'MAT6
B546: [W11] 'E17
A547: [W23] 'MAT7
B547: [W11] 'E18
A548: [W23] 'MJACKET
B548: [W11] 'F42..F48
A549: [W23] 'N/A
B549: [W11] 'X212
A550: [W23] 'NEUTRON
B550: [W11] 'J42..J48
A551: [W23] 'NINTRAD
B551: [W11] 'B247
A552: [W23] 'NITROGEN
B552: [W11] 'AN217..AO236
A553: [W23] 'NO
B553: [W11] 'A270
A554: [W23] 'NS3
B554: [W11] 'P217..Q236
A555: [W23] 'NS3STIF
B555: [W11] 'AQ217..AR236
A556: [W23] 'NUMBER1
B556: [W11] 'B38
A557: [W23] 'NUMBER2
B557: [W11] 'E38
A558: [W23] 'NUMBER3
B558: [W11] 'H38
A559: [W23] 'NUMBER4
B559: [W11] 'K38
A560: [W23] 'NUMBER5
B560: [W11] 'N38
A561: [W23] 'NUMBER6
B561: [W11] 'Q38
A562: [W23] 'NUMBER7
B562: [W11] 'T38
A563: [W23] 'OJACKET
B563: [W11] 'S42..S43
A564: [W23] 'OUTER
B564: [W11] 'G42..G50
A565: [W23] 'PARAM
B565: [W11] 'V13..AB19
A566: [W23] 'PURSTEAM
B566: [W11] 'BF217..BG236
A567: [W23] 'RAD
B567: [W11] 'W21
A568: [W23] 'RAD1
B568: [W11] 'A28..B30
A569: [W23] 'RAD2
B569: [W11] 'A306..B308
A570: [W23] 'REDWOOD
B570: [W11] 'BC217..BD236
A571: [W23] 'REPORT
B571: [W11] 'V1..AA27
A572: [W23] 'SS304
B572: [W11] 'A217..B236
A573: [W23] 'TABLE1
B573: [W11] 'A42
A574: [W23] 'TABLE2
B574: [W11] 'D42
A575: [W23] 'TABLE3
B575: [W11] 'G42
A576: [W23] 'TABLE4
B576: [W11] 'J42
A577: [W23] 'TABLE5
B577: [W11] 'M42
A578: [W23] 'TABLE6
B578: [W11] 'P42
A579: [W23] 'TABLE7
B579: [W11] 'S42
A580: [W23] 'THIGH
B580: [W11] 'F44
A581: [W23] 'TI1
B581: [W11] 'F12
A582: [W23] 'TI2
B582: [W11] 'F13
A583: [W23] 'TI3
B583: [W11] 'F14
A584: [W23] 'TI4
B584: [W11] 'F15
A585: [W23] 'TI5
B585: [W11] 'F16
A586: [W23] 'TI6
B586: [W11] 'F17
A587: [W23] 'TI7
B587: [W11] 'F18
A588: [W23] 'TLOW
B588: [W11] 'F43
A589: [W23] 'TM
B589: [W11] 'A74
A590: [W23] 'TMMAGMA
B590: [W11] 'F13..G13
A591: [W23] 'TMIJACKET
B591: [W11] 'F16..G16
A592: [W23] 'TMINNER
B592: [W11] 'F12..G12
A593: [W23] 'TMOJACKET
```

```
B593: [W11] 'F17..G17
A594: [W23] 'TMNEUTRON
B594: [W11] 'F15..G15
A595: [W23] 'TMOJACKET
B595: [W11] 'F18..G18
A596: [W23] 'TMOUTER
B596: [W11] 'F14..G14
A597: [W23] 'VOID
B597: [W11] 'AF217..AG236
A598: [W23] 'WATER
B598: [W11] 'AE217..AF236
A599: [W23] '\O
B599: [W11] 'B205
A600: [W23] '\C
B600: [W11] 'B184
A601: [W23] '\G
B601: [W11] 'B96
A602: [W23] '\I
B602: [W11] 'B68
A603: [W23] '\IJACKET
B603: [W11] 'B135
A604: [W23] '\K
B604: [W11] 'B174
A605: [W23] '\MJACKET
B605: [W11] 'B148
A606: [W23] '\N
B606: [W11] 'B122
A607: [W23] '\OJACKET
B607: [W11] 'B161
A608: [W23] '\R
B608: [W11] 'B208
A609: [W23] '\S
B609: [W11] 'B109
```

B.2 Range Listing

Range Names in Radial Worksheet

AIR	M217..N236
AIRCONV	Y217..Z236
ALUMINUM	AT217..AU236
ARGON	AH217..AI236
BALSA	AZ217..BA236
BSILICONE	G217..H236
CALC	A12..I18
COPPER	J217..K236
COUNTER	A70
CSTEEL	S217..T236
DURANIUM	V217..W236
EI	B29
EO	B30
FLAG	H31
GAMMA	D42..D48
H2OCONV	AB217..AC236
HELIUM	AK217..AL236
IJACKET	M42..M46
INNER	A42..A49
INTERP	B80
INTRAD	B252
KGAMMA	E13
KHIGH	Q44
KI	A76
KIJACKET	E16
KINNER	E12
KLOW	Q43
KMJACKET	E17
KNEUTRON	E15
KOJACKET	E18
KOUTER	E14

LAYER	Y21
LAYER1	A12
LAYER2	A13
LAYER3	A14
LAYER4	A15
LAYER5	A16
LAYER6	A17
LAYER7	A18
LEAD	D217..E236
MAT1	H12
MAT2	H13
MAT3	H14
MAT4	H15
MAT5	H16
MAT6	H17
MAT7	H18
MJACKET	P42..P48
N/A	X212
NEUTRON	J42..J48
NINTRAD	B247
NITROGEN	AN217..AO236
NO	A270
NS3	P217..Q236
NS3STIF	AQ217..AR236
NUMBER1	B38
NUMBER2	E38
NUMBER3	H38
NUMBER4	K38
NUMBER5	N38
NUMBER6	Q38
NUMBER7	T38
OJACKET	S42..S43
OUTER	G42..G50
PARAM	V13..AB19
PURETHAN	BF217..BG236
RAD	W21
RAD1	A28..B30
RAD2	A306..B308
REDWOOD	BC217..BD236
REPORT	V1..AA27
SS304	A217..B236
TABLE1	A42
TABLE2	D42
TABLE3	G42
TABLE4	J42
TABLE5	M42
TABLE6	P42
TABLE7	S42
THIGH	P4[illegible]
TI1	F1[illegible]
TI2	F1[illegible]
TI3	F14

TI4	F15
TI5	F16
TI6	F17
TI7	F18
TLOW	P43
TM	A74
TMGAMMA	F13..G13
TMIJACKET	F16..G16
TMINNER	F12..G12
TMMJACKET	F17..G17
TMNEUTRON	F15..G15
TMOJACKET	F18..G18
TMOUTER	F14..G14
VOID	AW217..AX236
WATER	AE217..AF236
\O	B205
\C	B184
\G	B96
\I	B68
\IJACKET	B135
\K	B174
\MJACKET	B148
\N	B122
\OJACKET	B161
\R	B208
\S	B109

ss304
304 Stainless Steel
Ref: HTAS1

T	k
32	8.1
212	8.7
392	8.7
572	9.4
752	10
1112	11
1472	13

Emmisivity
0.587

lead
Lead
Ref: HTAS1

T	k
32	20.3
212	19.3
392	18.2
572	17.2
630	12.1
717	9.7
800	9
980	8.7
1276	8.66

Emmisivity
0.63

bsilicone
Boro Silicone
Ref: Manufacturer

T	k
100	1.4

copper
Pure Copper
Ref: Lienhard

T	k
32	232
68	230
212	226
392	225
572	222
752	218

Emmisivity
0.15

air
Standard Atmosphere
Ref: Lienhard

T	k
80.6	0.0151
170	0.0172
261	0.0191
351	0.021
441	0.0228
531	0.0246
621	0.0263
711	0.028

NS3
NS3
Ref: Manufacturer

T	k
150	0.4882

CSteel
Carbon Steel
Ref: HTAS1

T	k
32	25
212	25
392	24
572	23
752	21
1112	19
1472	17
1832	16

Emmisivity
0.587

DUranium
Depleted Uranium
Ref: HTAS1

T	k
32	15
752	20.1
1472	27.6
1652	30.2

Airconv
Air with natural conv.
Ref: HTAS1

T	k
150	0.1

H2Oconv
Water with natural conv.
Ref: HTAS1

T	k
150	14.75
200	17.33
250	19.15
300	20.83
400	23.35

water
Pure Water
Ref: Lienhard

T	k
32	0.332
44.6	0.336
80.6	0.352
116.6	0.368
152.6	0.381
188.6	0.39
212	0.394
260.6	0.397
296.6	0.395
332.6	0.391
268.6	0.386
404.6	0.377
440.6	0.367
476.6	0.354
512.6	0.338
548.6	0.321
584.6	0.3
620.6	0.278

argon
Pure Argon Gas
Ref: Lienhard

T	k
0	0.00891
100.4	0.0105
200.3	0.012
300.2	0.0134
400.3	0.0148
500	0.016
1000	0.0215

nitrogen
Pure Nitrogen Gas
Ref: Lienhard

T	k
80.6	0.015
260.6	0.0189
440.6	0.0225
620.6	0.0258
800.6	0.0288

ns3stif
NS3 with Stiffeners

T	k
150	0.949

aluminum
Pure Aluminum
Ref: Lienhard

T	k
32	136.4
212	138.7
392	137.5
572	135.2
752	131.7
1112	124.2

Emmisivity
0.2

void
Internal Void

T	k
200	0

balsa
Balsa Wood (across grain)
Ref: HTAS1

T	k
150	0.0484

redwood
Redwood (across grain)
Ref: HTAS1

T	k
150	0.0636

purethan
Polyurethane Foam
Ref: HTAS1

T	k
150	0.0242

References

1) Holman, J.P., "Heat Transfer," Fourth Edition, McGraw-Hill Book Company, 1976.

2) "IF-300 Shipping Cask Consolidated Safety Analysis Report," General Electric Company, NEDO-10084-3, February, 1985.

3) Lienhard, John H., "A Heat Transfer Textbook," Second Edition, Prentice-Hall, Inc., 1987.

4) Rohsenow, Warren M., and Harry Choi, "Heat Mass, and Momentum Transfer," Prentice-Hall, Inc., 1961.

5) Turner, W.D., and C.K. Cobb, "HTAS1: A Two-Dimensional Heat Transfer Analysis of Fuel Casks," ORNL/NUREG/CSD-2/V1/R3, 1984.

6) U.S. Government, "Packaging and Transportation of Radioactive Material," Title 10 Code of Federal Regulations, Part 71, Office of the Federal Register, Washington DC (1988).

APPENDIX D

140B-WT.WK1: Lotus 123® Worksheet to Calculate the Weight of the NuPac 140-B Rail/Barge Transport Cask

Contents

1.0 Introduction

This report documents a Lotus 123® Release 2.2 worksheet, 140B-WT.WK1, that calculates the weight of NUPAC's 140-B rail/barge spent fuel shipping cask. The worksheet calculates the maximum hook weight and the maximum shipping weight of the cask for different thicknesses of shielding materials. The worksheet is intended to show the effects of changing the cask neutron and gamma shield thicknesses on the total cask weight.

The weights of the cask internals, ends, and accessories are input into the worksheet by the user, and the thicknesses of the shielding materials can either be manually input or retrieved from a linked file. The worksheet then calculates the weight of the shielding materials by determining the volume occupied by each cask layer. The volumes of layers with complicated geometries (the neutron shield and copper fins) are calculated using correction factors based on the weights reported in the cask preliminary design report (PDR) [3]. The use of the worksheet is described in Section 2 and the calculation technique is described in Section 3. The worksheet is reproduced in Appendix A and the cell formulas are listed in Appendix B.

2.0 Use of Worksheet

The parameters input into the worksheet by the user to calculate the total weight of the cask include the weights of the cask internals and accessories, and the thicknesses of the shielding materials. As an alternate to manually entering the material thicknesses, the user can easily link the worksheet to a worksheet which performs a thermal analysis on the cask shell. Pressing the key sequence alt-L then updates the link. A description of the input parameters is given below. The worksheet listing is given in Appendix A and default values are taken from Reference 3.

> Link To Thermal?: (label, "yes" or "no") If this cell contains the label "yes" then the worksheet uses the latest values obtained from a link to the worksheet which calculates the cask temperature distribution to determine the cask weight. Otherwise the cask weight is calculated using the shielding thicknesses input by the user.
>
> Path/File Name: (label) Tells the worksheet where to look for the thermal worksheet in order to perform the link. This entry has the form, *drive:\subdir\file*. If the thermal worksheet is in the current directory then the drive and path names can be omitted. The file extension, WK1, is appended to the filename by the worksheet and should not be input by the user. The link should be updated after any changes to the linked file. The link is updated by pressing alt-L.

The following parameters define the cask shielding thicknesses:

Cask Inner Radius: (value, in) The inner radius of the cask inner liner. Default value is 28.5 inches.

Inner Shell Thickness: (value, in) The thickness of the cask inner shell. Default value is 1.13 inches.

Gamma Shield Thickness: (value, in) The thickness of the cask lead gamma shield. Default value is 3.5 inches.

Outer Shell Thickness: (value, in) The thickness of the cask outer shell. Default value is 1.5 inches.

Neutron Shield Thickness: (value, in) The thickness of the cask Boro-Silicone neutron shield. Default value is 5.88 inches.

Inner Jacket Thickness: (value, in) The thickness of the copper inner thermal skin. Default is .125 inches.

Air Gap Thickness: (value, in) The thickness of the steel wire which maintains the air gap between the inner and outer thermal skins. Default is .134 inches.

Outer Jacket Thickness: (value, in) The thickness of the cask outer thermal skin. Default is .125 inches.

The following parameters define the weights of the cask internals and accessories:

Basket: (value, lb) The weight of the fuel basket. Default value is 14,225 pounds for the PWR basket.

Fuel: (value, lb) The weight of each fuel assembly. Default value is 1,515 pounds for a PWR assembly.

Water: (value, lb) The weight of water contained in the cask when the cask is removed from the fuel pool. Used to calculate the maximum hook weight. Default value is 8,000 pounds for the PWR basket.

Lift Fixture: (value, lb) The weight of the cask lift fixture. Default value is 2,325 pounds.

Impact Limiters: (value, lb) The weight of each of the impact limiters. Default value is 11,188 pounds.

The following parameters calculate the weights of the cask ends. These parameters are automatically scaled by the worksheet to account for changes in the cask radius and should not be modified by the user.

Bottom Closure Plate: (value, lb) The weight of the cask bottom closure plate. The default value is 15,105 pounds.

Bottom Neutron Shield: (value, lb) The weight of the Boro-Silicone in the cask bottom end. The default value is 272 pounds.

Bottom Inner Disk: (value, lb) The weight of the cask bottom inner disk. The default value is 281 pounds.

Top Closure Plate: (value, lb) The weight of the cask top closure plate. Default value is 14,784 pounds.

Top Neutron Shield: (value, lb) The weight of the Boro-Silicone in the cask top end. The default value is 324 pounds.

Top Inner Disk: (value, lb) The weight of the cask top inner disk. The default value is 331 pounds.

3.0 Calculation Technique

The worksheet determines the weight of the cask by summing the weights of the cask radial layers, the cask ends, the cask internals and payload, and the cask accessories. All of these quantities except the weights of the radial layers are input by the user. The weights of the radial layers are calculated by determining the volume occupied by each layer, and multiplying the result by the material density. The layer weights are calculated as follows:

1) **Inner Shell:** The inner shell is modelled as a cylindrical annulus, having a volume of $\pi(r_o^2-r_i^2)l$ where r_o and r_i are the outer and inner radii and l is the shell length. The density of SS304 is assumed to be 0.289 lb/in^3 [1].

2) **Gamma Shield:** The lead gamma shield is modelled in the same manner as the inner shell. The density of lead is 0.4097 lb/in^3 [1].

3) **Outer Shell:** The outer shell is modelled in the same manner as the inner shell. The density of SS304 is assumed to be 0.289 lb/in^3 [1].

4) **Neutron Shield:** The Boro-Silicone neutron shield is modelled in the same manner as the inner shell, with the volume of the copper fins subtracted from the total volume. To account for the non-constant radii of the outside surface of the neutron shield, the difference of the squares of the radii in the volume formula was reduced by 49.5 to give a weight for the Boro-Silicone that is in agreement with

Reference 3. The density of Boro-Silicone is assumed to be 0.0573 lb/in^3 [2].

5) **Copper Fins:** The twenty-four copper fins are modelled as 1/2 in thick plates running the length of the cask. The radial height of each plate is assumed to be the thickness of the neutron shield plus 3.66 inches (empirically determined to provide weights in agreement with Reference 3) and the circumferential length of each plate is assumed to be equal to 1/24th of the average circumference of the neutron shield region. The density of copper is 0.324 lb/in^3 [1].

6) **Inner Thermal Skin:** The copper inner thermal skin is modelled as three cylindrical annuli. The center section is modelled in the same manner as the inner shell, using the thickness input above. The tapered sections are modelled as an annulus using the average inner radius and a thickness of 0.125 inches. The density of copper is 0.324 lb/in^3 [1].

7) **Outer Thermal Skin:** The stainless-steel outer thermal skin is modelled in the same manner as the inner thermal skin. In addition to the center and two tapered sections, two more annuli are modelled at the top and bottom of the cask. The thickness of the tapered section and the top and bottom annuli is 0.25 inches [3]. The density of SS304 is assumed to be 0.289 lb/in^3 [1].

The cumulative radii calculated in cells D7 through D14 are used in all weight calculations. Cells D7 through D14 use the @IF statement to check the label in cell B3 which determines whether the file is linked to the thermal worksheet. If linking has been specified, the radii used to calculate the cumulative radius are taken from column B. Otherwise the radii are taken from column C. The macro "\L", called by pressing alt-L, inserts the proper link references into column B using the file name specified in cell B4 and replaces the values input by the user with the @NA function. The weights calculated by the worksheet are described below.

Cask Total Weight: The cask total weight is the sum of the weights of all of the radial layers; the bottom closure plate, neutron shield, and inner disk; and the top closure plate, neutron shield, and inner disk.

Loaded Cask Weight (dry): Includes the weights of the basket and fuel assemblies in addition to the cask total weight.

Loaded Cask Weight (wet): Includes the water weight in addition to the cask dry weight.

Total Hook Weight: Includes the cask lift fixture weight in addition to the cask wet weight.

Total **Transport Weight:** Includes the weights of the impact limiters in addition to the cask dry weight. The value calculated by the worksheet for the present cask geometry is 200,691 pounds which agrees closely with the 200,503 pounds reported in Reference 3

Appendix A: Workshee: Listing

NUPAC 140-B Weight Calculation Worksheet

Link To Thermal? Yes Press alt-L to update link
Path/File Name: Radialth .wk1

	Linked	Input	Cumulative
Cask Inner Radius	28.5	NA	28.500
Inner Shell Thickness	1.13	NA	29.630
Gamma Shield Thickness	3.5	NA	33.130
Outer Shell Thickness	1.5	NA	34.630
Neutron Shield Thickness	5.88	NA	40.510
Inner Jacket Thickness	0.125	NA	40.635
Air Gap Thickness	0.134	NA	40.769
Outer Jacket Thickness	0.125	NA	40.894

Cask Total Weight	132,275 lb
Loaded Cask Weight (dry)	178,315 lb
Loaded Cask Weight (wet)	186,315 lb
Total Hook Weight	188,640 lb
Total Transport Weight	200,691 lb

Payload Weights

Item	QTY	Weight Each (lb)	Total Weight (lb)
Basket	1	14,225	14225
Fuel	21	1,515	31815
Water	1	8,000	8000
Lift Fixture	1	2,325	2325
Impact Limiters	2	11,188	22376

Weights of Cask End Assemblies

Item	QTY	Weight Each (lb)
Bottom Closure Plate	1	15,105
Bottom Neutron Shield	1	272
Bottom Inner Disk	1	281
Top Closure Plate	1	14,784
Top Neutron Shield	1	324
Top Inner Disk	1	331

Shielding Cask Materials

Item	Density (lb/in3)	Weight (lb)	Reference
Inner Shell	0.290	10,593	Mark's
Gamma Shield	0.410	50,043	Mark's
Outer Shell	0.290	16,390	Mark's
Neutron Shield*	0.057	10,833	Manufacturer
Copper Fins*	0.324	9,430	Mark's
Inner Thermal Skin	0.324	1,493	Mark's
Outer Thermal Skin	0.290	2,397	Mark's
Total Cask Bottom End		15,658	
Total Cask Top End		15,439	

* Includes scaling factor from preliminary design report

Cask Total Weight	132274.8	lb
Loaded Cask Weight (dry)	178314.8	lb
Loaded Cask Weight (wet)	186314.8	lb
Total Hook Weight	188639.8	lb
Total Transport Weight	200690.8	lb

Appendix B: Formula Listing

```
A1: [W26] 'NUPAC 140-B Weight Calculation Worksheet
Z1: '\1
AA1: '{goto}link~
AA2: (F3) +"+<<"&$B$4&C4&">>b6~"
A3: [W26] "Link To Thermal?
B3: U 'Yes
C3: [W14] 'Press alt-L to update link
AA3: '{down}
A4: [W26] "Path/File Name:
B4: U 'Radialth
C4: [W14] '.wk1
Z4: @NA
AA4: (F3) +"+<<"&$B$4&C4&">>b12~"
AA5: '{down}
B6: ^Linked
C6: [W14] ^Input
D6: [W14] ^Cumulative
AA6: (F3) +"+<<"&$B$4&$C$4&">>b13~"
A7: [W26] 'Cask Inner Radius
B7: +<<C:\123\FILES\RADIALTH.WK1>>B6
C7: U [W14] @NA
D7: (F3) [W14] @IF(@UPPER(@LEFT(B3,1))="Y",LINK,C7)
AA7: '{down}
```

```
A8: [W26] 'Inner Shell Thickness
B8: +<<C:\123\FILES\RADIALTH.WK1>>B12
C8: U [W14] @NA
D8: (F3) [W14] @IF(@UPPER(@LEFT($B$3,1))="Y",(D7+B8),(D7+C8))
AA8: (F3) +"+<<"&$B$4&$C$4&">>b14~"
A9: [W26] 'Gamma Shield Thickness
B9: +<<C:\123\FILES\RADIALTH.WK1>>B13
C9: U [W14] @NA
D9: (F3) [W14] @IF(@UPPER(@LEFT($B$3,1))="Y",(D8+B9),(D8+C9))
AA9: '{down}
A10: [W26] 'Outer Shell Thickness
B10: +<<C:\123\FILES\RADIALTH.WK1>>B14
C10: U [W14] @NA
D10: (F3) [W14] @IF(@UPPER(@LEFT($B$3,1))="Y",(D9+B10),(D9+C10))
AA10: (F3) +"+<<"&$B$4&$C$4&">>b15~"
A11: [W26] 'Neutron Shield Thickness
B11: +<<C:\123\FILES\RADIALTH.WK1>>B15
C11: U [W14] @NA
D11: (F3) [W14]
@IF(@UPPER(@LEFT($B$3,1))="Y",(D10+B11),(D10+C11))
AA11: '{down}
A12: [W26] 'Inner Jacket Thickness
B12: +<<C:\123\FILES\RADIALTH.WK1>>B16
C12: U [W14] @NA
D12: (F3) [W14]
@IF(@UPPER(@LEFT($B$3,1))="Y",(D11+B12),(D11+C12))
AA12: (F3) +"+<<"&$B$4&$C$4&">>b16~"
A13: [W26] 'Air Gap Thickness
B13: +<<C:\123\FILES\RADIALTH.WK1>>B17
C13: U [W14] @NA
D13: (F3) [W14]
@IF(@UPPER(@LEFT($B$3,1))="Y",(D12+B13),(D12+C13))
AA13: '{down}
A14: [W26] 'Outer Jacket Thickness
B14: +<<C:\123\FILES\RADIALTH.WK1>>B18
C14: U [W14] @NA
D14: (F3) [W14]
@IF(@UPPER(@LEFT($B$3,1))="Y",(D13+B14),(D13+C14))
AA14: (F3) +"+<<"&$B$4&$C$4&">>b17~"
AA15: '{down}
AA16: (F3) +"+<<"&$B$4&$C$4&">>b18~"
A17: [W26] 'Cask Total Weight
B17: (,0) (B72)
C17: [W14] 'lb
AA17: '{goto}b3~
A18: [W26] 'Loaded Cask Weight (dry)
B18: (,0) (B73)
C18: [W14] 'lb
AA18: '{if @UPPER(@left(B3,1))="Y"}{Branch aa20}
A19: [W26] 'Loaded Cask Weight (wet)
B19: (,0) (B74)
C19: [W14] 'lb
```

```
AA19: '/cna~b7.b14~/ruinput~{quit}
A20: [W26] 'Total Hook Weight
B20: (,0) (B75)
C20: [W14] 'lb
AA20: '/cna~c7.c14~/ruinput~{quit}
A21: [W26] 'Total Transport Weight
B21: (,0) (B76)
C21: [W14] 'lb
A26: [W26] 'Payload Weights
A28: [W26] 'Item
B28: 'QTY
C28: [W14] ^Weight Each
D28: [W14] ^Total Weight
C29: [W14] ^(lb)
D29: [W14] ^(lb)
A30: [W26] 'Basket
B30: 1
C30: (,0) U [W14] 14225
D30: [W14] (B30*C30)
A31: [W26] 'Fuel
B31: 21
C31: (,0) U [W14] 1515
D31: [W14] (B31*C31)
A32: [W26] 'Water
B32: 1
C32: (,0) U [W14] 8000
D32: [W14] (B32*C32)
A33: [W26] 'Lift Fixture
B33: 1
C33: (,0) U [W14] 2325
D33: [W14] (B33*C33)
A34: [W26] 'Impact Limiters
B34: 2
C34: (,0) U [W14] 11188
D34: [W14] (B34*C34)
A40: [W26] 'Weights of Cask End Assemblies
A42: [W26] 'Item
B42: 'QTY
C42: [W14] ^Weight Each
C43: [W14] ^(lb)
A44: [W26] 'Bottom Closure Plate
B44: 1
C44: (,0) [W14] 15105*D14/40.894
A45: [W26] 'Bottom Neutron Shield
B45: 1
C45: (,0) [W14] 272*D14/40.894
A46: [W26] 'Bottom Inner Disk
B46: 1
C46: (,0) [W14] 281*D14/40.894
A47: [W26] 'Top Closure Plate
B47: 1
C47: (,0) [W14] 14784*D14/40.894
```

```
A48: [W26] 'Top Neutron Shield
B48: 1
C48: (,0) [W14] 324*D14/40.894
A49: [W26] 'Top Inner Disk
B49: 1
C49: (,0) [W14] 331*D14/40.894
A52: [W26] 'Shielding Cask Materials
A54: [W26] 'Item
B54: ^Density
C54: (,0) [W14] ^Weight
D54: [W14] 'Reference
B55: ^(lb/in3)
C55: (,0) [W14] ^(lb)
A57: [W26] 'Inner Shell
B57: (F3) 0.29
C57: (,0) [W14] ((D8^2-D7^2)*@PI*177*B57)
D57: [W14] 'Mark's
A58: [W26] 'Gamma Shield
B58: (F3) 0.4097
C58: (,0) [W14] (D9^2-D8^2)*@PI*177*B58
D58: [W14] 'Mark's
A59: [W26] 'Outer Shell
B59: (F3) 0.29
C59: (,0) [W14] (D10^2-D9^2)*@PI*177*B59
D59: [W14] 'Mark's
A60: [W26] 'Neutron Shield*
B60: (F3) 0.0573
C60: (,0) [W14] ((((D11^2-D10^2)-49.5)*@PI*177)-C61/B61)*B60
D60: [W14] 'Manufacturer
A61: [W26] 'Copper Fins*
B61: (F3) 0.324
C61: (,0) [W14]
(((3.66+D11-D10)^2+(2*@PI*(D10+(D11-D10)/2)/24)^2)^0.5)*0.5*177*2
4*B61
D61: [W14] 'Mark's
A62: [W26] 'Inner Thermal Skin
B62: (F3) 0.324
C62: (,0) [W14]
((99*(D12^2-D11^2))+2*(((23.25^2+(23.25*(D14-38.7)/33.25)^2)^0.5)
*((D11-(23.25*(D14-38.7)/(2*33.25)))^2-(D11-(0.125+(23.25*(D14-38
.7)/(2*33.25))))^2)))*@PI*B62
D62: [W14] 'Mark's
A63: [W26] 'Outer Thermal Skin
B63: (F3) 0.29
C63: (,0) [W14]
((D14^2-D13^2)*@PI*99+2*7.75*((38.7)^2-(38.7-0.25)^2)*@PI+2*(33.2
5^2+(D14-38.7)^2)^0.5*((D14-(D14-38.7)/2)^2-(D14-(D14-38.7)/2-0.2
5)^2)*@PI)*B63
D63: [W14] 'Mark's
A64: [W26] 'Total Cask Bottom End
C64: (,0) [W14] @SUM(C44..C46)
A65: [W26] 'Total Cask Top End
```

```
C65: (,0) [W14] @SUM(C47..C49)
A67: [W26] '* Includes scaling factor from preliminary design
report
A72: [W26] 'Cask Total Weight
B72:
(C57+C58+C59+C60+C61+C62+C63+B44*C44+B45*C45+B46*C46+B47*C47+B48*
C48+B49*C49)
C72: [W14] 'lb
A73: [W26] 'Loaded Cask Weight (dry)
B73: (B72+B30*C30+B31*C31)
C73: [W14] 'lb
A74: [W26] 'Loaded Cask Weight (wet)
B74: (B73+C32)
C74: [W14] 'lb
A75: [W26] 'Total Hook Weight
B75: (B74+C33)
C75: [W14] 'lb
A76: [W26] 'Total Transport Weight
B76: (B73+B34*C34)
C76: [W14] 'lb
```

Range Names

INPUT	C7..C14
LINK	B7
NA	Z4
TEXT	A1..D76
\L	AA1

References

1) Avallone, Eugene A. and Theodore Baumeister III, "Marks' Standard Handbook for Mechanical Engineers," Ninth Edition, McGraw-Hill Book Company, 1986.

2) "Boro-Silicone® Shielding," Reactor Experiments, Inc., Bulletin S-83N, 1985.

3) "NUPAC 140-B Rail/Barge Cask Preliminary Design Report," DOE Contract Number DE-AC07-88ID12700, Revision 0, 1989.

C.4.0 Estimation Of Fabrication Costs

ITEM	COSTS
Cask Body	$ 1,736,000
Impact Limiters ($95,000 x 2)	190,000
PWR Basket	445,000
BWR Basket	595,000
TOTAL	$ 2,966,000

Ancillary Equipment

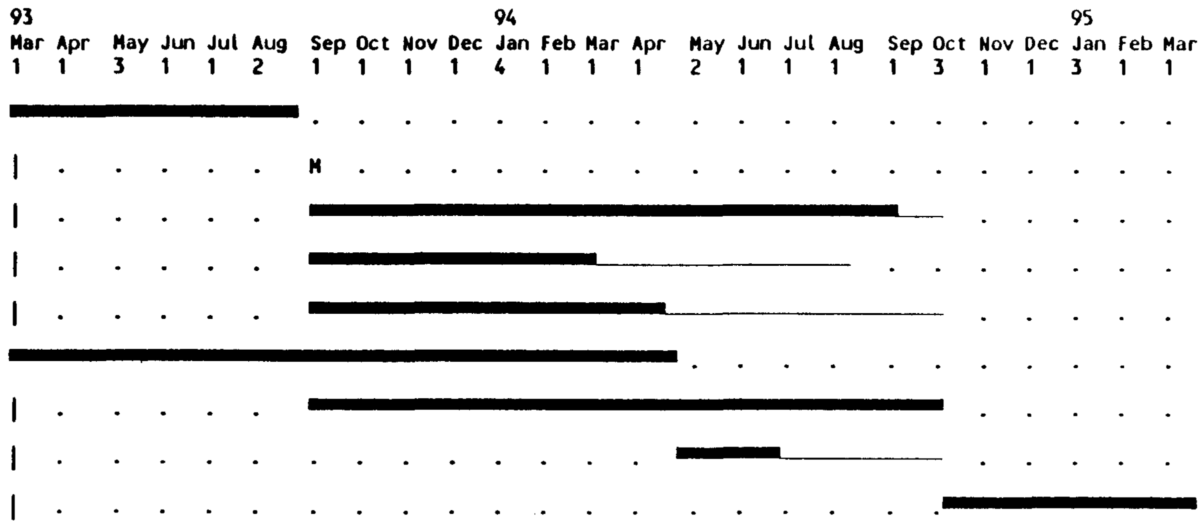
Railcar (less test)	$ 230,000
Craddle	250,000
Lift Fixtures	250,000
Uprighting System	175,000
Impact Limiters Removal System	150,000
Sunshield/Personnel Barrier	100,000
Cask Drain/Fill System & Misc. Equipment	75,000
TOTAL	$ 1,230,000

NOTES:
1. This cost estimate is for one cask system.
2. These costs are in 1989 dollars.

C.5.0 Estimation Of Fabrication Schedule

Schedule Name : PROTOTYPE CASK FABRICATION SCHEDULE
Responsible : W. WHEADON
As-of Date : 1-Mar-93 9:00am Schedule File : C:\TL3\DATA\CASKFABA

WBS	Task Name	Duratn (Wks)
	MATERIAL PROCUREMENT	25
	RECEIVE C OF C	0
	CASK FABRICATION	50.2
	IMPACT LIMITER FABRICATION	25
	BASKET FABRICATION	30.8
	RAILCAR FABRICATION	58
	ANCILLARY EQUIPMENT FABRICATN	55
	INSTALL IMP LIM REMOVAL SYSTEM	8.4
	ASSEMBLY AND TEST	21.6



Detail Task ===== Summary Task M Milestone
(Started) ==≡≡≡ (Started) >>> Conflict
(Slack) ≡≡≡— (Slack) .. Resource delay

Scale: 1 week per character

TIME LINE Gantt Chart Report, Strip 1

COMMENTS AND RESPONSES

ON THE

NUPAC 140-B RAIL/BARGE SPENT NUCLEAR FUEL CASK

PRELIMINARY DESIGN PACKAGE

REVISION 1

MARCH 30, 1990

GROUP NUMBER ONE
ADDITIONAL TRG MEMBER
COMMENTS AND RESPONSES

1. General Information The collection of water in the Trunnion during shipping appears to be a potential problem. Reviewer: R. B. Pope (ORNL).

   RESPONSE: NuPac will provide seal caps in final design to prevent intrusion of water.

2. Thermal Analysis Assure that the ambient temperature assumption is correct per the given requirements. Reviewer: P. Standish (Westinghouse Las Vegas).

   RESPONSE: The ambient temperature assumption of -20°F to 100°F is correct per 10 CFR 71 Para. 71.71b and 71.73b.

3. Criticality Evaluation Drain rates and fill rates for the PWR basket flux traps should be considered in the criticality evaluation. Reviewer: C. Hooper (ORNL).

   RESPONSE: Drain and fill rates of the PWR basket flux trap will be addressed very early in the final design phase. Because of the relatively slow drain rate of the cask at a reactor site, it is expected that the water will drain out of the flux trap at the same rate as experienced in the fuel storage cells. The forthcoming review will address this operation as well as the potential for rapid water fill which could occur during a hypothetical accident.

4. General Comment Off-gassing of the urethane used in the Impact Limiter design and the Boro-Silicone used in the neutron shield should be addressed with respect to personnel safety hazard during a fire. Reviewer: H. Peterson (INEL).

   RESPONSE: Carbon monoxide for both urethane foam and the borated silicone is the toxic gas of concern during a fire. In an open environment toxicity is not expected to build to harmful levels. This will be investigated further in final design.

GROUP NUMBER TWO COMMENTS AND RESPONSES
REVIEWER: R.R. RAWL,
OAK RIDGE NATIONAL LABORATORY

I. General comments

1. Impact Limiter and Lid handling

a. The fit of the impact limiter to the cask body and the fit of the lid to its seat involve moving heavy objects into areas with very close tolerances. The tolerances used in this design require that the need for careful control of the limiters and lid during installation and removal be addressed in the design. Specific concerns are addressed in Section II, and include such concerns as the installation of cold (smaller diameter) limiters on a warm (larger diameter) cask; and, the use of guide pins to install the lid.

RESPONSE: This is an operational as well as a design concern and will be resolved during final design and during preparation of the operating procedures.

b. In addition, the installation of these components requires torque values that can not be delivered manually. Special tools that can lock against some feature to provide the counter force are required. For example, a mechanical advantage power tool might lock against a bolt installed in an impact limiter bolt hole during torquing of the lid.

RESPONSE: NuPac will recommend the use of special air tools to perform these operations, similar to those used on the IF-300 cask.

c. No means of handling the limiters was found in the design, but one is required. Lift fixtures must act through the center of gravity to allow the yoke to hang vertically.

RESPONSE: Present design allows the impact limiters to slide longitudinally along the rail car away from the cask body and remain on the rail car.

d. It is not exactly clear how alignment of the lid for bolting is to be achieved. The two features intended to provide alignment, the cask lid securement, and the guide pins, each have problems with operability that are discussed in Section II.

RESPONSE: It is projected that three (3) guide pins will be utilized to provide lid/body alignment. Specific details will be provided during final design.

2. Contamination Control

a. Additional design consideration should be given to the control of contamination in the cask system. As noted early in the design document, the potential for contamination in the basket flux trap is a concern. In addition, the flow of water through the bottom of the basket around the bottom and around the spacers should also be considered.

RESPONSE: NuPac's operational experience in basket/cask decontamination for the IF-300 and truck casks will be used to provide an "optimized" basket design which reduces the potential for crud entrapment and/or accumulation. Water concerns will also be addressed in final design.

b. Design features should be considered that address contamination control (including weeping) of the cask surfaces. This should include a barrier for the annulus area of the lid, draining of "buckets" spaces such as the annulus and bolt holes, and treatment of the cask surface (or protection of it during pool loading) to facilitate decontamination.

RESPONSE: Contamination control has and will continue to be addressed in the final design phase utilizing actual cask operational experience.

c. A proposed arrangement for protection of the cask during underwater loading, along with the incorporation of the necessary attachment points on the cask in the design would be beneficial.

RESPONSE: NuPac will address this concern in the final design phase.

3. The Vent/Fill/Drain/Test Port Configuration

a. There was insufficient information available in the design report to understand how the various ports and fixtures were intended to operate. Many specific observations are provided below.

RESPONSE: NuPac will address this concern in the final design phase. All cask penetrations will be designed to be operated and/or accessed with remote handling techniques.

b. Of immediate concern is the size of the vent and drain lines. While the drilled portion of these lines was apparent from sketches and drawings, the size of the line as it passed through the port gear could not be determined. For the vent line .75 inches was considered adequate and for the drain 1 inch is probably adequate. Larger sized, or more valves, could improve handling time.

RESPONSE: NuPac will address this concern in the final design phase. (See above)

c. The amount of maintenance expected or required on these items could not be determined. For the numerous o-rings captured in the inserted equipment, the equipment must be designed to be removed as a unit or servicing is not possible. The drain "debris cover" installation/ removal is not obvious, there is neither handle nor socket for rotating it.

RESPONSE: NuPac will address this concern in the final design phase. (See above)

d. Connections to the fixtures used to operate the ports should be made with relatively common devices, snaptites, swagelocs or the like. Connection of the proposed adapter to the drain will be difficult due to the angle of the drain and because it is so close to the bottom of the cask that adapter contact with the floor is likely.

RESPONSE: NuPac will address this concern in the final design phase. (See above)

e. Pressure testing of the cask containment seals should be considered for verifying containment following loading at a facility. This seems less complicated than the method proposed which relies to some extent on the control cabinet. Besides the directness of using a pressure test, it is more easily understood by the typical reactor cask handling technician.

RESPONSE: Nupac will address this concern in the final design phase. Here again IF-300 and other cask operational experience will be utilized to develop the "optimum" method of testing.

4. Thermal Analysis

a. The Ther:: ıl Analysis should be revisited to remove the consideration of the "up to 1 cubic foot of water". This condition is not expected to exist in a cask that drains from the bottom (the water can't hide as it could in the IF-300 in the loop of the dip tube), and will be vacuum dried.

RESPONSE: To be considered during final design at which time alternate methods of cask draining will be addressed.

b. By eliminating the steam pressure from the water, it is expec that the rupture disc arrangement can be removed. (Since this stem would permit continuous venting once the disc actuatea, it is probably not acceptable.)

RESPONSE: The possible removal of the rupture disc will be evaluated and discussed with the NRC.

c. In addition, the thermal analysis appears to indicate that the impact limiters (some portion of them) will exceed a temperature of 180 degrees F. If so, then the personnel barrier should be extended to cover the limiters. Covering the limiters with the barrier is recommended even if it is not required by the analysis.

RESPONSE: The impact limiter external surface outside of the personnel barrier does not exceed 180°F.

d. Since this will serve to isolate the cask system from the environment, and will protect the system from the elements and from incidental damage in transit.

RESPONSE: See previous response.

e. Finally, the analysis appears to indicate that the loaded cask surface can achieve temperatures that would preclude hands-on work (OSHA Regulation). Design consideration should be given to both coc down and manual-remote handling needs.

RESPONSE: This concern will be studied during final design. Cask surfaces wi be significantly lower in temperature during handling when out of the sun and with impact limiters removed.

II. Specific Comments

Chapter 1.

1. Page 1-2, Section 1:1: Fissile Class III can establish restrictive transport configurations. It is not clear why this package is Class III. See additional comments at Chapter 6.

RESPONSE: The cask will probably end up being a Fissile Class I device. Final determination to be made during final design.

2. Page 1-2: The impact limiters are described as "Overpacks" which is an incorrect use of the terminology. The cask designers are referred to 49 CFR 171.8 where the "Overpack" is defined. Although an impact limiter does provide protection in handling of the package, it is not an "enclosure" in the full sense of the word. Even more important, when IAEA Safety Series No. 6 is adopted into the US regulation, the "enclosure to provide protection to a single package" aspect of the definition will disappear (IAEA Safety Series No. 6, 1985 Edition, para 133).

RESPONSE: All references to "overpacks" will be changed to "impact limiters".

3. Page 1-3, Sections 1.2.1 and 1.2.2: The drain/fill rate should be evaluated by mock up. The amount of decontamination that could occur is probably limited. It is not clear why the panel length is given as 180 inches, but the length of both baskets is only 168 inches.

RESPONSE: The 180 inch length is incorrect and will be changed to 168 inches. The drain/fill rate will be addressed in the final design phase. The outer shell of the basket is approximately 178.5 inches long to prevent longitudinal movement of the basket assembly within the cask cavity.

4. Page 1-3:

a. Relative to the inclusion of the "flux traps" in the basket and the design of the basket in general:

The flux traps, because of their design, could prove to be an operational nightmare since, as noted in other parts of the PDR, they could become "crud traps". Note for example the text at the bottom of this page. This is further addressed on page 1-19, where it is indicated that it must be "reviewed". From an operational point of view, a "review" may prove insufficient. Tests of the concept may be required since the basket could prove to be difficult to maintain, and possible could even create criticality problems if localized buildup of crud impacted the proper filling and draining of the flux traps. Although the potential problem with the flux traps is acknowledged on page 1-19, in the final design there may not be much that can be done about its operational problems. It is not clear how NUPAC will deal with the situation if operationally it is determined that the design won't work and the designers indicate the trap is needed to ensure design certification.

RESPONSE: **The design of the flux trap is subject to change during final design. Crud buildup, especially PWR crud, will not impact fill/drain rates, nor will it create criticality problems. Decontamination of the basket will be done underwater at the cask servicing facility. Basket panels will be fabricated and tested to verify final design assumptions. The IF-300 basket decontamination experience will be used.**

b. The joints of the webs are loose and open and would also be excellent voids for crud to accumulate.

RESPONSE: **NuPac will address this concern in detail in the final design phase. Chemical and/or mechanical decontamination will be used to remove crud.**

c. It is not evident that this problem can be solved in the final design phase. It could present such an operational problem that the casks would be uneconomical to use due to this basic design feature, and they could prove to be a significant source of unnecessary personnel exposure during all aspects of the cask use and maintenance.

RESPONSE: **Our experience in complicated basket design and decontamination of IF-300 baskets indicate this concern is unfounded. The 140-B baskets will be designed such that they will be easy to load/unload and can be easily decontaminated with minimal personnel exposure.**

d. The baskets contain void spaces in the area between the webs and the basket shell. There is no acceptance test to ensure that these voids are leak tight and the welding specifications on drawing 2111-210 does not specify NDE of these welds. Some assurance is needed that these voids will be leaktight and are periodically tested to insure that they remain leaktight.

RESPONSE: **NuPac is considering the fabrication of test panels in the final design phase to address such concerns. We are also considering allowing**

water to fill these spaces during fuel loading. The water would drain from the spaces during draining of the cask cavity.

5. Page 1-4, Section 1.2.4: The fact that personnel barrier removal does not require a crane is a plus; however, the advantage is lost because of the need to install the uprighting fixture which does require a crane.

RESPONSE: The feasibility of allowing the uprighting fixture to remain on the railcar will be investigated during final design. A key factor to be considered is the limit of 263,000 pounds on the rail bed.

6. Page 1-5, section 1.2.5: While the lid securement system has some benefit by not requiring bolts to be installed as the cask is removed from the pool, it also presents the opportunity for a major operator error if the bolts (two or three?) were not disengaged or if they snagged a thread and lifted the lid of the loaded cask. It would appear prudent to install two or three lid bolts hand tight in the cask as it comes out of the water. Operator exposure at this point is not a major consideration since the cask contains pool water which provides significant additional shielding. A consideration of this feature may be the extent to which it provides lid alignment during installation of the lid. The utility of this feature should be reconsidered. This design does not consider the consequences of a yoke separation causing a cask tip incident.

RESPONSE: The method described above is currently used on some casks. It does add to operator exposure and it seems prudent to consider alternate methods. A final decision as to how the lid is handled during removal/installation will be made during final design.

b. The operation of the lid security system is difficult to understand from what is provided in this PDR.

RESPONSE: NuPac will expand on operational techniques when the operating procedures are prepared.

7. Page 1-6, "Payload": The Phase 1, Initiative 1, Cask Physical Performance Specification, (RFP no. DE-RP07-86ID12625) Interface Guidelines 1.C.2. and 3 specify that the range of burnups for PWR assemblies shall be 18,000 to 35,000 MWD/MTU, and the initial enrichment range shall be 3.00 to 4.50 w/o U-235. The values shown at the bottom of page 1-6 do not match this guideline, the PWR assemblies enrichment range is coupled to burnup range; i.e., 3.2 w/o at zero (0) MWD/MTU up to 4.5 w/o at 18,000 MWD/MTU. Also, the lower burnup range between 3.0 and 3.2 does not appear to be addressed at all.

RESPONSE: The NuPac 140-B package was designed in accordance with the requirements of Contract No. DE-AC07-881D12700 for the following nominal fuel parameters:

Parameter	PWR	BWR
Number of Assemblies	**21**	**52**
Maximum Burnup, MWD/MTU	**35,000**	**30,000**
Burnup Credit, MWD/MTU	**18,000**	**0**
Maximum Initial Enrichment	**4.5%[1]**	**4.5%**
Minimum Decay Time, yrs[2]	**10**	**10**

The package is designed to provide adequate shielding and heat dissipation for both PWR and BWR fuels with initial enrichments of 3.0% and burnups of 35,000 MWD/MTU and 30,000 MWD/MTU respectively (worst case). In addition, the criticality analyses considered fresh fuel at 4.5% initial enrichment. In order to ship 21 PWR fuel assemblies with an initial enrichment of 4.5%, burnup credit of 18,000 MWD/MTU had to be assumed.

FOOTNOTES:

1. **Burnup credit of 18,000 MWD/MTU must be taken in order to ship 21 assemblies with an initial enrichment of 4.5%. Without burnup credit 21 assemblies can be shipped which have an initial enrichment of 3.2%.**

2. **The contract requires that cooling times of 5 years shall be evaluated. This evaluation was performed in the trade off studies documented in Section C.3 of the PDR.**

8. Page 1-10, Section 1.3.4: Is there enough water in this (very) small annulus to warrant evacuation of it? It does not appear so.

RESPONSE: We have removed reference to the removal of water.

9. <u>Page 1-11:</u> The maximum normal operating pressure is stated here to be 300 psia (i.e., 285 psig), on page 2.6-9 it is stated as 284 psig (almost equal), on page 3.42 it is calculated to be 299 psia (ie., 284 psig), however page 2-7.1 states that it is 351 psig. The actual figure needs to be consistently referenced. Apparently the 351 psig reference is to the maximum pressure in the cask under accident conditions (page 2-7.59) and not MNOP.

RESPONSE: **284 psig is the normal condition pressure and 351 psig is the accident condition pressure. This will be made consistent throughout the preliminary design report.**

10. <u>Page 1-12, Section 1.3.10:</u>

a. It is not clear that a pressure relief system is required. The inclusion of "up to 1 cubic foot of water" does not appear to be reasonable. See additional comments at Chapter 3.

RESPONSE: **NuPac will address this concern in detail in the final design phase.**

b. It was not clear what the sentence: "Rupture discs are provided in the cask to preclude catastrophic damage to the package should inadvertent over pressurization (in excess of Regulatory requirements) occur means." What is the "over pressurization" Regulatory requirement?

RESPONSE: **NuPac believes that "good engineering practice" dictates that an overpressurization devise be provided to prevent damage to the cask should inside pressures exceed the cask design pressure. A rupture devise was chosen to provide this protection. Other methods will be considered during final design.**

11. <u>Page 1-15:</u> Why is the C.E. 178.25 inch fuel excluded?

RESPONSE: **The 178.25 C. E. fuel can be shipped in the 140-B cask.**

12. <u>Page 1-19, Section 1.3.19.</u>

a. In the discussion of the impact limiter from an operational/human factors standpoint, it is indicated that additional shielding on the outside of the cask will be considered as appropriate. Is this possible since the shipping weight of the cask already exceeds 103 tons?

RESPONSE: **Our analyses indicate that the current shielding is adequate to meet regulatory requirements. The statement about additional shielding has been deleted.**

b. In the discussion of the cask surface from an operational\human factors standpoint, it is indicated that "various surface treatments must be investigated to reduce the incidence of surface 'weeping'..". What types of treatments are envisioned here and what would the maintenance aspects of the treatments be?

RESPONSE: **A "smooth" exterior surface is required, and electro-polishing is being considered as one of several techniques to obtain this "smooth" exterior.**

Chapter 2.

13. Page 2.0-20, Section 2.1.2.2.2.1:

a. The required torque value, 1,300 to 1,400 ft-lbs, can not be obtained by hand. A special tool will be required that is anchored against a fixed object. A torquing sequence and number of passes to achieve final torque is also required.

RESPONSE: **A special air operated torque wrench system will be supplied as part of the ancillary equipment. They will be similar to the ones used by PNS for the IF-300 and the reaction method will be involved in the design.**

b. Such high torque values can be expected to cause wear on the cask body, or insert, threads. Are inspections/replacement of these items also required?

RESPONSE: **Inspection of bolts and tapped holes will be required and will be furnished in the Maintenance manual during the final design phase.**

14. Page 2.0-24, Section 2.1.2.3: "maximum design life of 25..." delete the work "maximum" to be consistent with RFP guidelines.

RESPONSE: **Section 2.0 has been revised per this comment.**

15. Page 2.0-24, section 2.2: The quote of maximum hook weight is misleading since, as noted in the footnote on page 2.0-26, the weight of the channels is not included. This will increase the maximum hook weight from the value quoted of 190,108 lbs, to 193,488 lbs. Although this is still less than the required limit of 200,000 lbs, it should be correctly noted on page 2.0-24.

RESPONSE: **Agree, but such a change in one part of the report should be consistent with other parts that would involve extensive computer analyses reruns. Thus, such a change will be incorporated in the final design report and/or the SAR.**

16. Page 2.0-28: Only three of the eight materials listed in the first paragraph are present in Table 2.3-1. The material properties for these other materials are needed. Also, the designator of the fourth material listed on page 2.0-28 does not appear to be correct; shouldn't "Type A-320" be replaced by "Type L43" (see Table 2.3-1, page 2.0-31). Also, there is no table 2.3.2 as referenced in the second paragraph.

RESPONSE: **Section 2.0 has been revised to include this comment. A-320 is not a type, but an ASTM designation. Type L43 is the correct grade designation.**

17. Page 2.4-1, Section 2.4.4: Shouldn't the potential (or lack thereof) for galvanic reaction between copper and stainless steel at least be mentioned?

RESPONSE: **Section 2.0 has been revised to include this comment.**

18. Page 2.5.1-1, Section 2.5.1.1: Lifting trunnion, and lift gear, should be designed to address the requirements of ANSI N14.6 and NUREG-0612.

RESPONSE: **The trunnions are part of the cask and designed with a factor of safety of 3.0 per 10 CFR 71. The lifting yoke per Section B.1.1 meets the requirements of ANSI N14.6 and NUREG-0612.**

19. Page 2.5.1-7, Section 2.5.1.1.:

a. The required torque value of 455 ft-lbs will be difficult to achieve manually and difficult to apply to 1 inch socket head bolt. A torque sequence and the number of passes used to reach the torque value is required.

RESPONSE: **This will be investigated during final design. The 125-B cask specifies nearly the same torque for impact limiter attachment.**

b. The maximum torque is 455 ft-lbs, not 445.

RESPONSE: Section 2.0 has been revised to include this comment.

20. Page 2.6-2, Section 2.6.1.1:

a. Table 2.6.1-1 shows that the impact limiter temperature is above 180 degrees F. Based on this table, it would appear that the personnel barrier must cover the limiters.

RESPONSE: This table, which will be clarified during final design, is general in nature and does not show the local temperature distribution. Appendix 3.6.2, Figures 3.6.2-20 & 23 show that the exterior surfaces not covered by the personnel barrier will not exceed 180°F.

b. What is the meaning of the "Minimum" temperatures. These temperatures do not appear to be addressed in the text. Are they -40 based?

RESPONSE: Minimum temperatures are based on -40°F. Thermal and structural considerations for the cask at -40°F were not found to be a problem.

21. Page 2.7-1, Section 2.7.1: It is not clear why a maximum normal internal pressure of 351 psig is used. 284 is used elsewhere (See pages 1.11, 2-7.59 and 3.42).

RESPONSE: This inconsistency will be taken care of in the final design report and/or SAR. 284 psig is a normal condition calculation. 351 psig is an accident condition calculation.

22. Page 2.7-59, Section 2.7.3.1: Rupture discs require both a temperature and a pressure rating.

RESPONSE: NuPac will address this concern during the final design phase.

23. Page 2.7-59: At two locations on this page, the "fire transient" condition is mentioned. The regulations do not specify a "hypothetical fire conditions, "rather they specify a "hypothetical thermal test" condition (see 10 CFR 71.73 (c) (3)). Please be accurate in describing this test. Fire test is misleading.

RESPONSE: Section 2.0 has been revised to incorporate "hypothetical accident thermal event".

24. Page 2.7-61: Same comment concerning the use of the term "fire accident" as on page 2.7-59.

RESPONSE: Section 2.0 has been revised to incorporate "hypothetical accident thermal event".

25. Page 2.7-68, Section 2.7.8: Some discussion is required as to the condition of the inner shell after the pin drop. It is assumed that testing will be done to confirm analysis, but the effects of on the inner shell could be operationally important.

RESPONSE: NuPac will address this concern during the final design phase. Similar type constructed casks show very little damage to the inner shell from the pin drop.

26. Page 2.10.2-27: The analysis of forces on the impact limiter attachments does not appear to take into account forces resulting from the sunshield/personnel barrier. Since the barrier rides in tracks on the limiters, their contribution to impact forces needs to be considered.

RESPONSE: During separation of the cask from the railcar, the personnel barrier, which is very light in weight relative to the weight of the cask, is designed to break away from the cask. A more complete description will be prepared during final design.

Chapter 3.

27. This analysis is very difficult to follow and to understand.

RESPONSE: As a comment in response, part of the problem is the following of the Reg Guide 7.9 format. However, this presentation is typical of a final SAR document that the PDR document attempts to emulate.

28. Pages 3-3 and 3-4: Nothing could be found in the drawings or description in Chapter 1 concerning either a thermal shield or the coating of surfaces with black paint to enhance thermal rejection through thermal radiation. However, on page 3-3 it is mentioned that "Interior surfaces of the thermal shield and attached load collar are painted with a high emittance black paint. Adjacent surfaces of the neutron shield are painted with the same material." Furthermore, figure

3.1-1 indicates that surfaces are coated with a "High IR EMITTANCE BLACK PAINT" (see item "D" on the figure). A number of questions arise from this:

a. What is the thermal shield referred to in item D, page 3-3?

RESPONSE: The thermal shield is the cask outer cylindrical layer of steel, which is 1/8 inch in the center and 1/4 inch thick on the ends and will be further defined during final design.

b. Will the Boro-silicone shield material itself be coated?

RESPONSE: No. The borated silicone material is covered on the outside by a 1/8 inch thick copper cylindrical sheet. The copper sheet surface adjacent to the inside surface of the thermal shield is painted black.

c. How will the performance and longevity of this coating be verified?

RESPONSE: It may be required that periodic thermal tests of the cask will have to be performed during routine maintenance. Coating longevity will be determined from these tests.

29. <u>Page 3-5, Section 3.1:</u> The temperature values given in Table 3.1-1 should be clearly presented as the allowable temperatures. As presented, they appear to be the maximum temperatures of Critical cask components.

RESPONSE: The temperature values will be clearly identified as maximum allowables during final design.

30. <u>Page 3-6, Section 3.1:</u> It is not clear why thermal output from a design basis fuel assemble was not obtained using ORIGEN2, instead of for"... one metric ton of heavy metal...". Reference "g" is "unpublished data sheet transmittal from George Townes of BEI to Dan Kent of NuPac, dated April 3, 1989." While there is no reason to doubt the data contained in the transmittal, there is no way to cross-check or compare the basis for or the results of the analysis.

RESPONSE: This comment will be considered during final design.

31. Page 3-12: The selection and properties of the neutron shielding material is briefly discussed here. A number of comments on the neutron shield material and design follow:

a. Properties and information on the Boro-silicone material: If the material is Reactor Experiments Boro-silicone 236, a significant amount of design/testing experience is available which is not mentioned here. For example, a summary of a design/testing program which selected this material for further assessment is provided in SAND81-2055 (Pope and Diggs, April, 1982); details of developmental testing of this and other materials can be found in the PATRAM'80 proceedings in a paper by Pope, et. al. and detailed thermo-mechanical evaluations can be found in SAND80-2303 (Rack and Pearson, February, 1981).

RESPONSE: Obtaining the above reports will be pursued and more testing for the 140-B application will be planned during final design.

b. Neutron Shield Design, Testing, Evaluation: A number of significant concerns relative to the use of this material in this application arise and must be addressed. Unless this material has already been successfully used in cask applications such as this. A detailed and possibly extensive test program will be required before this material can be shown to be acceptable as a neutron shield for this cask. Undocumented experience with a material similar to the one proposed here (i.e., with Bisco NS1) showed that, although it performed well in mechanical, neutron and fire exposure environments, it did not perform well in the long-term above ambient temperature environments which will exist in the cavities of a shipping cask. When exposed at these temperatures for a long time periods, the material produced what can be referred to as a "toothpaste" effect. The containing metal cavities were eventually ruptured due to internal pressure (from gases?) and the material was extruded from the failure points in the same fashion that toothpaste would be extruded from tears in a toothpaste tube when squeezed. Care must be taken to demonstrate that the proposed neutron shield material will behave properly under normal operating conditions, and that unacceptable pressures in the neutron shield cavities will not be produced.

Also, it will be necessary to demonstrate that the material will retain its neutron shielding qualities under such conditions, i.e., after long exposure to the higher, cask operating temperatures. Furthermore, the consistency and properties of "as fabricated" material, and the method in which the neutron shield is fabricated, must both be addressed.

RESPONSE: Additional DOE funded test data will be obtained and evaluated during final design. Additional testing will be performed as required to demonstrate the acceptability of the neutron shield material.

d. Copper Fins in neutron shield--interaction w materials: The presence of copper fins in the neutron shield cavity is mentioned many times, but details are sketchy. On page 2.4-1, the chemical and galvanic reactions between materials are discussed, but the presence of copper with stainless steel is ignored. The potential for copper/stainless steel reactions must be addressed.

RESPONSE: Section 2.0 has been revised to include data on galvanic reactions between stainless steel and copper.

e. Behavior of neutron shield in hypothetical accident thermal test environment: The PDR does not mention the need to vent the neutron shield cavity during the thermal test. The neutron shield material can be expected to experience significant degradation during the 30 minute thermal exposure and to produce -- as a result -- large quantities of gases. The design needs to be able to accommodate the rejection of these gases from the neutron shield cavity without encouraging the combustion of these gases in such a fashion that the neutron shield does not become a significant heat source to the package (in addition to the external heat source). Consideration should be given to providing fusible plugs in the outer neutron shield shell to accomplish this. The potential for puncture of the shield in the puncture test (10CFR 71.73(c)(2)) will add to the combustion potential of the neutron shield material. The discussion in Section 3.5 (page 3-55) appears to assume that no combustion of the n-shield occurs; this assumption needs to be verified. The tests reported in NUPAC'S reference q indicated a substantial loss of material. NUPAC is also requested to verify the source of the data in reference q. It is believed that it is the PATRAM'80 paper noted in the neutron shield comment

(1) above, and if so it is work by Sandia National Laboratories not LANL (see Attachment I). This neutron shield material loss could be accompanied by burning which potentially is a heat source to the cask. Has this been evaluated?

RESPONSE: Items mentioned in this comment (e.g. fusible plugs, etc.) will be reviewed during final design.

32. Page 3-53, section 3.4.6: This section should conclude that a personnel barrier is required. Further, based on the temperatures given, the personnel barrier must cover the impact limiters.

RESPONSE: Local impact limiter surface temperatures outside of the personnel barrier are below 180°F. See response to comment #20.

33. Page 3.54, and elsewhere in this chapter: Same comments as earlier concerning the inappropriate use of the term "fire" (see comment on page 2.7-59).

RESPONSE: Reference to the term "fire" will be revised to "hypothetical accident thermal event".

34. Page 3-74, Section 3.5.4:

a. The basis for doing this calculation needs to be revisited. The analysis (apparently based on the IF-300) assumes up to 1 cubic foot of water in the cavity; but, step 7.1.2.17 requires that a vacuum be pulled on the cavity. What would be the point of this vacuum process except to dry the cask? The basis for the residual water assumption needs to be explained, if it is retained. There does not seem to be a basis for its inclusion.

RESPONSE: The current analysis is conservative. It will be refined per comments during final design.

b. The assumption of water in the cavity leads to dramatically higher pressures and results in the pressure relief system for the cask. The residual water assumption should be dropped, which should result in the "lack of need" for the pressure relief system. Since the internal pressure would drop to 88.4 psia (approximately 75 psig, which still seems high.)

RESPONSE: This comment will be considered during final design.

c. If the residual water assumption is not dropped, then it must be verified in acceptance testing that less than this amount remains in the cask after the vacuum condition intended by step 7.1.1.17 of the operating procedure.

RESPONSE: This comment will be considered during final design.

Chapter 4.

35. Page 4-4, Section 4.1.3.2:

a. It does not seem possible that the helium leak test proposed in 8.1.3 could test the containment boundary welds due to the fact that a number of the welds on non-containment boundary welds occur before the containment boundary welds, and these welds could prevent the helium from even reaching the containment welds. The standard method of testing these welds is by radiography during fabrication, and then by pressure testing during acceptance, and thereafter annually. It is noted that drawing 2111-201, sheet 1 of 12, note 14 indicates that such a pressure test is required.

RESPONSE: Nupac will address this concern in detail in the final design phase. Manufacturing acceptance tests will be performed which will satisfy the stated concern.

b. Torque values of 1300-1400 ft-lbs can not be obtained manually. A special tool will be required.

RESPONSE: The torques have been analyzed in detail and are used on existing casks. Special tools will be provided as part of the ancillary equipment.

36. Page 4-7, Section 4.3.1: Second paragraph should be deleted since "leaktight" is assumed.

RESPONSE: NuPac will address this concern in final design phase.

37. Page 4-9: It is stated that the package is a type B(U). With a MNOP in excess of 100 psig, it can only be a B(M) as stated in Section 1.1 (see 10CFR71.4.)

RESPONSE: This is an error and will be corrected to B(M).

Chapter 5.

38. A detailed analysis of the shielding calculations shows many areas where it could be improved for accuracy; however the results appear adequate for a preliminary design since they are conservative. Details of the detailed analysis are attached for further reference (Attachment II).

RESPONSE: None required.

39. Page 5-1, Section 5.1: The analysis should include the Loss of neutron shielding, either totally or at least locally. Page 3-55 indicates that, in one thermal test, the neutron attenuation factor was reduced by approximately 35%. (Some analysis should be done to establish the post accident dose rate assuming the loss of the neutron shield material.)

RESPONSE: Preliminary calculations showed that normal operational dose rates are bounding over the accident case dose rates. Results for the accident and post accident cases will be provided during final design analysis.

40. Page 5-4, figure 5.1-1:

a. Dose rates at the closure lid are of concern for operational assessment. Additional dose rate values at both ends of the cask, normally occupied by the operator, are needed.

RESPONSE: These dose rate values will be provided during the final design analysis.

b. This figure does not make it clear where the "2 meter dose" is taken. Later (page 5-22), it specifies that it is from the package. The estimate used here may need to be made 2 meters from the projected edge of the transporter.

RESPONSE: The "2 meter" shown in Figure 5.1-1, page 5-4, is from the edge of the package. For the dose rate in the radial direction, the 2 meter is taken from the edge of the package. For the dose rates in the axial directions, the 2 meter is taken from the edge of the impact limiters for the cask top and bottom ends. Since the transporter is longer and wider than the package and also part of the package is covered by the Sunshield/Personnel barrier, the 2 meter from the package surfaces gave conservative dose rate results as compared to the 2 meter from

the edge of the transporter case. Because the exact dimensions of the transporter were not finalized at the time of the shielding analysis, this conservative approach was selected.

c. Estimated dose rates are neither provided nor discussed for the 1 meter post accident condition.

RESPONSE: See response #39.

d. No discussion of contribution from non-fuel components.

RESPONSE: The contribution from non-fuel components will be provided during final design analysis.

<u>Chapter 6.</u>

41. <u>Page 6-1, Section 6.0</u>:

a. The package should be evaluated as a Fissile Class I, rather that a Fissile Class III. Class III will require transport configuration control, and theoretically could result in single cask shipments.

RESPONSE: Yes, the NuPac 140-B Cask could be likely classified as a Fissile Class I Package. However, additional criticality analyses must be performed to reach this conclusion. But we will aim toward this direction in our criticality safety analyses for the final design.

b. Based on the results of Table 6.1-1, note 4 of the Table, and the discussion of Section 6.3, it appears that a Fissile Class I could be assigned, if some additional work is done on arrays of damaged casks.

RESPONSE: See response #41(a).

<u>Chapter 7.</u>

42. It must be recognized that the procedures that will eventually appear in this section of the SAR will ultimately be the basis for part of the Certificate of Compliance. Thus, the procedures need to be the best, generic set that can be assembled. They will need close scrutiny. They need to recognize that options exist that

may be exercised on a plant- by-plant basis, and wherever possible, these options need to be listed. The procedures contained in the current document are not adequate, steps are missing, steps are out of sequence, optional steps are not shown, etc. The comments which follow address only a few of TOPO's concerns in this area.

RESPONSE: Section 7 is being rewritten for the PDR and will include all comments shown. This section will have two parts, one for the reactor and one for dry unloading into a Hot Cell.

43. Page 7-2, Section 7.1.1: This section is probably more properly called: "Verification that the Spent Fuel Assemblies to be Shipped Comply with the Conditions of the Certificate." This step (except for visual inspection prior to loading) is expected to be done well in advance of fuel loading.

RESPONSE: This concern will be addressed in rewrite of Section 7.

44. Page 7-2, Section 7.1.2: In general, the steps in this procedure vary widely in detail. It is noted that in Step 7.1.2.1 The cask impact limiters are removed and the cask is moved to the preparation area. The following step (7.1.2.2), includes the activity: "Rotate the vent port plug counterclockwise to unscrew the vent port plug".

RESPONSE: This concern will be addressed in rewrite of Section 7.

45. Step 7.1.2.1: Add "Open personnel barrier."

RESPONSE: This concern will be addressed in rewrite of Section 7.

46. Step 7.1.2.3: The exterior of the cask should be surveyed prior to washing the surface.

RESPONSE: This concern will be addressed in rewrite of Section 7.

47. Step 7.1.2.4: This activity will cause an airborne contamination problem and will not be allowed at loading facilities unless it can be shown that there are very low levels of internal contamination. The design of the cask cavity and basket are not likely to result in low levels

of internal contamination. Removal of the closure lid after the cask is placed in the pool is an alternative that the procedure should allow. This would reduce exposure of plant personnel to contamination and radiation from the open cask cavity. This is a plant-specific option and illustrates how the procedures need to be flexible and show alternatives.

RESPONSE: This concern will be addressed in rewrite of Section 7.

48. Step 7.1.2.4: The lid should be provided with a stand or it should be required to be placed on blocks to avoid damage and debris pickup.

RESPONSE: This concern will be addressed in rewrite of Section 7.

49. Step 7.1.2.7: Has an "optional" sealing surface protection device, and/or an "optional" contamination control skirt been designed? Is there a means of attaching these optional devices?

RESPONSE: This concern will be addressed in rewrite of Section 7.

50. Step 7.1.2.11: What determines whether "new vacuum grease" should be applied?

RESPONSE: This concern will be addressed in rewrite of Section 7.

51. Step 7.1.1.12: The cask lid locking equipment is mentioned here and on page 1-5; what is this equipment? Where described? Should this equipment be removed after step 7.1.2.14?

RESPONSE: This concern will be addressed in rewrite of Section 7.

52. Step 7.1.2.13: The vent valve should be opened to permit draining. No mention of the "1 cu. ft. of water" requirement is made. How will this requirement be satisfied? Is this accomplished by step 7.1.2.17?

RESPONSE: This concern will be addressed in rewrite of Section 7.

53. Step 7.1.2.14: This torque can not be achieved manually. Is a special tool designed to accomplish this? The tool must brace against something that does not move. The torquing sequence, as well as the number of passes to achieve the final torque value must be specified. Page C.2-7 indicates all bolts will be safety wired. This is not shown in the procedure.

RESPONSE: This concern will be addressed in rewrite of Section 7.

54. Step 7.1.2.17: This step should recognize that the length of time that vacuum is applied is important.

RESPONSE: This concern will be addressed in rewrite of Section 7.

55. Step 7.1.2.18: The thermal analysis uses ONLY nitrogen (pages 3.9 and 3.18), so only nitrogen may be used unless the thermal analysis (chapter 3) shows that the other three gases are equivalent or better.

RESPONSE: This concern will be addressed in rewrite of Section 7.

56. Step 7.1.2.19: The leak testing steps should not be outside of the loading procedure. It should be in this section.

RESPONSE: This concern will be addressed in rewrite of Section 7.

57. Step 7.1.1.22: This torque could be difficult to achieve on these bolts since the torque value is high, the bolts will be hard to reach, and because the bolts are located well inside of (40 inches) the limiter. A special tool for this operation is required. The tool must consider the torsional effects of the 40 inch reach to ensure that the torque indicated on the tool is being applied to the bolts. Considerations should be given to attachment of the limiters to the side of the cask body rather than to the ends of the cask body.

RESPONSE: This concern will be addressed in rewrite of Section 7.

58. Page 7-7, section 7.2: This over-simplification is simply unacceptable, especially since the OCRWM receiving facilities are planned to be dry. A dry unloading procedure is needed.

RESPONSE: This concern will be addressed in rewrite of Section 7.

59. Page 7.3: This over-simplification is unacceptable also.

RESPONSE: This concern will be addressed in rewrite of Section 7.

60. Page 7.4-5 Section 7.4-2:

a. This section, as written, would prove to be essentially incomprehensible to an in-plant user. The reference to ANSI-N14.5 should not be made in a way to infer the operator needs to have that standard available. The procedures need to be clear, to use well defined terminology (e.g.,"cask" not "containment vessel"), and stand-alone. The section needs to tell the operator how to perform the tests and what results are expected.

RESPONSE: This concern will be addressed in rewrite of Section 7.

b. What is the "gas pressure rise leak detection equipment."? In addition, no details of the operation of the ports, or the fixtures (except the drain) has been given. The operation and inter-relationship of these fixtures needs to be provided.

RESPONSE: This concern will be addressed in rewrite of Section 7.

61. Page 7.4-5: It sounds as if the pressure rise leak detection equipment comes complete from a single source and doesn't have to be constructed from gauges, lines, etc. Is this correct to the point that manufacturer' instructions will be supplied?

RESPONSE: This concern will be addressed in rewrite of Section 7.

62. Steps 7.4.2.2.3 and 7.4.2.3.3: The device to be attached to the vent port to perform this test could not be identified. Does it replace the debris cover during the test? Where is design shown?

RESPONSE: This concern will be addressed in rewrite of Section 7.

CHAPTER 8

63. Page 8-2: The maximum lift weight is 193,488 lbs (see comments on page 2.0-24). The value here must be corrected

RESPONSE: NuPac will resolve this concern in the final design phase. See response to comment number 15.

64. Page 8-4, Section 8.1.3.1:

a. The purpose of this test is not clear. It does not seem possible that any meaningful results could be obtained from the proposed test. There are too many intervening welds and layers of materials. How long would it take to conduct the proposed test? How would the helium external atmosphere be provided? This would require a large tight envelope.

RESPONSE: This test is required by ANSI N14.5-1987, Section 6.3. Detailed procedures of how this test is performed will be provided during the final design phase.

b. This test will be affected by the integrity of every penetration through the containment simultaneously. It would seem preferable to test the individual penetrations first (steps 8.1.3.2 through 8.1.3.5) and eliminate any leaks before testing the total containment (in order to be able to determine any leaks in a systematic manner).

RESPONSE: NuPac will address this concern in the final design phase.

65. Page 8-13: Should there be a parallel neutron shield inspection and installation acceptance test?

RESPONSE: Yes, there will be a neutron shield acceptance test developed in the final design phase.

66. Page 8-17, Section 8.1.5.2.10: No provision made for lead expansion zone.

RESPONSE: This will be addressed during final design.

67. Page 8-18, Section 8.1.6: It is agreed that the thermal analysis of Chapter 3 seems conservative. However, given the high heat load of the cask (compared to the 125-B),

and the complexity of the design, a thermal performance test would appear to be called for. The design of this system relies on the use of copper fins and shells and on the use of emissivity control paints to achieve the analysis results. While this is primarily a licensing issue, it is also operationally important to know how conservative the analysis is (ie. what are the expected surface temperatures.)

RESPONSE: Nupac will consider this concern in the final design phase.

68. Page 8.18, Section 8.1.7: This section does not require that any blackness tests be done on samples of either the neutron shielding or the basket poison. It seems reasonable that these tests must be done.

RESPONSE: Nupac will consider this concern in the final design phase. Such tests will be performed by the material suppliers prior to acceptance for use on the 140-B cask program.

69. Page 8-19, Section 8.2:

a. Are there any annual maintenance requirements for the basket(s), such as visual inspections?

RESPONSE: All welds will be examined during fabrication to verify integrity. Annual maintenance and inspection requirements will be developed in final design.

b. It is not clear why there is no annual pressure test of the cask cavity required. What test verifies the continued structural integrity of welds?

RESPONSE: The maintenance procedures and annual inspection requirements will be described in detail in the final design phase. An annual pressure test is not an NRC requirement.

c. Sections of documents that constitute an integral part of the test procedure must not be incorporated by reference (such as A3.10.1 and " Section 5.4(3) of reference 8.3.1.4"). The tests that are to be done should be described.

RESPONSE: These procedures will be described in detail in the final design phase.

d. It is not clear why the leak tests described in Section 8.2.2 are not integrated. The testing of individual components includes the same major steps- ie. We would go though a lot of helium if each step of each test is performed sequentially.

RESPONSE: **Where applicable these tests are integrated and will be described in detail in the final design phase.**

e. Is there some aspect of the cask design that precludes integration of these tests?

RESPONSE: **No.**

70. Page 8-26.Section 8.2.3.2: Does the narrative following the first sentence describe "A sound industrial maintenance program...", or are some additional maintenance steps suggested by the first sentence? Is a "sound industrial maintenance program" appropriate for a safety related component?

RESPONSE: **Will Change "A sound industrial maintenance program" to "An inspection program..." Since there is no maintenance required on the impact limiter itself.**

Section B.1

71. Page B.1.6, Section B.1.1.1:

a. In step 2, What is the intent of "...and place it on a stand".

RESPONSE: **This will be changed. There is not a "Cask stand".**

b. In order to demonstrate that the lift fixture has been load tested, each item in the load path must have a part and serial number. As "stirrups" are changed, it must be possible to verify that the stirrup to be installed has a current load test.

RESPONSE: **The yoke will be redesigned in the final design phase to eliminate the stirrup change out at the reactor.**

c. It should not be the intent of the designer that stirrups would be changed out for each lift in a facility. The yoke should be able to arrive at the site ready for use. The changing of stirrups could be time consuming operationally.

RESPONSE: **The yoke will be redesigned in the final design phase to eliminate the stirrup change out at the reactor.**

d. It is not clear from the narrative what a "critical lift" is. (See top of page B.1.8 for example). Is this the same thing as a redundant lift?

RESPONSE: **No, a critical lift can be a redundant yoke (dual yoke using four cask trunnions) or it can be a single yoke (using two cask trunnions) with a 10 to 1 load factor on ultimate stress and a 6 to 1 load factor on yield stress (see ANSI N14.6 or NUREG 0612).**

e. What is used to remove the lid when the yoke is not used, as in step 7.1.2.4 of the loading procedure.

RESPONSE: **Section 7 will be rewritten for the PDR and the step for lid removal on the decon pad will be removed. Lid removal will be done underwater or in Hot Cell except for routine maintenance at a Cask maintenance Facility or for repairs at a reactor.**

f. The yoke should have a built in feature, or a stand, that will support the yoke in a vertical position so that it may be connected to the station hook.

RESPONSE: **Yoke stands will be provided as ancillary equipment in the final design phase.**

g. The yoke should have provisions for lifting it in the horizontal position (as when it is shipped) and rotating it in a controlled fashion to the vertical position for attachment to the hook. The yoke should stand vertically for attachment to the hook, either independently or using a stand.

RESPONSE: **These provisions will be provided in the final design phase.**

72. Page B.1.46, Section B.1.3: It is noted that the uprighting fixture "... is not carried on the railcar so that its substantial weight is not added to total gross vehicle weight, but would be at the facility prior to the arrival of the cask." Provision should be made on the railcar so that this, and other items, can ride with the empty cask to the facility. Will the lifting yoke be used to handle the uprighting fixture?

RESPONSE: **Ancillary equipments such as yokes, uprighting fixture, seal surface protector will be shipped LSA by exclusive use truck prior to the rail cask arrival. The lifting yoke is not planned to be used for installing uprighting fixture.**

73. Page B.1.53. It is not clear how the personnel barrier is "locked" at the top. Since the impact limiters are predicted to exceed 180 F (page 3.35) in normal transport, a personnel barrier over the impact limiters will be required.

RESPONSE: **The personnel barrier is not "locked" at the top, but is secured in place by equipment near the lower part of the cask cradle. Tamper resistant devices are also provided. Also, see response to comment #20.**

74. Page B.1.54, Section B.1.5:

The use of a "control system enclosure" has several operational problems. One is that the drain/fill system must have a provision for ensuring that the components of the drain/fill contain no water when shipped. Since the internal system contained contaminated water, the internals are contaminated. For shipping you must be able to say with some authority, what the level of internal contamination is, and you must be able to say that it will stay where it is. Hoses (except non-standard) should not be provided because of the difficulties with estimating internal contamination for shipping and with ensuring there is no water in them. If the use of non-standard hoses can not be avoided, then the possibility of discarding the hose after the use is and option. The inclusion of a vacuum pump must be carefully considered. If the pump is of the reciprocating type that can mix the evacuated gas with the compressor oil, then it cannot be used. These pumps create a mixed waste (radiologically contaminated oil) that can not be disposed of. It is suggested that the use of the control enclosure be reconsidered in favor of individual systems.

RESPONSE: **The systems for filling, draining, inserting and vacuum drying will be revised in the final design phase. It is our plan to use separate systems for each task.**

75. Page B.1.58: Simple scaling of this drawing and drawing 2111-201 sheet 12 indicates:

a. The thread on the tool tightening collar is too short to clear the inset of the female thread in the cask body; and the tightening collar is too large in diameter to clear the floor with the cask sitting flat on the floor.

RESPONSE: **This condition will be changed in the final design phase.**

76. Page b.1.7-17, Section b.1.7.8:

a. It should be noted that these bolts will take the weight of the yoke and crane gear if someone forgets they are screwed into the lid. In addition, the lid could be lifted from a loaded cask if the bolts are not completely disengaged. All aspects of the use of this feature should be reviewed. Are these bolts needed to achieve lid alignment?

RESPONSE: **The design and method of use will be reviewed during the final design phase.**

77. Section B-3, page number 1: The maximum internal pressure is stated to be 315 psia. Other sections indicate this value is 351 psig (i.e., 365 psia). The seals must be tested to the maximum value plus some conservatism.

RESPONSE: **The structural integrity of the cask body will be verified by test during fabrication. The test requirements will be developed based upon the calculated maximum internal pressure, which is expected to be less than 315 psia. In addition, the seals will be tested annually and prior to each shipment.**

78. Section C.1.0: Because so much of the cask system is not defined in the PDR, it is difficult to assess the time shown here. In addition, because of the many comments on the operating procedures themselves, it was not deemed productive to devote resources to such an assessment at this time.

RESPONSE: **Section C.1 has been rewritten to include IF-300 field experience. Estimates of Hot Cell operations have also been included.**

79. Page C.2-7, Section C.2.3: 49 CFR 173.393 limits should read 49 CFR 173.441 and the limit of 10mr/hr is not 6 feet but 2 meters.

RESPONSE: **All references to Title 49 will be verified and corrected as appropriate.**

80. Page C.2-7. The citation of 49 CFR 173.393 is obsolete. The dose rate is now specified in 173.441 and in the case of a "flat-bed style vehicle" (which the railcar is) is specified at 2 meters from the outer edges of the vehicle.

RESPONSE: **All references to Title 49 will be verified and corrected as appropriate.**

DRAWINGS

81. There is no detailed drawing of the lid.

RESPONSE: **Nupac will add detailed drawings of the lid in the final design phase.**

82. There were no drawings of the yoke assembly, and only a limited number of dimensions are given.

RESPONSE: **NuPac will provide drawings of the Yoke assembly in the final design phase.**

83. Drawing 2111-003, sheet 1 of 1: Consideration should be given to extending the personnel barrier to cover the impact limiters. (Note that per the comments on the thermal analysis, temperature conditions may require that the limiters be covered.) The advantage of this is that the cask system has the appearance of being isolated form the environment, and the impact limiters as well as the cask are protected from the environment and from incidental damage.

RESPONSE: **A need to cover the impact limiters with the personnel barrier is not anticipated. Should the cask break away from the rail car, the impact limiters and the cask cradle remain with the cask body. This will be addressed in final design. See response to comment #20.**

84. Drawing 2111-201 Sheet 3 of 12:

a. No method of draining the water from the closure lid/cask annulus could be found. Provisions must also be made for draining the 32 closure bolt holes.

RESPONSE: **The closure lid/cask annulus are filled with borated silicone and therefore do not need to drained. Provisions for draining closure bolt holes will be addressed in the final design phase.**

b. There is a channel cut in the lid between diameters 50 inches. Removing water from this channel will require blotting.

RESPONSE: **This channel will be flushed during cask wash down and decontamination. Clean water which remains can be removed with blotters or air hoses.**

c. Guide pins should be in one to two lengths - long, and very long, and should be designed to engage a slot rather than a hole. Specifically, the 11.5 inch pin (Detail C) should be longer to facilitate lid alignment. Once the lid is close to the cask, short guide pins cannot be seen by the operator. In this design the operator will be trying to hit a hole that is Only 3/4 inch from the containment O-rings. Unless the alignment bolts attached between the lid and yoke can retain the necessary alignment, then one guide pin should be very long so that it can be engaged from the side (slot in lid), to begin centering the lid before the opposite side pin is engaged.

RESPONSE: **NuPac will address this comment in the final design phase.**

d. Are "shipping bolts" inserted in the positions occupied by the guide pins during transport? The guide pin arrangement is not clear.

RESPONSE: **The guide pins will probably be inserted in lid closure bolt holes during lid removal/installation. The guide pins will be removed and replaced with head closure bolts prior to head bolt torquing. Actual configuration will be determined during final design.**

e. A contamination barrier must be provided between the top impact limiter and the annulus around the closure lid. This annulus will be contaminated and may contain residual amounts of water. The contamination and water should be prevented from reaching the limiter. The method used to form the barrier could include a seal in the annulus, a sheet seal that bolts to the lid or cask flange or similar feature. (The barrier should not remain with the limiter.)

RESPONSE: **This comment will be considered in the final design phase. See response to comment 84.b.**

85. Drawing 2111-201, Sheet 7 of 12:

a. The hole in the center of the trunnions will be difficult to remove water from and to decontaminate because of its size compared to the size of a hand. The bolts can be expected to leak pool water for some time after removal from the pool. The ability to drain and decon these areas should be considered (for example, the trunnion "hole" could be machined so that the diameter at the bolt circle is 3.5 inches, but the diameter decreases smoothly to only 3.25 inches at the interior end. this would force water to drain during lifting. Alternately, the hole could be eliminated.)

RESPONSE: **NuPac will include a seal cap in the final design phase.**

b. The "flats" on the handling (upper) trunnion provide a pathway by which the yoke could "walk off" of the trunnion during rotation. The lip should be extended full circle. With the yoke oriented in any other orientation than the "mate up" orientation, it is not clear how the yoke would then be removed. Further yoke details are needed.

RESPONSE: **NuPac will consider this comment during the final design phase.**

c. If the bottom and top trunnions are uniquely different, then the bolt holes should be different (or bolt sizes could be different) to preclude installation of the trunnions at the wrong locations.

RESPONSE: **Nupac will address this comment in the final design phase.**

86. Drawing 2111-201, Sheet 8 of 12: The guide pin appears to be too close to the o-rings, it could either unseat them or cause damage.

RESPONSE: **NuPac will consider this comment in the final design phase.**

87. Drawing 2111-201, Sheet 9 of 12:

a. The operation of the o-ring pressure test port could not be determined from the drawing, or from the description given in Section 7.4.2.

RESPONSE: **NuPac will describe this operation in detain and look at alternate designs in the final design phase.**

b. The complexity of the test should be considered from a maintenance and use point of view. The opening is too small for any hands on work. Is it intended that the whole piece be installed as a unit?

RESPONSE: **The unit is installed as one assembly. This will be addressed in detail in the final design phase.**

c. It is noted in passing that vacuum systems have a tendency to leak at connectors. Frequently, it takes more time to find and fix leaks than it does to complete the testing. Pressure testing should be considered.

RESPONSE: NuPac is considering the use of pressure testing instead of the stated vacuum tests. This will be decided in the final design phase

d. The vent and drain port test "fixtures" should consider the connection to plant systems at the user facility. Exotic connectors must be avoided.

RESPONSE: Nupac will consider this comment in the final design phase.

88. Drawing 2111-201, sheets 9, 10 and 11: The design of the inside portion of the lid does not match that shown in drawing 2111-2 , sheet 3, where the lid is shown as having a step reduction in the thickn which is filled with Boro Silicone and covered with stainless steel. She 9 10 and 11 do not show this step to accommodate the neutron shielding material.

RESPONSE: The borated silicone step does not occur beneath the ports. This will be clarified on the final design drawings.

89. Drawing 2111-201, sheets 9 and 11: The section of the lid behind the test port (sheet 9) shows a lead shielding wafer whereas the section of the lid behind the vent port (sheet 11) does not show such a shielding wafer Since the depth of penetration of the two devices is approximately the same, it would appear that if a shielding wafer is required for one, it is required for the other.

RESPONSE: NuPac will consider this comment in the final design phase.

90. Drawing 2111-201, Sheet 10 of 12: The need for the rupture disc assembly should be reviewed. The assumption of "up to 1 cubic foot of water" left in the cask that can turn to steam is a hold over from the If-300. This consideration should be deleted in light of vacuum drying (Step 7.1.2.17, page 7-5). The inclusion of rupture disc adds complexity, and once operated, vents the cask cavity continuously, this is not going to be acceptable. See comments at chapter 3.

RESPONSE: NuPac will consider this comment in the final design phase.

91. Drawing 2111-201, Sheet 11 of 12:

a. . The operation of the vent valve could not be determined from the drawing or from the text. The vent valve must be designed so that it is serviceable as a unit, since there is not enough space for manual maintenance.

RESPONSE: Design of the vent valve will be reviewed further in the final design phase and include detailed operating descriptions.

NOTE: All cask penetrations are being examined such that all valving will occur exterior to the cask body.

b. The vent line is considered small, and should be increased to at least .75 inch for this size cask. One half inch is too small to allow efficient recirculation of water or liquid decontaminants when the need will arise. The method of leak testing this valve could not be determined.

RESPONSE: NuPac will address this comment in the final design phase.

c. It is not clear how the "Hydrophobic filter" could be serviced or maintained. It is not clear what the purpose of the Hydrophobic Filter is since it will be underwater during head replacement and will likely only slow flow during cask venting and flushing operations.

RESPONSE: NuPac is considering removal of all Hydrophobic Filters in final design.

d. The complexity of the test should be considered from a maintenance and use point of view.

RESPONSE: NuPac will address this comment in detail in the final design.

92. Drawing 2111-201, Sheet 12 of 12:

a. The operation of the drain valve could not be determined from the drawing or from the text. An important issue is the size of the drain line from the drilled line (1.5 inches?) to the outside. The line appears to be only 0.5 inches. If so, then draining will be inhibited. This line should be at least .75 inches for this size cask. Two drain lines could be considered to reduce the time needed to drain the cask - If the valve is easy to operate and easy to leak test. The method of leak testing the valve could not be determined. It is likely that the drain adapter will contact the floor during installation attempts. The "snap-tite" must point down to prevent creation of a water seal.

RESPONSE: **These comments will be addressed in the final design phase.**

b. If only one drain valve is used, then it should be on the "top" of the cask when the cask is on the railcar in the transport configuration. This would assist in minimizing crud buildup in the valve area.

RESPONSE: **Nupac will consider this comment in the final design phase**

93. Drawing 2111-201, Sheet 12:

a. It is suggested that the lid of the penetration in the cask body which the drain plug barrel seal contacts for sealing should be chamfered. Otherwise, if it is square shouldered as shown, the o -ring could quickly wear or tear upon opening and closing the plug.

RESPONSE: **Agree, NuPac will address this in the final design phase.**

b. The lid test port and vent port covers are indicated to 3-4UNC-2A while the drain cover is 3-2UNC-2B. All 3 should be the same in order to minimize the number of adapters required to fit the leak testing equipment.

RESPONSE: **NuPac will consider this comment in the final design phase**

94. Drawing 2111-202, Sheets 3 and 4: The dimensions in Section A-A (sheet 3) of 77.9 and 79.7 are not consistent with the dimensions of the slope on this section provided in Detail H (sheet 4). If one takes the inner dimensions of 77.9 to be correct, and adds the increase in radius of 0.66 (taken twice for increase in diameter) the larger diameter in Section A-A appears to be 79.2 rather than 79.7. The problem may be that Section A-A is too small to accurately determine the locations to which the leaders point.

RESPONSE: **Agree, NuPac will correct the drawings.**

95. Drawing 2111-203, Sheet 1 of 4:

a. It is noted that the bolt holes are approximately 40 inches deep. A special tool will be required to reach this far into a limiter and start a bolt. The torsional effects of the tool must be considered in application of the torque to the bolts. External attachment of the limiter to the cask body should be considered.

RESPONSE: **NuPac will address this comment in the final design phase.**

b. There are no details of the equipment intended to allow the limiters to be slid off of the cask. These carts should be sufficiently sturdy to provide the "stand" for the limiters during periods of non-use, and to allow for movement of the railcar with the limiter on the cart as will (usually) be required in cask rotation to vertical.

RESPONSE: **Agree, details will be provided in the final design phase.**

c. Lift points must be provided for the limiters to allow handling for replacement, or for removal from the car for cask handling at certain facilities.

RESPONSE: **Lift points are provided (see zone C.4,5 sheet 2). Further details to be provided in the final design phase.**

d. There are foam installation ports around the outer area of the limiter, but none in the inner area (or are not shown). Is this correct?

RESPONSE: **Yes, based on previous experience the locations provide for complete foam filling of impact limiters.**

e. Provisions for leak testing the impact limiters should be considered. Can the foam installation ports be used for testing?

RESPONSE: **The heavy flat flanges (see zone B-8) sheet 2) used for the fire consumable plugs can also be used for leak testing, should this be required.**

96. Drawing 2111-210, Sheet 2 of 4 (and others):

a. As noted in the narrative of Chapter 1, some attention must be given to decontamination of the basket, which at first blush does not appear possible.

RESPONSE: NuPac will address this comment in the final design

b. Both fuel baskets are only 168 inches long, but the cavity is 180.5 inches. Some feature is required to ensure that the baskets do not slide in the cavity.

RESPONSE: The basket does not extend the full length to allow for grappling of the fuel assemblies. The outer shell of the basket is approximately 178.5 inches long which will prevent longitudinal movement of the basket while it is in the cask cavity.

c. Information on spacers for fuel of differing lengths was not found either in the drawings or text. Would spacers go in the bottom of the basket for short fuel, or would the basket be removed and a large, disk-shaped, spacer be used to move the basket closer to the top of the cask?

RESPONSE: NuPac recognizes that due to the varying lengths of fuel assemblies, individual spacers located in the bottom of the full basket will be required. Fuel spacers may also be attached to the cask lid.

d. There does not appear to be any feature to keep the baskets from rotating inside of the cask. For ease of handling in a facility the basket should remain "square" with the trunnions.

RESPONSE: NuPac agrees. This locking feature to prevent rotation will be detailed in the final design phase.

e. The basket lift details are not specifically shown.

RESPONSE: Basket lift locations are shown (see Dwg 2111-210 sht 2 plan view, flag Note 8) with detailed design and lifting fixture to be shown in the final design phase.

f. The basket bottom appears to sit essentially flat on the floor of the cask cavity. This will lead to poor draining since the water will not flow freely from the basket.

RESPONSE: **The bottom of the basket cell walls does not rest on the bottom of the cask cavity. The outer shell of the basket rests on the cask bottom. There is space between the bottom of the fuel cell panels and the bottom of the basket outer shell to allow drainage. The bottom of the basket outer shell will be slotted as well.**

g. The openings in the basket should have as generous a sloping lead-in as possible to reduce damage to the top of the separators as much as possible.

RESPONSE: **Agree, this comment will be considered in the final design phase. Experience with lead-in angles on high density fuel storage racks indicates our design has adequate lead-in.**

h. The bottoms of the fuel cells should allow water to flow between cells to maximize flow between cells which in turn would maximize self draining and the flushing of crud from the cell.

RESPONSE: **This comment will be considered in the final design phase.**

97. Drawing 2111-210, sheet 4: The built up cruciform will provide several sharp surfaces that will wear quickly from shock vibration during transport (sharp corners fitted into a circular hole). This wear could generate additional contaminated waste that might be avoided by using a rounded end on the cruciform shape. Also, sealing the ends of the cruciform openings should be considered.

RESPONSE: **NuPac will address this comment in the final design phase. No sharp surfaces will be allowed in final design.**

GRC NUMBER THREE
COMM TS AND RESPONSES
REVIE ER: K.B.SORENSON,
SANDIA NATIONAL LABORATORIES

1.0 MATERIAL AND FABRICABILITY

1.1 General Comments:

1. 1.1.1 The materials used in the NuPac 140-B are, in general, common to the cask industry and have been qualified for use in specific cask component applications. The primary structural material is SA-240, Type XM-19 (plate) and SA-182, Type XM-19 (forging). This material is included in the IE Boiler and Pressure Vessel Code, Section III as a Class I material. Adc on as a Class I material in Section III will facilitate the certification process. For these two materials, it is recommended that they be referenced by the ASME "SA" designation and not by the equivalent ASTM "A" designation.

RESPONSE: ASME designations will be used in the final design phase.

2. 1.1.2 The gamma shield (lead) and neutron shield (boro silicon) have both been certified for shielding in transport casks and should not represent any significant certification issues in this design.

RESPONSE: Agree

3. 1.1.3 The lid bolts are SA-320, Type L43 and are included in ASME, Sec. III as a Class I material. The bolts are Cadmium plated to prevent corrosion and galling. The preliminary design does state that the material should exhibit a Charpy impact value of 20 Ft.-lbs. at -150 F. In order to achieve this value, limits may need to be placed on phosphorous and sulphur which are more restrictive than the limits in the specification or in the AISI 4340 specification. Also, impact performance is very dependent on heat treatment and the heat treatment must be specified in order to achieve the stated impact properties. SA-320 is not specific in the type of heat treatment required for the L43 grade.

RESPONSE: Based on past experience the Type L43 bolt material can be procured with the required Charpy impact values required for this application.

4. 1.1.4 The fracture toughness discussion on the bolts is inadequate. While it is recognized that brittle fracture is a remote possibility, if a discussion is included, it should address current regulatory philosophy. The equation K-(5E(CVN))**0.5 is valid for the lower shelf only and for a select class of ferritic steels. A more appropriate approach would be to measure the nilductility (NDT) temperature directly and compare it with the U.S. NRC draft Regulatory Guides for brittle fracture acceptance criteria. Further, if brittle fracture is addressed, the trunnion material, 17-4 PH (a martensitic stainless steel) and the trunnion bolts, SB-637, UNS N07718, should also be included in the analysis.

RESPONSE: **It is felt that the fracture toughness of the bolts does not warrant a major discussion since they provide multiple redundancy. NuPac will further address this comment in the final design phase.**

5. 1.1.5 The lid bolt specification, SA-320, is designated for low temperature service whereas the trunnion bolt specification, SB-637, is designated for high temperature service. Some discussion regarding the selection of particular specifications may be appropriate.

RESPONSE: **This comment will be considered during final design.**

6. 1.1.6 From the preliminary drawings, it is not clear how the lead will fill the space in the 16.5" top forging once the forging is welded to the cask walls.

RESPONSE: **In the final design phase NuPac will provide detailed dwgs showing vent and fill lines required for the lead pouring process.**

7. 1.1.7 Both the PWR and BWR basket designs are fairly complex from a fabrication standpoint. It would be helpful in the next phase to discuss the fabrication processes in terms of bonding strength and repeatability of the process.

RESPONSE: **Agree, NuPac will provide this information in the final design phase. Preliminary discussions with potential basket fabricators indicate that fabrication will not be difficult.**

8. 1.1.8 The poison material in both the PWR (copper with enriched bo: baskets is not specification material. What controls are provided to ensure that a consistent quality of material will be provided? There is a new ASTM specification, A-887, which covers borated stainless steel.

RESPONSE: **All neutron absorbing material will be verified as being acceptable to the NRC prior to use. Several materials previously used which are acceptable to the NRC are under consideration.**

9. 1.1.9 The selected materials exposed to the environment have a good corrosion resistance and the compatibility of the materials is such that galvanic reactions should be negligible.

RESPONSE: **Agree.**

1.2 Specific Comments

10. 1.2.1 Sheet 3 of the impact limiter drawings; XM-19 is referred to as Type 304 stainless steel.

RESPONSE: **The drawing will be corrected to delete reference to type 304.**

11. 1.2.2 Sheet 7 of the cask body drawings; the trunnions are called out as A-182, Type XM-19. The structural section, page 2.5.1-2 specifies the trunnion material as SA-564, Type 630 (17-4 PH).

RESPONSE: **The drawing will be corrected to agree with the text.**

2.0 Structural

2.1 General Comments

12. 2.1.1 The buckling analysis for the two baskets has not been performed yet. This analysis should be performed as soon as possible since it is a critical evaluation due to the basket design. The assumed frictionless pinned connections for the basket webs result in boundary conditions which enhance the potential for buckling.

RESPONSE: **Basket structural analysis Section 2.6.8 and 2.7.7 have been revised to include buckling.**

13. 2.1.2 it is not clear if structural credit is being taken for the basket poison material (borated stainless steel and copper). If not, how are the shear loads transferred in the sandwich design from one structural member, across the poison material, to the other structural member? If the materials are being used as structural members, then mechanical properties should be characterized and ASTI, ASME materials should be used where possible.

RESPONSE: Structural credit is not being taken for basket poison material, nor do shear loads pass through the poison material.

2.2 Specific Comments

14. 2.2.1 Page 2.0-31, Table 2.3-1; include SA-182 in the table.

RESPONSE: Section 2.0 has been revised to include this comment.

15. 2.2.2 Page 2.5.2-14; The buckling evaluation for the tie down stiffeners is incorrect. The terms in the equation for calculating the critical stress result in units of lbs., not psi. Also, the buckling evaluation of a plate should include a Poisson's Ratio Effect.

RESPONSE: Section 2.0 had been revised and corrected per this comment.

16. 2.2.3 Page 2.6.8; the table shown is incomplete. Locations P7-P10 are not shown in the table as described in the test.

RESPONSE: Typographical error. P7-P10 should have been P5 & P6. Section 2.0 has been revised.

17. 2.2.4 Page 2.6-21; table 2.3-5 referenced on this page does not exist.

RESPONSE: Section 2.0 has been revised to include Figure 2.3-3.

18. 2.2.5 Page 2.6-20; lead properties are referenced back to TABLE 2.4-1, but are not included in the table.

RESPONSE: Section 2.0 has been revised to include lead properties in table 2.3-1.

19. 2.2.6 Page 2.6-18; Fig. 2.3-8 referenced on this page does not exit.

RESPONSE: **Section 2.0 has been revised to include the appropriate figure, which is Figure 2.3-6.**

20. 2.2.7 Page 2.6-75; the bending analysis assumes shear transfer through the lead to calculate stresses on the inner shell.

RESPONSE: **Stresses in the lead will be considered during final design.**

21. 2.2.8 Page 2.7-19; the lead slump data is incorrectly referenced to Table 2.6.7.1-6

RESPONSE: **Section 2.0 has been revised to reference Table 2.6.7.1-8**

22. 2.2.9 Page 2.7-54; the equivalent thickness calculations for the puncture evaluation should be based on the ratio of the Moduli of Elasticity for the two materials, not on the ratio of the tensile strengths.

RESPONSE: **Tensile strengths were utilized because all three simi-empirical puncture equations utilized this material property. Testing has been recommended to verify the calculations.**

23. 2.2.10 Page 2.6-99; referenced Fig. 2.6.8-6 is labeled as Fig. 2.6.8-7. Subsequent figure numbers should also be changed.

RESPONSE: **Section 2.0 has been corrected to reference correct figures.**

24. 2.2.11 The payload basket stress analysis section 2.7.7 does not exist.

RESPONSE: **Section 2.0 has been revised to include Section 2.7.7.**

3.0 Conclusions

25. 3.1 The selected materials, in general, have precedence for application in transport cask construction. From a materials qualification standpoint, there should be no "show-stopper" issues. Clarification should be made on the role of the poison material in the basket web in both the PWR and the BWR baskets. If the material does transfer load, it should be characterized and nationally recognized material specifications should be used when possible.

RESPONSE: The poison material in the baskets is not utilized to transfer load.

26. 3.2 The buckling analysis for the baskets should be made in the near-term. Results of the analyses could have programmatic impact concerning the design of the baskets.

RESPONSE: Section 2.0 has been revised to include the basket buckling analysis. Other considerations, such as static equilibrium, will be evaluated during the final design phase.

GROUP NUMBER FOUR COMMENTS AND RESPONSES
REVIEWER: C.M HOPPER,
OAK RIDGE NATIONAL LABORATORY

6.0 CRITICALITY EVALUATION

1. PARA 1-

a. The statement that "the NuPac 140-B cask complies with the requirements of 10 CFR 71.55 and 71.61 for a Fissile Class III Package for the contents described in Section 6.2" requires further support as acknowledged within the PDR and identified within these comments.

RESPONSE: **Yes, the NuPac 140-B Cask could be likely classified as a Fissile Class I Package. However, additional criticality analyses must be performed to reach this conclusion. We will aim toward this direction in our criticality safety analyses for the final design.**

b. It would appear that the cask would likely qualify as a Fissile Class I Package as determined by nuclear criticality analyses. It is suggested that the designer consider completion of the analyses to demonstrate the nuclear criticality safety qualification of the cask to be a Fissile Class I Package. The classification of the cask as a Fissile Class III package would then be determined for legitimate 10 CFR 71 reasons of package content/handling /transport or radiation indexes.

RESPONSE: **This will be addressed in final design.**

6.1 Discussion and Results

2. Para 1- Most of this section deals with the primary issue of concern, i.e., the interchangeable poison baskets. Little is said about the cask body or its influence on reactivity.

RESPONSE: **Detail description of the cask body, as stated in the second sentence, can be found in Section 1.2. The study of the influence on reactivity of the cask body is not needed since there is only <u>one</u> design of the cask body.**

3. Para 4-

a. Says "the maximum k-eff is 0.887 for an infinite array of casks with 52 BWR fuel assemblies". This agrees with Para 2 of "6.4.3.2 Criticality Results for BWR Fuel", which immediately follows "TABLE 6.4-2 BWR KENO Calculations Summary", and states that the "system reactivity was calculated to be 0.88706 including all calculational uncertainties at a 95 % confidence level". TABLE 6.4-2 states that KENO Model Case 3 is a Finite Array Type with a Calculated K equal to 0.85231 but Para 4 of the referenced section "6.3.1.2 Models Used for BWR Fuel Assemblies in the Cask" states that the third model is an infinite array as does the last sentence of Para 1 in "6.3.1 Description of the Calculational Model".

RESPONSE: **All inconsistencies had been corrected to reflect "the maximum k_{eff} is 0.887 for an <u>infinite</u> array of casks with 52 BWR fuel assemblies".**

b. Sentence 3 may be a true statement but obtaining regulator concurrence in accepting "Minimum Burnup (case 2) " of "TABLE 6.2-2 Design Characteristics for Westinghouse PWR Fuel" will be a trick even if benchmark experiments with spent fuel are available.

RESPONSE: **We believe sentence 3 is a true statement, therefore no text modifications were made.**

6.2 Package Fuel Loading.

4. Para 1 - Sentence 3 expectations should be supported with reference to documents, other studies, or studies presented in the SARP.

RESPONSE: **Criticality safety analyses for consolidated fuel option will be analyzed in the final design to confirm our claims.**

5. Para 2 - Some effort should be made to demonstrate/verify the thesis of section 6.4.2 referenced in the last sentence. Such a demonstration or verification would provide a basis for "TABLE 6.2.-1 Fuel Assemblies Acceptable for Transport in the NuPac 140-B Cask".

RESPONSE: **As cited in Section 6.4.2 "Fuel Loading or Other Contents Loading Optimization", many previous works and published data support our claims that Westinghouse 15x15 and General Electric 8x8R are the most reactive PWR fuel and BWR fuel among the fuel assemblies considered, respectively. At this preliminary stage, we feel that our**

evaluations are prudent and are based upon technical judgement and experience.

6.3.1 Description of the Calculational Model.

6. Para 1- An array of two (or more) undamaged NuPac 140-B Casks with PWR fuel should be demonstrated to be safely subcritical.

RESPONSE: **As stated in Section 6.1, k_{eff} calculations of an array of two undamaged NuPac 140-B Casks with PWR fuel assemblies will be performed in the final design.**

7. Para 5- The last sentence requires some supportive information, considering the cask/basket environment.

RESPONSE: **Reference to NUREG-0612 "Control of Heavy Loads at Nuclear Power Plants" has been added to the PDR to support the last sentence.**

6.3.1.1 Models Used for PWR Fuel Assemblies in the Cask.

8. Para 1- The first sentence presumes safety from nuclear criticality by ensuring a K-eff less than 0.95. Nuclear criticality safety is not ensured by having calculated k-eff less than 0.95. Consider restating the first sentence to say something like; The NuPac 140-B Cask with a basket for 21 PWR fuel assemblies was designed to maintain a calculated k-eff plus biases and uncertainties to be less than 0.95. This statement would be consistent with the content of section "6.1 Discussion and Results".

   Reference to "a hollow copper tube (was) modeled in the center of each cruciform" causes some concerns. If this information is pertinent to the safety analysis or some intermediate results leading to the end results then state how so, otherwise remove such references.

RESPONSE: **Comments have been incorporated into the PDR.**

9. Para 2- There needs to be a better correlation and identification of materials/dimensions between FIGURE 6.3-1 and TABLE 6.3-1.

   Improve FIGURE 6.3-1 (or provide other figures) to give fuel assemble details similar to FIGURES 6.3-7 and 6.3-8.

RESPONSE: **Figure 6.3-3A has been added to the PDR to show the PWR fuel assembly dimensions.**

10. Para 3- Second sentence makes no sense. Remove it or fix first sentence parenthetic values. Sixth sentence makes reference to a hollow copper tube in a cruciform that is not shown in Appendix 1.4 or FIGURE 6.3-1 or referenced in TABLE 6.3-1. If calculations assumed copper tubing which is not actually a part of the cask, then conservatism of the model should be demonstrated.

RESPONSE: **The second sentence has been removed from the text. In the sixth sentence, the word "copper" has been removed from the phase "hollow copper tube in the cruciform". Currently, the stainless steel cruciform still has a "hollow tube" to be filled with water in the KENO-IV model.**

11. Para 4- The technique of modeling for maximum neutron return to the basket will likely misrepresent neutron interaction within an array of casks. Consider evaluating systems at both extremes.

RESPONSE: **This technique of modeling is only conservative for a single cask model, which was the case being considered. See the response to question 41.a, Group 1.**

12. Para 6- The cuboidal representation of the "Quarter Cask Model" significantly offsets the cask, as a reflector, from the basket of fuel assemblies. For instance, as per Appendix 1.4 the inner stainless steel and lead liners (total thickness about 6.125 inches) are offset from the basket of fuel assemblies by no more than about 0.25 inch whereas the cuboidal minimum of 0.25 inch and a maximum of more than 12.06 inches from the basket of fuel assemblies. Additionally, the cuboidal model offers a much larger volume (about 27% more) of neutron absorbing cask materials than is really encountered in the cask design, thereby reducing neutron interaction within arrays. Demonstrate the conservatism of the modeling technique for both single and multiple package analyses.
Additionally, there is a need to evaluate off centered fuel assemblies, fabrication tolerances, and manufacturing tolerances on the poison materials. This should be completed.

RESPONSE: **For a single cask model, we expect that there would be very little differences between the existing KENO model (square cask) and the actual model (round cask). In the final design, we will model the cask as closely as possible to its actual configration. Likewise, uncertainty evaluations of the k_{eff} due to off centered fuel assemblies, fabrication tolerances, and manufacturing tolerances on the poison materials will be considered in the final design.**

6.3.1.2 Models Used for BWR Fuel Assemblies in the Cask.

13. Para 1- The first sentence presumes safety from nuclear criticality by ensuring a k-eff less than 0.95. Nuclear criticality safety is not ensured by having calculated k-eff less than 0.95. Consider restating the first sentence to say something like; The NuPac 140-B Cask with a basket for 52 BWR fuel assemblies was designed to maintain a calculated k-eff plus biases and uncertainties to be less than 0.95. This statement would be consistent with he content of section "6.1 Discussion and Results".

RESPONSE: Comments have been incorporated into the PDR.

14. Para 6- There is an implied promise to evaluate off centered fuel assemblies, fabrication tolerances, and manufacturing tolerances on the poison materials. This should be completed

RESPONSE: See response #12

6.3.1.2.3 Array of Casks with BWR Fuel Assembles.

15. Para 2- The cuboidal representation of the "Quarter Cask Model" significantly offsets the cask, as a reflector, from the basket of fuel assemblies. For instance, as per Appendix 1.4 the inner stainless steel and lead liners (total thickness about 6.125 inches) are offset from the basket of fuel assemblies by no more than about 0.25 inch whereas the cuboidal model (unless loaded with 64 fuel assemblies) places the cask at a minimum of 0.25 inch and a maximum of more than 12.06 inches from the much larger volume (about 27% more) of neutron absorbing cask materials than is really encountered in the cask design, thereby reducing neutron interaction within arrays. Demonstrate the conservatism of the modeling technique for both single and multiple package analyses.

RESPONSE: See response #12

6.3.2.1 Package Regional Densities for the PWR Basket and Fuel Assemblies.

16. Para 1- Provide material densities and documenting references for all mixtures presented in TABLE 6.3-3.

RESPONSE: Material densities of these mixtures are calculated and documented in our calculation packages which are available for review upon request.

17. Para 2- Provide material densities and documenting references for all mixtures presented in TABLE 6.3-4

RESPONSE: See response #16

6.3.2.2 Package Regional Densities for the BWR Basket and Fuel Assembles.

18. Para 1- Provide material densities and documenting references for all mixtures presented in TABLE 6.3-5.

RESPONSE: See response #16

19. Para 2- Provide material densities and documenting references for all mixtures presented in TABLE 6.3-6.

RESPONSE: See response #16

20. Para 3- Provide material densities and documenting references for all mixtures presented in TABLE 6.3-7.

RESPONSE: See response #16

6.4.1 Calculational or Experimental Method

21. Para 1- GENERAL COMMENTS- Sections 6.4.1.1 and 6.4.1.2 need to be reorganized to place the common information as to source of codes and cross sections and their use and processing and references into this section.

    Provide assurances that the base computer hardware and systems, codes performances and cross sections data did not change during the evaluation of benchmarks and cask analyses. This might be done by processing a specific representative calculation on the computer used before, during and after the benchmark validation and safety analysis evaluations.

RESPONSE: Sections 6.4.1.1 and 6.4.1.2 have been combined as section 6.4.1 "Calculational Method". The computer system has had quality checks performed on it, and the method which demonstrates the adequacy of these checks will be described in the final design phase.

6.4.1.1 Calculational Method for PWR Fuel.

22. Para 2- Input decks provided in Appendix 6.6.2 are too incomplete to permit verification of input data. Provide complete input listing of base cases.

RESPONSE: Complete input decks of the BWR case are given in Appendix 6.4.2.

23. Para 3 - Provide the basis of modeling for the statements in sentences 2,3, and 4.

RESPONSE: The fuel-cladding gap is essentially filled with void material and very small compared to the fuel cell dimension; thus, it has very little effect on the cell-weighted homogenization process.

6.4.2 Fuel Loading of Other Contents Loading Optimization.

24. Para 2- Last sentence is too general, i.e., "appropriate for consideration". The statement leads a reader to believe that the W15 X 15 fuel assembly is only one of the more reactive PWR types. If references 6.6.1.6 and 6.6.1.7 do not specify relative reactivity for all of the other 12 PWR fuel assembly types, demonstrate conservatism of using the W15 X 15 fuel assembly of the analysis. Even if the references specify relative reactivities for all of the other 12 PWR fuel assembly types, some verifying calculations should be performed.

RESPONSE: See response #8

25. Para 4- if reference 6.6.1.8 does not specify relative reactivity for all of the other BWR fuel assembly types, demonstrate conservatism of using the GE 8 X 8R fuel assembly for the analysis. Even if the references specify relative reactivities for all of the other 8 BWR fuel assembly types, some verifying calculations should be performed.

RESPONSE: See response #8

6.4.3 Criticality Results

26. Para 1- GENERAL COMMENTS- Computer code outputs of crucial computations are not provided to permit review of code imputs and code execution which would include assurance that only qualified and validated computer hardware and systems, programs and data bases are used in the analyses and benchmarking.

Provide computer outputs for crucial computations used in the analyses.

The outputs should include enough information to show;

* The computer systems, program and data sets used,
* The date of usage,
* Input data for materials and geometries,
* Intermediate results of cross section processing
* Plots of avg K-eff by generation completed, and
* Summary table of k-eff by generations skipped.

This information should provide confidence that the same computer hardware and systems, programs and data sets were used in the preparation of section "6.5 Critical Benchmark Experiments".

RESPONSE: **All computer code inputs and outputs are contained in NuPac's calculation packages. These packages are on file at our office and are available for review upon request.**

6.4.3.1 Criticality Results for PWR Fuel

27. Para 2- Provide reference to the determination of uncertainties and bias of calculations relative to the computational methodology and experimental benchmarks. Approximate the descriptive effort provided in section 6.4.3.2.

RESPONSE: It is felt that Section 6.4.3.2 provides adequate discussion of the calculational approaches used by NuPac for the determination of uncertainties and bias. Reference to the discussion in Section 6.4.3.2 will be included in the paragraph in the Final Design report.

28. Para 3- Elaborate on the "tradeoff calculations" and provide demonstration of the model conservatism. if reliance is to be placed on an expected k-eff value of 0.944, then the specific model should be evaluated.

RESPONSE: **Detail calculations of the Tradeoff study are documented in our calculation package. As mentioned in the footnote #4 of page 6-38, the PWR Quarter Cask model will be evaluated and included in the final design.**

6.4.3.2 Criticality Results for BWR Fuel.

29. Para 1- Para 4 of section 6.3.1.2 states that the "third computer model was constructed to calculate the reactivity of an infinite array of NuPac 140-B shipping casks'; however, TABLE 6.4-2 case 3 creates the impression that the model is a "finite Array Type ". If this is real, modify the text to reduce the uncertainty of understanding.

RESPONSE: **See response #3**

30. Para 3- See GENERAL COMMENTS of section 6.4.3 Para 1.

RESPONSE: **See response #28**

31. Para 2- Organizationally, reference to TABLE 6.5-1 should be made in this section. Change column heading in TABLE 6.5-1 from "KENO Measured" to "KENO Calculated". Make reference to specific input/output data of the benchmark calculations as provided in an Appendix, Like Appendix 6.6.4.

See GENERAL COMMENTS of section 6.4.3 Para 1.

:SPONSE: **Editorial comments have been incorporated into the PDR. The input/output data of the benchmark calculations are stored and kept on file at Power Co:nputing Company.**

6.5.1 Validation Bias Calculation for PWR Fuel

32. Para 1- This would make a good follower narrative for describing TABLE 6.5.1 in Para 2 of section 6.5.1

RESPONSE: **Sections 6.5.1 and 6.5.2 have been consolidated into one section 6.5 "Critical Benchmark Experiments".**

33. Para 2 - Considering the 3/8" composite thickness of the stainless steel (about 0.23 inch) and copper (about 0.16 inch) in the basket walls, use additional benchmark experiments which address these materials. Otherwise, demonstrate the conservatism of not using copper and stainless steel benchmark experiments to validate the use of the cross sections in the safety analyses of section "6.4 Criticality Calculations".

Demonstrate calculated nuclear properties and neutron spectrum similarities between the benchmark experiments and the cask design.

RESPONSE: **Copper material in the basket walls of the NuPac 140-B Cask is expected to have a very small effect on the k_{eff} of the cask. This will be verified in the final design.**

6.5.2 Validation Bias Calculation for the BWR Fuel.

34. Para 1- This would make a good beginning for Para 2 of section 6.5 to introduce Table 6.5-1.

RESPONSE: See response #31

35. Para 2- Considering the 5/16 composite thickness of the stainless steel (about 0.28 inch) and copper (about 0.06 inch) in the basket walls, use additional benchmark experiments which address these materials. Otherwise, demonstrate the conservatism of not using copper and stainless steel benchmark experiments to validate the use of the cross sections in this safety analyses of section "6.4 Criticality Calculations".

Demonstrate calculated nuclear properties and neutron spectrum similarities between the benchmark experiments and the cask design.

RESPONSE: See response #33

36. Para 3- First sentence - appears to be true in all but Core XI of TABLE 6.5-1 which appears to have a large positive calculational bias at close spacing between assemblies (0.5644 inch).

RESPONSE: No action is required at this time. All aspects of the criticality evaluations will be reviewed during final design.

37. APPENDICES - See review comments of text.

RESPONSE: The Appendices have been reorganized, see previous response.

GROUP NUMBER FIVE
COMMENTS AND RESPONSES
REVIEWER: R.E. BROZ
WESTINGHOUSE HANFORD COMPANY

1. Page 1-19, first bullet at top of page: The cask penetrations section must include the criteria that the design will allow easy decontamination, possibly remotely before human access and maintenance. This addition constitutes an ALARA practice.

RESPONSE: NuPac will incorporate this in the final design phase.

> **NOTE: All cask penetrations are being reviewed and will be redesigned as appropriate to utilize actual cask operational experience and to facilitate remote handling.**

2. Page 1-19, third bullet: The cask drain must include a statement that allows for easy decontamination possible remotely before human access, maintenance or operation. this addition constitutes an ALARA practice.

RESPONSE: NuPac will investigate the drain design in the final design phase.

3. Page 1.4-1, Appendix 1.4, Drawing No. 2111-201, Sheet 11 of 12; The hydrophobic filter does not show a means for access if it becomes highly contaminated and or needs maintenance. Include a means of access.

RESPONSE: We are considering the removal of the hydrophobic filter and will address this comment in the final design phase. See the response to question 91.b in Group 2.

4. Page 1.4-1, Appendix 1.4, Drawing No. 2111-201, Sheet 11 of 12; Several inches of shielding material (304 Stainless) are lacking within this Vent port. Ensure that the shielding calculations have included this void when determining the does equivalence rates.

RESPONSE: The shielding is there, NuPac will clarify these details in the final design phase.

5. Page 1.4-1, Appendix 1.4, Drawing No. 2111-201, Sheet 12 of 12; The debris cover does not show how it can be easily accessed, especially since the operators will have one or more pair of protective gloves while operating. Explain and show how this is to be operated.

RESPONSE: **The cover can be easily unthreaded. Details of how this is accomplished will be shown in the final design phase.**

6. Page 1.4-1, Appendix 1.4, Drawing no. 2111-201, Sheet 12 of 12; Provide an explanation of page 1-19, third bullet, of how this drain is expected to operate and refer to the explanation on this sheet.

RESPONSE: **See response to Comment 1.**

7. Page 5-1, 5.0, second sentence; This design refers to fuel which has been out of the reactor for no less than 10 years. Ensure that this requirement is a control which is listed in the Certificate of Compliance, when and if issued.

RESPONSE: **The NRC when issuing a certificate places all payload restrictions that are assumed in the SAR into the certificate.**

8. Page 7-2, 7.1.1; This operating procedure does not list the requirement that the reactor fuel be cooled no less than 10 years in this section since it is a known.

RESPONSE: **Section 7.0 has been rewritten. The concern addressed in this comment will be addressed when the specific operating procedures are prepared.**

9. Page 7-2, 7.1.2: Nowhere is there a mention of the need for Radiation or Industrial Safety. There will be a likelihood of internal contamination and high close rates. Industrial Safety is needed for hoisting and rigging required for this large and massive container. Include these warning statements wherever needed in this entire section.

RESPONSE: **Radiation & Industrial Safety requirements will be included in the cask Maintence & Operating Procedures as appropriate.**

10. Page 7-3, 7.1.2.2; This section does not suggest that residual radioactively contaminated water may exist and must be mentioned.

RESPONSE: **These warnings and cautions will be used throughout the Operating and Maintenance Manual and will not be included in Section 7.0 of the SARP which is not intended to provide specific detailed Operating procedures. The following are some of the warning and caution notes which may be included in the actual procedures.**

WARNING

A WARNING is provided where a potentially dangerous condition to personnel could exit.

WARNING RADIATION HAZARD

A WARNING - RADIATION HAZARD is provided where a potential radiation hazard could exit.

CAUTION

A CAUTION is provided where a condition or situation exists with potential for damage to equipment.

11. Section B-3, Helium Leak Test Data Sheet, -29 degrees C (-20 degrees F) The final leak rate at the bottom of the page shows "less than 2x10-8 atm-cm3/sec. The leak rate just above is 2.4x10-7. 10-7 is more than 10-8. This data sheet and all others must be reevaluated.

RESPONSE: The data supplied was accumulated during rough scoping for candidates. Final candidates will be evaluated further using formal test data from future testing. Appropriate values will be used to insure the adequate sensitivity of the methods used.

GROUP NUMBER SIX
COMMENTS AND RESPONSES
R.P. WADKINS
EG & G IDAHO

1. Please discuss NuPac's computer code verification and validation procedures, pg 1-17.

RESPONSE: **The Quality instructions (QI's) used for the computer code verification have been made available for EG&G review. Also, guidelines for verification and validation have been established by EG&G/DOE for contractors use. A discussion of these procedure would exceed the intent of Section 1.0 of the Preliminary report.**

2. Be prepared to discuss if continual heating and freezing causes boro-silicone compound degradation, pg 3-3.

RESPONSE: **NuPac is investigating the effects of heating and freezing with the material manufacturer. The manufacturer is being asked to submit information on the effects of these phenomena.**

3. Be prepared to discuss sensitivity and/or parametric analysis on thermal runs, i.e., what happens if black paint chips off, what if copper fins oxide, emissivity changes, etc.

RESPONSE: **This comment will be addressed during final design.**

4. a. What appears to be a conservative condition for a steady state run with internal heat generation may not be conservative under accident conditions, e.g., assuming no wire between thermal shield and outer neutron shield may be conservative when the energy transfer is out but during a fire, where energy flow may be in and we are concerned about temperatures of the cladding, it's probably not conservative.

RESPONSE: **This is true however the thermal shield heats to 1,100°F in about 2 minute per Figure 3.5.3-2 and expands away from the wire.**

b. I would suggest for the accident case (fire) the steel wire be factored in by an effective thermal conductivity across the gap.

RESPONSE: **This comment will be considered during final design.**

5. The decay heat values are put in as uniform throughout the 21 (PWR) areas. We should look at a "hot" assembly with say a 1.5 peak average axial peaking and see what the maximum cladding temperature is when the assembly is near the center of the basket.

RESPONSE: **Analysis will not satisfy this comment. The situation becomes an operational problem due to the variability of the decay heat rates of individual fuel assemblies. Hotter assemblies will have to be put in selected basket tubes. The total heat load of the cask cannot exceed 11 KW.**

6. How do we assure ourselves that with the lead pour that no gap exists between the stainless steel sheath's on each side of lead? Shouldn't we take a gap conductance or contact coefficient at these surfaces? I don't see this in the "Half Axisymmetric Model" (HAM).

RESPONSE: **Gaps may exist however NuPac experience seems to indicate that sufficient contact exists to negate significant increased resistance due to the phenomenon of resistance in parallel.**

7. The detail thermal models take temperature boundary conditions from other models, usually the HAM. Is there an iteration on B.C.'s so that a temperature of a component in each model is the same? For example, in the 30° model a 177° F personnel barrier temperature is used as input from HAM, do the gamma shield lead temperatures have the same value in both models or does the 177° F B.C. temperature need to be adjusted?

RESPONSE: **These situations have been handled in a conservative manner. For instance, the HAM model predicts a 291°F inner shell boundary temperature based on an inner shell emittance of 0.5. When either basket model was utilized, the inner shell emittance assumed was 0.3. Probably a valve of 0.5 is more realistic. This comment will be given more thought during final design.**

GROUP NUMBER SEVEN
COMMENTS AND RESPONSES
REVIEWER: G.R. HAYES
IDAHO NATIONAL ENGINEERING LAB

1. Any design consideration of capability to transport failed fuel (breach of cladding)?

RESPONSE: **Failed fuel must be placed in a sealed cannister before it can be shipped in the 140-B cask.**

2. SAR drawings. Recommend that the "top tier" SAR drawings not contain fabrication details that are dependent on vendor selection and do not specify final configuration. Examples would be weld preparation configuration. This will eliminate unnecessary SAR revisions, as these "in process" dimensions are revised.

RESPONSE: **The final SAR drawings will comply with the recommendation contained in this comment.**

3. Cask load test of trunnions, is specified as 150% of maximum working load (drawing 2111-201 Note 13). Single failure criteria for ANSI N14.6 may require a higher test load. This is facility dependent. Cask trunnions must comply with facility lifting requirements, since they form part of the load path. This should be discussed with all potential users of the cask to determine most stringent load test requirements.

RESPONSE: **The design of the cask trunnions and lifting yoke may not necessarily** be **facility dependent. The NuPac design is based upon satisfying the requ irements of ANSI N14.6 and NUREG 0612 by providing a dual load path (single failure point) for critical loads (see response to item 18, page 13). Therefore the testing requirements of ANSI N14.6, para. 6.3(2) apply, which require a load test equal to 150% of the total weight to be lifted.**

4. The cask drawing 2111-201 references several NuPac documents for further design information: i.e., L-01 for lead pour, weld inspection per VT-01, inspection per L02, load test per Lot-21, leak test per LT-21. Will these documents be included in the SAR? An alternative would be to only reference regulations/standards on the drawing.

RESPONSE: **NuPac agrees with your alternate approach and is revising the drawings accordingly. However, it is recognized that the instructions are not sufficient to demonstrate how they are made.**

5. Note 22 of Drawing 2111-201 should specify that all containments shell welds are full "penetration".

RESPONSE: This is actually note #29. NuPac agrees and will correct the note.

6. Inspection/test personnel certifications and qualifications: Section 9 of the Preliminary Design Report (PDR), states that "qualification reviews are performed periodically..." Recommend that test/inspector personnel certifications be verified prior to actually performing the inspection or test. This will assure that all personnel have valid and current certifications before they do the work. Not an NQA-1 requirements but certainly a good procedure for preventing problems and avoiding repeat inspections/tests. Note: May not be possible to repeat all inspections - may become inaccessible during subsequent fabrication.

RESPONSE: The first Part of Sect. 9.2.10 states that these reviews are performed by the QA manager prior to performing the test or inspection.

7. General comment on "field fitting" of components. This would apply primarily to the cask ancillary equipment. In situations where fabrication drawings/plans specify "field fitting" of structural steel components, controls must be placed on fabrication operations to assure that the minimum material conditions allowed by the field fitting operations are consistent with material thicknesses assumed in the stress analysis.

RESPONSE: All drawings and/or specification will include the stated recommendations.

8. Two general comments regarding fasteners:

   a. Beware of bogus bolts. Suggest sample testing of completed fastener.

RESPONSE: NuPac is aware of "bogus bolts" and our procurement of bolts will address this issue during the fabrication cycle. A grade approach to quality will be applied to all materials procured for this contract. NuPac will invoke Quality Requirements and Verifications appropriate to the assigned graded quality category.

   b. For cap screws subjected to high torque (e.g., fasteners, lid bolts), previous experience has shown a problem with the internal hex "rounding out" due to application of high torques and the fasteners becoming unusable. These problems occurred with the same material (A320, Grade L43). This is due to the wide variability in the QC of the hex dimensions within the fastener industry. Suggest first article inspection of lid fasteners.

RESPONSE: **Items such as Fasteners are procured and inspected in accordance with industry standards with required tolerances applied. NuPac will look into this issue in final design. We will also investigate the use of 12 point bolt heads or other head configurations.**

9. PDR, Section 8 - Acceptance Tests. Paragraph 8.1.6 specifies "no testing required." Recommend a test to verify the heat dissipating capability of the cask, i.e., how well the copper fins perform.

RESPONSE: **Typically calculations are sufficient though thermal testing can be performed by the customer. NuPac will ensure the thermal performance of the cask and recommend to the DOE any additional testing which would appear to be appropriate for consideration during the testing to be performed by the DOE, e.g., confirmatory demonstration.**

10. Has a producibility review been performed? Especially for the copper fins.

RESPONSE: **Yes, All components undergo a producibility review. As the design moves into final design, more specific reviews are performed.**

11. Impact limiters, drawing 2111-202 and 2111-203, why are you painting SST?

RESPONSE: **To decrease the solar absorbtivity and increase the surface emmissivity.**

12. Comments 2 and 4 on the cask itself, apply to the impact limiters also.

RESPONSE: **See response numbers 2 and 4.**

13. Impact limiters. Need to reference a specification for the brazing process. Procedure and personnel qualifications apply here.

RESPONSE: **Brazing processes will include use the appropriate specification criteria.**

14. Cask operation, PDR Se ion 7.1.24. Suggest use of sleeves to protect both the cask and lid O-ring aling surfaces. Addressed for cask in 7.1.2.7; but should be mandatory, not optional.

RESPONSE: **A cask seal surface protector will be mandatory at the utilities, but may not be required at the MRS or Repository. It will depend on the remote handling equipment to be used. There is no need to protect the lid O-rings because they are side mounted. Section 7.0 is being rewritten.**

15. Loading of fuel assemblies. Will it be necessary to prescribe a loadin pattern (spec fuel assemblies in specific locations)? If so, should addressed in ction 7.

RESPONSE: **There is no indication at this time that a specific location or loadir sequence for placing the fuel assemblies into the fuel basket is required. Should an operational problem arise due to variability of the decay heat rate of individual fuel assemblies, a loading scheme would be developed.**

16. Operations. Is it acceptable to drain the cask before it is moved from the pool to a work area?

RESPONSE: **No, the water remains in the cask to provide shielding (ALARA) during the decontamination process and during the head bolt installation and tightening operation.**

17. General comment on maintenance. Cask maintenance, including records, require planning "up front;" otherwise, it will probably not comply with NRC requirements. The cask licensee is responsible for this planning. The licensee must "own" maintenance and have a system to assure that maintenance is conducted as required and that the required QC records are maintained. This will require much communication and coordination because of the numerous companies involved.

RESPONSE: **This will be included in the Maintenance manual which will include sections on records and QA/QC requirements.**

GROUP NUMBER EIGHT
COMMENTS AND RESPONSES
REVIEWER: M.D. RUSKA
EG & G IDAHO

1. Section 1.2.3, Page 1-4, third sentence (also ref. section B.1.6.1.2, page B.1.61) States the maximum allowable weight for the railcar was set at 40,000 lbs. There is no way a 4 axle railcar, capable of handling approximately 214,000 lbs., can be constructed and weight 40,000 lbs. The realistic weight is closer to 100,000 lbs. and will probably end up being a 6 or 8 axle railcar in order to distribute the load in accordance with AAR rules. It must be kept in mind that with this kind of concentrated weight, you can only go to 75% of the railcar capacity.

RESPONSE: **The requirement for 75% of capacity is for standard railcars (FM). Cars can be and have been designed for 100% capacity for loads in the center as long as each set of trucks doesn't exceed the AAR wheeloading. These flat cars have AAR FMS designation. The NuPac railcar designer has indicated the railcar to meet our specification with weight approximently 39,500 pounds.**

2. Section 1.2.4, Page 1-4 Is there a weight calculation for the sunshield/personnel barrier and is it added into the overall gross weight?

RESPONSE: **Yes, there is a weight estimate of 2,000 pounds for the sunshield/personnel barrier and it is added to the overall weight on rails.**

3. Section 1.3.16, Page 1-16

   a. The figure shows a total gross weight of 206,539 lbs. This number conflicts with Section B.1.2.1, Page B.1.21, which shows 203,159 lbs. This difference can significantly change the bottom line on Page B.1.21.

RESPONSE: **Yes, there are inconsistences in the weights which will be corrected in the final Preliminary Design Report. The 206,539 pound number is correct.**

   b. Throughout Section 2.7.1, references are made to the NuPac 125-B cask test results. Do you know if this will satisfy the requirements for the 140-B cask considering the performance testing standards taking effect in 1991? Should the 140-B cask have its own test results?

RESPONSE: The 140-B cask will have its own test results per the contract. The comparison with the 125-B cask were made for reference only.

4. Section 2.5.1.2, Page 2.5.1 - 12, first sentence. The BWR basket weight should be 5,000 lbs. not 50,000 lbs.

RESPONSE: The 50,000 lbs refers to a BWR basket fully loaded with 52 BWR fuel assemblies.

5. Section 2.6.4, Page 2.5.1-122, second line NuPac 125-B cask should be, Nupac 140-B cask.

RESPONSE: Yes. Section 2.0 has been corrected and revised per this comm t.

6. Section 7.3, Page 7-8 This section is technically correct; however, the requirements of 49 CFR 173.427 are aimed at excepted packages. Once used, I don't think the cask can meet these requirements; unless there is a decon procedure to bring it within the excepted limits. If not within the excepted limits, the shipper must go back to Sections 7.1.2.26 and 7.1.2.27.

RESPONSE: The Final Design Report will address this concern.

7. Section 7.4, page 7.4-3 Need to reference title 49 CFR Part 171, General Information Regulation and Definitions. Not only lists definitions of such things as radioactive, but since the package certificate is being pursued with a multi-lateral (M) designation, 171.12 discusses import/export shipment requirements.

RESPONSE: 49 CFR Part 171 will be added to the list of references.

8. Section C, Page C.1.3

   a. This turnaround time does not appear realistic.

   b. Loading and unloading time appears to be approximately 10 hours short each (this is using TMI as an example and they are loaded dry), also need to build in some maintenance time for the railcar (TMI is taking 1 day including switch times and PM time)

RESPONSE: Section C is being rewritten to include only turnaround times estimates for utilities (loading site) and the MRS/Repository (unloading site). Transit time and maintenance time will not be part of Section C.

9. Section C.2.2, Page C.2-3 If addressing the Section as 10 CFR 71 as C.2.2.1, General Standards for all packaging (71.43) intended to include all of 71 (i.e. 71.51 "additional requirements. for Type B packages" , 71.55 "general requirements for all fissile material packages ", and 71.61 "special requirements. For fissile III shipments, etc.)

RESPONSE: **No, rather it follows Regulatory Guide 7.9 (Proposed Revision 2) format for SARP Section 2.4.**

10. Section B.1.4, Page B-1-51, Paragraph 2, last sentence A personnel barrier for maintaining maximum dose rate is not a requirement of 10 CFR 71.

RESPONSE: **10 CFR 71.47 - "External Radiation Standards for all Packages" uses the term "closed transport vehicle". The personnel barrier is the method used to obtain a closed transport vehicle.**

11. Section B.1.6.2, Page B-1-62 More specific detail needs to be given to the maintenance of the railcar, similar to that given the IDOX/NPIX railcars used on the TMI project. Acceptable industry standard does not buy much with the regulators and public.

RESPONSE: **Detailed maintenance requirements for the railcar will be part of the Cask System Maintenance Manual.**

12. Section C.2.3, Page C.2-7, second sentence Article 173.393, 49 CFR does not have a 173.393. Radiation level Limitation can be found in 173.441 and it is 10mr/hr at 2 meters from the vertical planes of the vehicle.

RESPONSE: **Agree, we will correct the final issue of the Preliminary Design Report.**

GROUP NUMBER NINE
COMMENTS AND RESPONSES
REVIEWER: R.J. BURIAN
BATTLE NUCLEAR SCIENCE GROUP

1. 1.0 GENERAL INFORMATION

SECTION NUMBER: 1.3.2.1 PWR Basket
PAGE NUMBER: 1-9 Third Line
SECTION NUMBER: 1.3.2.2 BWR Basket
PAGE NUMBER: 1-10 Fourth line

The neutron absorbing material should be described or the reader shou..i referred to Section 6.3.1.1 for the description.

RESPONSE: Reference has been included in Section 1.0.

2. 2.0 STRUCTURAL EVALUATION

The phrase "outer cask inner shell" is used frequently throughout the structural analysis section. It is not clear if this refers to the "inner shell" which forms the cask cavity as defined in Section 1.3.1, Package Description, Cask, or to some other component. The nomenclature should be made consistent and the "prefix"-"outer cask" be purged if reference to the inner shell is meant

RESPONSE: Section 2.0 has been revised to delete reference to the term "outer" cask.

3. SECTION NUMBER: 2.3 Mechanical Properties of Materials
PAGE NUMBER: Following 2.0-29

Table 2.3-1 Mechanical Properties of Materials which follows Page 2.0-29 is only 2 pages long and appears to be incomplete. In addition, the last line of the second paragraph on Page 2.0-29 states that stress-strain curves and creep data are in Figures 2.3-1 through 2.3-6. However these figures are missing from the package. Review of some sections was hampered by lack of data.

RESPONSE: Section 2.0 has been revised to include the missing material data.

4. SECTION NUMBER: 2.4.4 Chemical and Galvanic Reactions
PAGE NUMBER: 2.4-1

The statements that the materials are chemically compatible and that no galvanic reactions will occur should be substantiated by appropriate references for all material combinations including the impact limiter and neutron shield materials.

RESPONSE: **Section 2.0 has been revised to include substantiating references.**

5. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-1

It would improve the clarity of this section if the calculation of the bolt loads, Page 2.5.1-6 through Page 2.5.1-8, was moved to the beginning of this section and placed after the table summarizing the margins of safety.

RESPONSE: **This comment will be considered during final design.**

6. SECTION NUMBER 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER 2.5.1-2 First paragraph

The bolt base material, IN-718 Nickel Spec SB637, Type N07718, is not the material specified on Drawing 2111-201, Sheet 2 of 12, Zone 4D. The discrepancy should be corrected and all calculations using the bolt material properties should be checked to ensure that the correct values are being used.

RESPONSE: **The calculations were checked to ensure use of correct bolt material properties. The drawing will be corrected during final design.**

7. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-2 last sentence in third paragraph from bottom of page

The flexural stresses are probably small as indicated, but this should be demonstrated by calculation.

RESPONSE: **This comment will be considered during final design.**

8. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-4 Figure 2.5.1-2

It is not evident why the triangular load pattern for the bolts was assumed to intersect the base of the trunnion at the uppermost bolt (location of reaction force P_k in the figure). The model shown is not physically correct. Under a lift load the triangular load pattern will intersect the fact of the trunnion at its top edge and the reaction force will act at this point. In addition, application of the load at near the mid-length of the trunnion is too optimistic. The sketch for the lifting device in Section B.1, Auxiliary Equipment, does not give sufficiently detailed dimensions to identify how the lifting hook mates with the trunnion. However, it would be appropriate to assume a worst case loading and apply the Lifting load, " P_{load} "at the end of the trunnion (at the 5.25 inch dimension shown in Figure 2.5.1-2).

RESPONSE: This comment will be considered during final design.

9. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-6 Equations at top and middle of the page

The equation for the moment on the trunnion should use the more conservative moment arm of 5.25 inches as noted in the preceding comment.

The equations for the force in bolts 7 and 8, at the top of the bolt pattern (Figure 2.5.1-2) should be added to the equation for the other six bolts. The value for "R" in all equations should be changed to "4".

RESPONSE: This comment will be considered during final design.

10. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-7 Second paragraph

The friction factor assumed for the bolt tightening is unrealistically low for this diameter bolt. A more realistic value is 0.20 -0.25.

RESPONSE: This comment will be considered during final design.

11. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-7 Second last paragraph

It is not understood what is meant by this paragraph. No negative sign appears in the preceding equations and the reference to an "unclamping force" is not clear.

RESPONSE: Clarification will be supplied during final design.

12. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-8 Equation for F_{max}

The equation for F_{max} has the parentheses misplaced.

RESPONSE: **Section 2.0 has been corrected to include this comment.**

13. SECTION NUMBER: 2.5.1.1 Trunnions Lifting Devices
PAGE NUMBER: 2.5.1-8 Bearing and Thread Stresses in the Socket

a. This calculation assumes that the upper half of the circular area of the trunnion within the socket bears evenly on an area of the socket equal to the product of the diameter and the insert distance. This is a meaningless calculation since the loading area is a line which changes to rectangle on a curved surface as the trunnion and socket elastically (and plastically ?) deform. It would be more appropriate to calculate the shear stresses in the bolts assuming that, as a worst case, they are in shear.

RESPONSE: **This comment will be considered during final design.**

B. Bearing of the end face on the trunnion on the face of the socket has been neglected. The contact force produced by the triangular bolt load pattern in Figure 2.5.1-2 can be used to obtain an average, end bearing stress.

RESPONSE: **This comment will be considered during final design.**

14. SECTION NUMBER: 2.5.2 Tiedown Devices
PAGE NUMBER: 2.5.2-1 First two paragraphs

The tiedown components described are not shown in detail on the 2110 Series Drawings. Better sketches than the computer drawn models would be very helpful in understanding the configuration and location of the load bearing components.

RESPONSE: **More detailed sketches of tie-down components appear in Section B.1, figures B.1.2-2 and B.1.2-5 along with sketches associated with paragraph B.1.8.10. Also, see drawing 2111-201 in Section 1.0.**

15. SECTION NUMBER: 2.5.2.1.2 Results of calculations for the tie-down side load
PAGE NUMBER: 2.5.2-13 Center of page

It is not evident how the side loads acting at the tie-down trunnions can be reacted by the full 140-inch length of the cask. It also appears that the reference to Figure 2.5.2-7 is in error. Figure 2.5.2-7 is related to the following Section., 2.5.2.2, "Vertical Transportation loads in the Tie-Down Structure".

RESPONSE: **Section 2.0 has been revised to incorporate this comment. Appropriate corrections and clarifications have been made.**

16. SECTION NUMBER: 2.5.2.2 Vertical Transportation loads in the Tie-Down Structure
PAGE NUMBER: 2.5.2-16 First sentence

Reference to figures is incorrect and/or figures are missing.

RESPONSE: **Section 2.0 has been revised and appropriate corrections have been made per this comment.**

17. SECTION NUMBER: 2.6.1.2 Thermal Stress Due to Differential Thermal Expansion
PAGE NUMBER: 2.6-3

This section should address the stresses which may be produced by the thermal expansion of the lead within the gamma shielding lead annulus, or explain why the stresses will be inconsequential.

RESPONSE: **Stresses in the lead will be considered during final design.**

18. SECTION NUMBER; 2.6.1.2 Thermal Stress due to differential Thermal Expansion
PAGE NUMBER: 2.6-3 last paragraph

The purpose for adding the stress in the load collar to the stress in the outer cask lid is not clear. The resultant value is meaningless.

RESPONSE: **The purpose of this calculation was to show that problems do not exist even under unrealistically conservative assumptions.**

19. SECTION NUMBER: 2.6.1.3.1 Stresses due to Unit Pressures
PAGE NUMBER: 2.6-6 figure 2.5.1-1

As part of demonstrating containment, the stress and the deflections at the cover seal surface should also be calculated. It would be probably be appropriate to use a finite element code for these calculations to account for the exact geometry of the mating parts.

RESPONSE: This comment will be considered during final design.

20. SECTION NUMBER: 2.6.1.3.2 Stresses due to Maximum Pressures
PAGE NUMBER: 2.6-9 First sentence ; and
SECTION NUMBER: 2.7.1.1 Flat End Drop
PAGE NUMBER: 2.7-5 (2) Outer Cask Lid Bending Analysis Assuming No Impact Limiter Support

The value of 284 psig for the maximum internal pressure at normal conditions and the value of 351 psig for the pressure in an accident are incorrect. this is discussed further in the comments on the thermal analyses, Sections 3.4.4 and 3.5.4.

RESPONSE: We agree, but the end effect is conservative. A more detailed analysis will be pursued during final design.

21. SECTION NUMBER: 2.6.2 Cold (Fabrication stresses due to lead pour)
PAGE NUMBER: 2.6-23 Second last paragraph

This paragraph indicates that the outer shell will be welded to the base after lead pour. The design should address how the weld will be kept free of lead contamination.

RESPONSE: This comment will be incorporated in the manufacturing procedures for welding the joint of concern.

22. SECTION NUMBER: 2.6.7 Free drop
PAGE NUMBER: 2.6-34 Top line

Reporting that the cask has a high natural frequency is surprising. Normally a lead filled cask has a low natural frequency.

RESPONSE: The ratio of the shock or load duration to the cask natural period is significantly high because of the relatively "soft" impact limiters.

23. SECTION NUMBER: 2.6.7.1 Free drop
PAGE NUMBER: 2.6-39 Equation for q' at center of page

It would seem to be more appropriate to perform this calculation for the case of a 24.7 g load from the basket acting as pressure "q" on the inner surface of the cask lid and use the actual foam compressive stress for the pressure acting on the outer surface. The method which was used, applying counteracting pressures for 1-q and then multiplying by 24.7 g should achieve the same end result. However, since Appendix 2.10.2 in which the results of the impact calculations are given is not included in the design package, this can not be confirmed.

RESPONSE: **This comment will be considered during final design and Section 2.0 has been revised to include Appendix 2.10.2.**

24. SECTION NUMBER: 2.6.7.1 flat End Drop, (6) Stresses in the Outer Cask Shells and lead
PAGE NUMBER: 2.6-41 Sentence starting on third last line and the following test which continues on Page 2.6-44

It is not obvious why the lead will initially flow radially away from the inner shell after friction has been overcome. This should be explained.

RESPONSE: **NuPac will consider performing a lead stress analysis in the final design phase to address this comment.**

25. SECTION NUMBER: 2.6.7.1 Flat End Drop
PAGE NUMBERS: 2.6-41 to -60 (6) Stresses in the Outer Cask Shells and lead, (7) Stresses in the Outer Cask Shells and lead, and (8) Lead Slump

This section examines the axial load of the lead on the inner shell. However, only the force developed by friction between the lead and the stainless steel is considered. Shear within the lead should also be examined to verify that frictional forces are controlling.

RESPONSE: **See previous response.**

26. SECTION NUMBER: 2.6.7.2 Corner and Oblique Drops
PAGE NUMBER: 2.6-60

This section should also include the secondary impact effect of the cask falling over (slap-down mode) after the initial corner impact. These effects will be different from those for the side impact orientation examined in Section 2.6.7.3 since the velocity of the CG at impact will be likely greater than for the 1-foot side drop condition.

RESPONSE: This comment will be considered during final design.

27. SECTION NUMBER: 2.6.7.2 Corner and Oblique Drops
PAGE NUMBER: 2.6-64 (6) Impact Limiter Attachment Forces

The assumed orientation of the attachment bolt pattern relative to the impact point on the cask "corner" is not the one which produces the greatest bolt stress. A worse condition exists if the impact point is moved 22.5 degrees around the cask and impact is assumed directly in line with a bolt location. The moment of the bolts about the impact point is reduced about 6 per cent with a corresponding increase in the maximum bolt stress. The margin of safety is reduced about 12 percent.

RESPONSE: This comment will be considered during final design.

28. SECTION NUMBER; 2.6.7.3 (2) Outer Cask Shell Carriers impact load
PAGE NUMBER: 2.6-70 Last Paragraph

The assumption of the distributed load is not conservative as is stated. The reaction forces, R_I and R_{II}, are positioned at mid-thickness of the cask end forgings. Neither the basket, spent fuel, shells, or lead extend the full distance between the reaction forces. Although the effect will be small, the model can not be considered conservative and the load diagram in figure 2.6.7.3-1 should be changed to reflect the correct weight distribution.

RESPONSE: The load diagram will be refined during final design.

29. SECTION NUMBER; 2.6.8.1 PWR Basket Analyses
PAGE NUMBER: 2.6-88 (5) Longitudinal gusset plates...

The second paragraph under Item 5 states that the gusset weldments are fluid tight to reduce the amount of water that is lifted with the cask. The operations sectionshould then identify what routine procedures will be employed to ensure that the compartments remain fluid-tight during use.

RESPONSE: Serious consideration of changing the basket design to negate fluid tight compartments will be pursued during final design.

30. SECTION NUMBER: 2.6.8.1.1 PWR Basket Side Drop Analysis
PAGE NUMBER: 2.6-93 Table 2.68-1; and
SECTION NUMBER: 2.6.8.2.1 BWR Side Basket Analysis
PAGE NUMBER: 2.6-104 Table 2.6.8-3

The stress summary tables do not indicate for which orientation in the list on Page 2.6-92 the stresses are given. Since Appendix 2.10.4 is not included in the design package, the orientation can not be identified.

RESPONSE: **Section 2.0 has been revised to help clarify the situation stressed in this comment. Also, Appendix 2.10.4 will be included in the final design, report and/or the SAR.**

31. SE‌‌TION NUMBER: 2.7 Hypothetical Accident Conditions
E NUMBER: 2.7-1

Throughout this section the accidents are evaluated assuming undeformed impact limiters. However, since the 1-foot free drop is considered a normal operating occurrence, the cask presumably should be able to withstand the 30-foot free drop accident after experiencing a 1-foot free drop. Thus, the impact limiters' performance in the accident should assume that they have been previously deformed by the 1-foot fall.

RESPONSE: **This comment will be considered during final design.**

32. SECTION NUMBER: 2.7.1.1 Flat End Drop
PAGE NUMBER: 2.7-5 (2) Outer Cask Lid Bending Analysis Assuming No Impact Limiter Support

Mixed conditions are used in this calculation. The 30-foot free drop accident occurs before the fire accident. Therefore, it is incorrect to use the fire accident internal pressures for stress calculations related to the impact. The temperature and pressures within the cask at the time of the impact accident are those for normal operation.

RESPONSE: **This comment will be considered during final design.**

33. SECTION NUMBER: 2.7.2 Puncture
PAGE NUMBER 2.7-54 Side Puncture, Second Paragraph

It is inappropriate to degrade the equivalent XM-19 thickness in the manner shown. The method followed assumes that the Su of the boro-silicone and copper experience the same temperature reduction with temperature as the XM-19. This is not so. The Su of cold drawn ETP Cu-110 copper at 240°F is about 8 percent below that at room temperature (Alloy Digest, Filing Code Cu-222, November 1970). Since the three correlations for puncture result in widely varying values of required shell thickness and the wall thickness may be marginal. It would be more appropriate to expedite the planned puncture tests and not depend on taking credit for components such as the boro-silicone or the copper. It is doubtful in an NRC reviewer would accept the approach presented.

RESPONSE: **The proposed puncture test will be performed such that test results will be available to support the final design/SAR requirements.**

34. SECTION NUMBER: 2.7.3.2 Differential Thermal Expansion
PAGE NUMBER: 2.7-64 Last Paragraph

This section should address the stresses which may be produced by thermal expansion of the lead within the gamma shielding lead annulus, or explain why the stresses are inconsequential. The lead should be assumed to have been deformed or to have slumped during the impact accident.

RESPONSE: **This comment will be considered during final design.**

35. SECTION NUMBER: 2.7.3.2 Differential Thermal Expansion
PAGE NUMBER: 2.7-65 Table at top of page

It is not clear what the "cask root" is. This should be better defined.

RESPONSE: **Section 2.0 has been revised to clarify the item mentioned in this comment.**

36. SECTION NUMBER: 2.10.1.1.2 Side Drop (SYNDROP-PC)
PAGE NUMBER: 2.10.1-5 First Paragraph
SECTION NUMBER: 2.10.1.1.3 Corner Drop (SYNDROP-PC)
PAGE NUMBER: 2.10.1-7 First Paragraph
SECTION NUMBER: 2.10.1.2 Oblique Impact Dynamic Analysis
PAGE NUMBER: 2.10.1-11

The type of QA code validation should be explained, e.g. by finite element analysis, tests performed for this program, test performed as part of the 125-B Cask design, etc.

RESPONSE: **The referenced documents in Section 2.0 explain that drop computer code validation is achieved via tests performed as part of the 125-B cask design.**

37. SECTION NUMBER: 2.10.2.2 Basic Polyurethane Foam Stress/Strain Characteristics
PAGE NUMBER: 2.10.2-6 Table 2.10.2.7 Impact Limiter Manufacturing Quality Assurance Considerations

The QA density check for the foam should also include a minimum acceptable density.

RESPONSE: **A density lower than 12.5 PCF is allowable if the stress vs strain characteristics are within the range of Table 2.10.2-7.**

38. SECTION NUMBER: 2.10.2.3 Drop Program Evaluation Results
PAGE NUMBER: 2.10.2-6

The evaluations performed in this section for the deformation of the impact limiters during the 30-foot fall accident should consider impact on a location which has been previously deformed as a result of the normal transportation, 1-foot fall incident.

RESPONSE: **This comment will be considered during final design.**

39. SECTION NUMBER: 10.2.3.2 Hot Conditions - Maximum Impact Limiter Defections
PAGE NUMBER: 2.10.2-20 Table 2.10.2-17

Footnote (2) to the table states that the impact limiter was assumed to be 86 percent effective. It is not clear what this means. Since it has been earlier stated that the limiter material will deform 80 percent before it becomes solid (lockup). The meaning of "86 % partially effective" should be explained.

RESPONSE: **This comment will be considered during final design.**

40. 3.0 THERMAL EVALUATION

SECTION NUMBER: 3.1 Discussion (Thermal Evaluation)
PAGE NUMBER 3-5 footnote (1) for Table 3.1-2

I addition to showing that the Eypel-F elastomeric O-ring seals remain leak tight up to 350 F, they should also be shown to remain leak tight at depressed temperatures to -40 F. Reference the tests reported in Test Report #L-9775, O-Ring Seal Test Program Report, attached to the design package.

RESPONSE: This comment will be incorporated in the final design report and/or the SAR.

41. SECTION NUMBER: 3.4.1.1 Half Axisymmetric Model of Cask with Impact Limiter (Thermal Model)
PAGE NUMBER: 3-18 Assumption E.

a. Assumption E states that half of the heat rejected from the cask surface by radiation passes through the vent holes in the personnel barrier, i.e., half of the surface area of the cask "sees" the outside environment. This is inconsistent with the assumption made in the top paragraph on Page 3-10 -- that the solar heat is absorbed only by the impact limiters and the personnel barrier. That assumption led the reader to the conclusion that no part of the environment above the horizon can "see" the cask.

RESPONSE: This assumption has been dropped. Original calculated results, which are currently published, did not include this assumption. There was not enough time to make revisions in the published calculations based upon this assumption. Such revisions would have resulted in lower temperatures. For instance, the o-ring seals, at 300°F during normal conditions, would have dropped to 292°F.

b. Section B.1.4 "140-B Cask Sunshield/Personnel Barrier", (Last paragraph on Page B.1.51) states that the top 30 degrees of each barrier door is covered by solid panels and the next 60 degrees by louvered panels. The remaining vertical section is slotted to allow 30 percent open space. if the louvers on the 60 degree portion of the barrier provide complete shielding of the cask from the sun, it is unlikely that the holes in the vertical panels and the open area of the rail car under the cask provide a clear line of sight to the environment for 50 percent of the radiant heat from the entire cask surface. Thus, we question the validity of Assumption E.

RESPONSE: Assumption E has been dropped.

c. Moreover; since the top of the cask is well shielded from the environment by the personnel shield, the cask circumferential temperature distribution should be examined.

RESPONSE: This comment will be considered during final design.

42. SECTION NUMBER: 3.4.1 Half Axisymmetric Model of Cask with Impact Limiter (Thermal Model)
PAGE NUMBER: 3.20 Assumption J.

It should be demonstrated that the equation for free convection heat transfer is valid for a horizontal cylinder surrounded by a second "cylinder" -- the sunshield/personnel barrier. The presence of the barrier produces an annulus at the top half of the cask. This is a unique configuration, however, because the outer cylinder has a number of openings to enhance free convection to the environment.

RESPONSE: This comment will be considered during final design.

43. SECTION NUMBER: 3.4.1.2 Thirty Degree 2-d Model of Cask Wall
PAGE NUMBER: 3.21

The comments above regarding solar heat input and radiation from the cask surface also apply for the 30-degree model.

RESPONSE: Same response applies as presented above (item 41).

44. SECTION NUMBER: 3.4.1.2 Thirty Degree Model of Cask wall
PAGE NUMBER: 3.23 Assumption E.

For the worst case condition of radiation from a 30 degree sector of the cask, the sector should be assumed to be opposite the solid panel section of the sunshade/personnel barrier and thus, the view factor to the outside environment is zero. Convection from this region will also be impeded by the sunshade/personnel barrier.

RESPONSE: The assumption has been revised to include this comment.

45. SECTION NUMBER: 3.4.1.5 Full 2-D Model of Center PWR Fuel Assembly
PAGE NUMBER: 3-31 Assumption A.

It is thought that the reference to the fuel region of the fuel rods as "depleted uranium" is a typographical error and the "UO_2" was intended. However, beyond that, to assume an unrealistically high conductivity for the fuel region can lead to erroneous results. This assumption will increase the apparent, overall heat transfer from the center of the fuel assembly. It is thought that this will cause an unrealistically low temperatures to be predicted at the center of the assembly. A better approach would be to use an existing model such as the empirical Wooton-Epstein Correlation developed at Battelle Columbus for this type of fuel element configuration. It has recently been modified by lawrence Livermore to increase its accuracy for low decay heat rates.

RESPONSE: Wooton-Epstein was applied and the maximum fuel cladding temperature dropped from 682°F to 665°F.

46. SECTION NUMBER: 3.4.1.5 Full 2-D; Model of Center PWR Fuel Assembly
PAGE NUMBER: 3-33 Figure 3.4.1-7 (Model at right of page)

The model with the pins in a triangular spatial configuration is incorrect. The pins should be modelled in a square configuration as in a fuel element.

RESPONSE: The pins are modeled in a square configuration as depicted in the fuel assembly cross section shown at the bottom of Figure 3.4.1-6.

47. SECTION NUMBER: 3.4.2 Maximum Temperatures
PAGE NUMBER: 3-34 Table 3.4.2-1

Since the calculated, maximum fuel cladding temperature is only 56°F below the design limit, the above comments regarding the correctness of the thermal model assumptions are especially significant.

Moreover, the high cladding temperature indicates that an uncertainty analysis should be done to determine the consequences of uncertainties in the material thermal properties and critical dimensions. Such an analysis uses error analysis techniques to estimate the uncertainty of the temperature difference in each portion of the heat flow path. These "local" uncertainties are then combined statistically to obtain an uncertainty in the overall calculated temperature difference.

RESPONSE: **As mentioned above (item 45) Wooten-Epstein predicts a fuel cladding temperature 17°F lower than NuPac. Comparisons with MC-10 actual experimental data in Appendix 3.6.8 shows fuel cladding temperatures could be 43°F higher. The situation is marginal and more basket heat transfer material will be considered in final design.**

48. SECTION NUMBER: 3.4.4 Maximum Internal Pressures
PAGE NUMBER: 3-412 Table 3.4.4-1

The manner of arriving at the mixture temperature in Table 3.4.4-1 is very approximate. Emphasis should be given to the volume of gas affected rather than the bounding areas.

RESPONSE: **The area approach has been standard procedure in the past and has resulted in conservative results; however, this comment will be considered during final design.**

49. SECTION NUMBER: 3.4.4 Maximum Internal Pressures
PAGE NUMBER 3-41 Equation for P[illegible] near bottom of page

The pressure for the water vapor in the cask has been calculated incorrectly. Until the lowest temperature in the cast rises to a value such that the water vapor becomes superheated, the pressure of the water vapor will be that of saturated water. The specific volume of 1-cubic foot of water in the cask cavity is:

V[illegible]=135.5 ft^3/[(1 ft^3) (62.4 lb/$ft^3$0]= 2.17 ft^3/lb

The temperature of the cask walls is 290 F. At that temperature, the specific volume of saturated water vapor is 7.461 ft^3/lb. Thus, the water in the cask is a mixture of liquid and vapor. The saturation pressure for water vapor at 290 F is 57.56 psia.

Since the cask walls act as the condenser in a reflex condenser system, the heat transfer coefficient at the wall surface should be calculated to ensure that sufficient heat transfer takes place to maintain vapor condensation.

RESPONSE: **The methods described in this comment will be considered during final design. The methods used by NuPac lead to conservative results which were sought for structural validation.**

50. SECTION NUMBER: 3.4.5 Maximum Thermal Stress
PAGE NUMBER: 3-42

This section fails to consider the thermal stresses produced by the difference in the axial expansion between the copper fins in the neutron shield region and the shells to which it is attached.

RESPONSE: This comment will be considered during final design when the copper fin attachment details are finalized.

51. SECTION NUMBER: 3.5.3 Package Temperatures
PAGE NUMBER: 3-58 Table 3.5.3-1

The calculated temperature of the fuel rod cladding is only 36 F below the design limit. As noted above (Section Number 3.4.4), all assumptions regarding the thermal model should be made as accurately as possible and an uncertainty analysis should be performed.

RESPONSE: This comment will be considered during final design. Also, see response to comment #47.

52. SECTION NUMBER: 3.5.4 Maximum Internal Pressures
PAGE NUMBER: 3-75 Equation for P[illegible] near middle of page

The pressure of the water vapor in the cask was calculated incorrectly. At the cask wall temperature of 326°F, the specific volume of saturated water vapor is 4.538 ft^3/lb. Since this is greater than the specific volume of 1-ft^3 of water in the cask cavity (2.17 ft^3/lb as noted in an earlier comment), the water is a mixture of vapor and liquid. Therefore, the pressure of the water vapor is the saturation pressure at 326 F, 97.52 psia.

Since the cask walls act as the condenser in a reflex condenser system, the heat transfer coefficient at the wall surface should be calculated to ensure that sufficient heat transfer takes place to maintain vapor condensation.

RESPONSE: The same response as presented for item 49 applies.

53. SECTION NUMBER: 3.5.5 Maximum Thermal Stresses
PAGE NUMBER: 3-77

This section fails to consider the thermal stresses produced by the difference in the axial expansion between the copper fins in the neutron shield region and the shells to which it is attached.

RESPONSE: This comment will be considered during final design.

54. SECTION NUMBER: 3.5.6 Evaluation of Package Performance for the Hypothetical Accident Conditions
PAGE NUMBER: 3-81 First paragraph

Because of the concern expressed above about possible unconservative assumptions, the thermal analyses are not considered conservative.

RESPONSE: **Appropriate design consideration will be made during final design to deem the thermal analyses conservative beyond any reasonable doubt.**

55. 4.0 CONTAINMENT

SECTION NUMBER: 4.1.1 Containment Vessel
PAGE NUMBER: 4-2

The need for the rupture disk is questioned, and the resultant possibility that it could fail at a pressure below its design failure point of 700 psi. We agree with the need to include residual water in the maximum pressure calculation, and the quantity of residual water present (1 cubic foot) is quoted as having been previously observed with large casks. The concern arises from the realization that the area around the rupture disk will be below the saturation temperature of the water present in the cask. Thus, the rupture disk is likely to be consistently immersed or coated with liquid water raising the concern over corrosion in the region of the rupture disk assembly.

An alternative is to determine if a change in operating procedures - such as vacuum drying the cask for longer periods of time or initiating the vacuum drying after the cask has partially heated up, would lower the residual amount of water present in the inner cavity. The result of either evaluation may provide a justification for eliminating the rupture disks. If the rupture disks must stay, there should be an extensive discussion of the transport experience with rupture disks, the maintenance requirements and the assurances that can be given that the rupture disk will not release material at below its design failure point.

RESPONSE: **The design pressure is conservative at this stage of the design. Maximum realistic design pressure will be performed in final design. Several methods of cask draining/drying are being considered which may allow removal of the rupture disk. NuPac has extensive experience with the IF-300 cask which contains such a disk. Our decision as to how the cask will be drained and dried will be made early in the final design phase.**

56. SECTION NUMBER: 4.1.2 Containment Penetrations
PAGE NUMBER: 4-3

The leakage from the cask should be related to A_2 quantities as specified in 10 CFR 71.51 (a).

RESPONSE: **Since the cask carries material with very low A_2 values, a leak tight design of 10^{-7} scc/sec was chosen. NuPac will address this in the final design phase.**

57. SECTION NUMBER: 4.1.2 Containment Penetrations
PAGE NUMBER: 4-3

The rupture disk is one of the containment penetrations but there is no discussion of the leak tests that will be performed on the rupture disk to insure that no leakage past the disk is occurring.

RESPONSE: **General leak testing of the rupture disc is discussed in section 8.1.3.4. Specific tests will be detailed in the cask operating and maintenance procedures.**

58 SECTION NUMBER: 4.1.3.1 Seals
PAGE NUMBER: 4-3 First sentence in paragraph

The sections in which the seals affecting containment are described should be referenced by number.

RESPONSE: **This will be corrected by referencing section 4.1.1.**

59. 5.0 SHIELDING

SECTION NUMBER; 5.1 Discussion and Results (Shielding Evaluation)
PAGE NUMBER: 5.1 Last paragraph

The statement that only slight changes in the shield will occur under accident conditions may be true for cask drops, but may not be true for the hypothetical fire accident. Generally, the fire is assumed to destroy the neutron shield.

A discussion of the fire accident should be presented which provides justification for assuming that the neutron shield remains functional. Alternately, shield calculations with the neutron shield removed from the cask model should be performed and the missing dose rate values in Table 5.1-1 should be supplied.

RESPONSE: **Preliminary calculations showed that normal operational dose rates are bounding over the accident cask dose rates. Results of the accident case dose rates will be provided during final design analysis.**

60. SECTION NUMBER: 5.2 Source specification
PAGE NUMBER: 5-5

The activation products associated the fuel assembly hardware appear to have been homogenized with the fuel for the shielding analysis. The principal contribution of activated hardware to the gamma source is associated with the fuel assembly end fittings. Their homogenization with the fuel could substantially underestimate their contribution to external dose rates. A more appropriate model would incorporate the end fittings as discrete sources at the ends of the fuel region, with additional dose measuring points at the side of the cask in the region of these sources.

To determine the fittings' contribution to the dose rate at both the side and ends of the cask, additional gamma shielding calculations should be performed with the fuel assembly end fittings modelled as discrete sources at the ends of the fuel.

RESPONSE: **The activation products were accounted for in calculating the dose on the ends of the cask. For the final design the approach suggested will be utilized.**

61. SECTION NUMBER: 5.0 Shielding Evaluation
PAGE NUMBER : 5-6, 5-11, 5-11, 5-14, 5-22

Correction factors associated with ORIGEN2 initial enrichment differences are discussed on these pages. The formulation of the correction factors is inconsistent. For example, the correction found for the PWR gamma source from Figure 5.2.1.1-1 is 18%, and the correction actually applied is a conservative 25%. On the other hand, the correction for the BWR gamma source is 14% which is applied directly without conservatism. A similar situation exists with the neutron sources. Also, the BWR neutron source correction is omitted from the summary on page 5.22.

Either the radiation source correction factors should be applied consistently, or the rationale for treating the PWR and BWR corrections differently should be given.

RESPONSE: For PWR fuel, the correction factor of 18% was for 3.2% enriched fuel. The 25% correction factor corresponds to 3.0% enriched fuel. The radiation source correction factors are consistant between PWR & BWR fuels.

62. SECTION NUMBER: 5.2.1.1 PWR Fuel (Gamma Source)
PAGE NUMBER: 5-8 Last paragraph

A symbol (phi) is referred to in the text, but does not appear in Table 5.2.1.1-1. Also, the value 0.375 MeV should be 0.0375 MeV.

RESPONSE: Will show columns represented by phi and will change 0.375 to 0.0375 in the final issue of the PDR.

63. SECTION NUMBER: 5.3 Model Specification
PAGE NUMBER: 5-16

Flux-to-dose conversion factors should be based on ANSI/ANS-6.1.1-1977. It should be demonstrated that the flux-to-dose conversion factors presented in Table 5.3.1 are equivalent to those of ANSI/ANS-6.1.1-1977.

RESPONSE: Flux-to-dose conversion factors are equivalent to ANSI/ANS-6.1.1-1977. It will be demonstrated that conversion factors are equivalent in the final design phase.

64. 6.0 CRITICALITY

SECTION NUMBER: 6.0 Criticality Evaluation
PAGE NUMBER: 6-2 First Paragraph

It may be useful to consider the 140-B Cask as Fissile Class I package.

RESPONSE: Yes, the NuPac 140-B Cask could be likely classified as a Fissile Class I Package. However, additional criticality analyses must be performed to reach this conclusion. It should be emphasized here that Nuclear Packaging, Inc. is not contractually required to demonstrate the nuclear criticality safety qualification of the cask to be a Fissile Class I Package. But, we will aim toward this direction in our criticality safety analyses for the final design.

65. SECTION NUMBE .2 Package Fuel loading
PAGE NUMBER -2 First paragraph

The first paragraph states that "canisters of consolidated fuel with the same external cross section... are also expected to be an acceptable payload...". It should be demonstrated by calculation that this is, in fact, true.

RESPONSE: **Criticality s analyses for consolidated fuel option will be analyzed in the final design to confirm our claims.**

66. SECTION NUMBER: 6.3.1 Description of the Calculational Model
PAGE NUMBER: 6-9 Second paragraph

It is stated that "hypothetica ccident condition analyses als assumes intact fuel assemblies. This is conservative since the normal pitch of a fuel assembly is at or near the maximum K_∞ pitch." It should be demonstrated that the as-designed pitch yields the highest K_∞. If it doesn't, rod spreading for accident conditions should be considered.

RESPONSE: **Reference to NUREG-0612 "Control of Heavy Loads at Nuclear Power Plants" has been added to the PDR to support the last sentence.**

67. SECTION NUMBER: 6.3.1.1 Models Used for PWR Fuel Assemblies in the Cask
PAGE NUMBER: 6-10

It appears that the neutron shield is assumed to remain intact for the accident calculation. it should be demonstrated that the neutron shield would remain intact during and after the hypothetical fire. If the neutron shield would be destroyed by the fire, then the cask should be modeled with water in place of the neutron shield.

RESPONSE: **Results of the thermal analysis show that the neutron shield would not be destroyed by the fire.**

68. SECTION NUMBER: 6.3.1.2 Models Used for PWR Fuel Assemblies in the Cask
PAGE NUMBER: 6-17 Figure 6.3-4

It should be demonstrated that the cask model is conservative or equiva t to the actual cask geometry (i.e., curved walls). A more explicit treat t of the cask wall surfaces, perhaps using generalized geometry inp o KENO, would provide additional confidence in the results.

RESPONSE: For a single cask model, we expect that there would be very little differences between the existing KENO model (square cask) and the actual model (round cask). In the final design, we will model the cask as closely as possible to its actual configuration. Likewise, uncertainty evaluations of the k_{eff} due to off centered fuel assemblies, fabrication tolerances, and manufacturing tolerances on the poison materials will be considered in the final design.

69. SECTION NUMBER: 6.4.1.1 Calculational method for PWR Fuel
PAGE NUMBER: 6-35 Second last sentence of partial paragraph

It states "an example of a typical KENO-IV input deck is shown as Input deck 5 in appendix 6.6.2." While Input deck 5 is a typical input deck, it is for BWR fuel, not PWR fuel. This should be explicitly noted in order to avoid confusion. It would be quite useful to include a typical KENO-IV input deck for PWR fuel, as well.

RESPONSE: Contents of the Appendix 6.6.2 have been completely removed. All input and output decks performed in this criticality safety analysis are fully documented in our calculation packages. They can be reviewed and examined upon request.

70. 7.0 OPERATING PROCEDURES

SECTION NUMBER: 7.1 Procedures for Loading the Package
PAGE NUMBER: 7-2

A step titled "Closing the Cask" should be added after Step (2).

RESPONSE: This has been addressed in the rewrite of Section 7.

71. SECTION NUMBER: 7.1.2.1
PAGE NUMBER: 7-2

Withdrawal and storage of the personnel barrier/sunshield should be mentioned in the loading procedure.

RESPONSE: This has been addressed in the rewrite of Section 7.

72. SECTION NUMBER? 7.1.2.7
PAGE NUMBER:7-3

The sealing surface protection device should <u>not</u> be optional.

RESPONSE: This has been addressed in the rewrite of Section 7.

73 SECTION NUMBER: 7.1.2.9
PAGE NUMBER; 7-4

This step should not specify that all fuel element locations in the basket will be filled. It would be better to state that a cask loading document will specify the number of fuel elements for each shipment.

RESPONSE: This has been addressed in the rewrite of Section 7.

74. SECTION NUMBER: 7.1.2.19 to 7.1.2.21
PAGE NUMBER: 7-5

A step should be added at the appropriate location in this general part of the loading instructions which moves the cask from the work location (step 7.1.2.13) to the transport vehicle.

RESPONSE: This has been addressed in the rewrite of Section 7.

75. SECTION NUMBER: 7.2 Procedures for Unloading the Cask
PAGE NUMBER: 7-7

A step-by-step sequence should be given for dry unloading of the cask mated to a hot cell port. The same level of detain should be provided for dry unloading as is given for wet loading in Section 7.1.

RESPONSE: Detail Procedures will be written in final design and will be part of the Casks Operating Manual. A General Cask Handling Procedure will be included in Section 7 of the SARP.

76. 8.0 ACCEPTANCE TESTS

SECTION NUMBER: 8.1.2 Structural and Pressure Tests
PAGE NUMBER: 8-2

The description of the tests in this section should be made as descriptive as those presented in Sections 8.1.3, 8.1.4, and 8.1.5.

RESPONSE: In final design the pressure tests will be described in sufficent detail to meet the regulatory requirements.

77. SECTION NUMBER: 8.1.2.1 Lifting Device Load Testing
PAGE NUMBER: 8-2 First paragraph

This section should include an indication of acceptable and/or unacceptable methods for applying the 150 percent load, i.e., placing lead weight in the cavity, hanging weights from the rotation trunnion, etc.

RESPONSE: NuPac will expand on this section in the final design phase.

78. SECTION NUMBER: 8.1.6 Thermal Acceptance Tests
PAGE NUMBER: 8-18

The thermal acceptance tests are insufficient. Included should be a thermal acceptance test of the fabricated cask. Such a test will verify the design calculations as well as the quality of fabrication.

RESPONSE: Thermal acceptance tests will be added to include this area of concern in the final design phase.

79. SECTION NUMBER: 8.2.5 Shielding
PAGE NUMBER: 8-28

Periodic testing of the shield may be needed particularly with a lead gamma shield which can be subject to cold flow. The contractor should consider the possibility of periodic shield evaluation.

RESPONSE: NuPac will consider this comment in the final design phase.

80. 9.0 QUALITY ASSURANCE

SECTION NUMBER: 9.2 Description of the PNSI, 10CFR71, Subpart H Quality Program.
PAGE NUMBER: 9-3

A preliminary Q-list should be provided. All items on the Q list must be graded for their importance to safety. The methods used to determine the quality assurance categories should be included.

RESPONSE: **A preliminary Q-List has been provided to EG&G/DOE in response to contractual requirements. This list which will be provided in the final design package is in accordance with the requirements for a graded approach to quality established by NRC and NuPac's QA program.**

81. SECTION NUMBER: 9.2.1 Organization
PAGE NUMBER: 9-3 Last Paragraph

It should be indicated to whom the PNSI Corporate Director of Quality reports within the organization. Include formal organization charts showing the organizational relationships among relevant groups both within NUPAC and between NuPac and PNSI.

RESPONSE: **The PNSI Corporate Director of Quality reports to the PNSI Chief Operations Officer (COO). Formal organization charts are not normally included as part of a design package but are contained in our approved QA plan.**

82. B.1.0 140-B Cask Ancillary Equipment

SECTION NUMBER: B.1.5.3.3 Vacuum Drying 140-B CAsk Drain/Fill System
PAGE NUMBER: B.1.59

Often as part of a drying procedure the exhaust air is tested to determine the humidity and is used as a criterion for having accomplished liquid removal. this may be considered as an addition to the procedure to ensure a dry cask cavity.

RESPONSE: **The purpose of Vacuum Drying is for evacuating the cask (removal of air). The cask design permits 1 cubic ft of water to remain. Another method such as water displacement with inert gas may be used in final design. This would eliminate vacuum drying. This will be addressed further in the final design.**

83. SECTION NUMBER: B.1.6 140-B Cask Railcar
PAGE NUMBER: B.1.60

The design appears to satisfy the spirit of the design guidelines. The following comments are offered:

a. The design shares many design aspects with currently used and widely accepted railcar equipment. The railroads and the AAR would probably accept this railcar.

RESPONSE: Agree, our preliminary discussions with AAR personnel suggest this is true.

b. The length of the railcar for its weight appears to meet the standards of the Association of American Railroads (AAR). However the railcar is very close to the minimum weight. NUPAC should run a Cooper Rating Analysis using the AAR Technical Center Fortran Program "Moment and Shear Tables for Heavy Duty Cars on Bridges, 1971 Versions".

RESPONSE: The car designer will investigate this concern as part of the final design.

c. It can not be determined if the center of gravity complies with the AAR standards.

RESPONSE: The center of gravity is within the AAR requirement of 98" from the top of rail (AAR Interchange Rule 89 "B" .1.3). Preliminary calculations show the center of gravity is approximately 94" from the top rail.

d. The design appears to make extensive use of readily available, "off-the-shelf" components. This will help to keep down fabrication and maintenance costs.

RESPONSE: NuPac will continue to use these type of components, whenever possible, in the final design phase.

e. The AAR requires that railcars transporting radioactive materials be fitted with shelf couplers that prevent uncoupling in accidents. The couplers in Figure B.1.6-1, 140-B Cask - Railcar Assembly, on Page B.1.63, appear to be standard, non-shelf couplers.

RESPONSE: Type E bottom shelf couplers are used in the NuPac design. The drawings will reflect this configuration in the final design.

f. The skeletal design could hamper radiological inspection because there is no working platform alongside the cask.

RESPONSE: Removable platforms will be installed at the utility site. Final design will address how the platforms are attached and used.

g. The placement of brake equipment such as reservoirs, valves, and rigging, can be a design problem on skeletal designs regardless of the commodity for which the car is intended. Spent fuel exacerbates the problem because the usual placement of this equipment in the middle of the car will place the worker attending to the equipment in the area of greatest exposure from the cask surface radiation. The design should address this problem

RESPONSE: **The railcar design calls for truck mounted brake system one for each set of trucks. The railcar weight in the Preliminary Design Report includes this weight.**

84. C.1.0 SPENT FUEL RAIL SHIPMENT TURNAROUND TIME

SECTION NUMBER: C.1.0 Spent Fuel Rail Shipment Turnaround Time.
PAGE NUMBER: C.1.3, Column 1, Paragraph 2, Lines 4 and 5

The reactor to destination distances used are reasonable representatives. However, it would be better to use MTU weighted average distances (2,400 miles to the repository and 850 miles for Eastern reactors to an Eastern MRS) to evaluate a typical system, or to select a group of reactors covering a range of distances from about 300 to 3,000 miles to analyze sensitivity.

RESPONSE: **Use of reactor to destination distances are beyond the scope of the existing contract. Section C.1 has been re-written to include only turnaround time estimates for loading and unloading sites.**

85. SECTION NUMBER: C.1.0
PAGE NUMBER: C.1.3, Column 2, Figure 2

The load fuel step requires 17 hours, more than half of the total time. A more detailed breakdown should be provided. The loading sequence should be consistent with the procedure described in Section 7.1.2.

RESPONSE: **Section C.1 has been rewritten to provide the suggested time breakdown.**

86. SECTION NUMBER: C.1.0
PAGE NUMBER: C.1.4, Column 1, Figure 3

The unload fuel step requires 9 hours, almost half of the total time. A more detained breakdown should be provided.

RESPONSE: **See previous response.**

87. SECTION NUMBER: C.1.0
PAGE NUMBER: C.1.5, Column 1, Paragraph 2

There should be an explanation of how the Brunswick 1 and 2 cask requirements are scaled up to give the total number of rail casks required.

RESPONSE: **Section C.1 has been rewritten to delete the estimate of the total number of rail casks required.**

GROUP NUMBER TEN
COMMENTS AND RESPONSES
REVIEWER: P.N STANDISH

A. Section 1

A.1 Page 1-3, 1.2.1- I.G.17.A States that the cask interior and exterior surfaces should be of sufficient smoothness and contour to ... provide ease of surface contamination measurement and removal.

Comment - The design of the PWR basket neutron trap provides a large surface area that can be neither measured nor cleaned.

RESPONSE: **The PWR flux trap is a candidate for redesign and will be looked at closely during final design. It can be cleaned in its present configuration by mechanical or chemical means at the cask maintenance facility. This will be done on an annual basis. The internal portion of the cask body is only cleaned on an annual basis, if required. The amount of crud contained in a basket between periods of cleaning is insignificant when compared to the radiation readings from a spent fuel bundle.**

A.2 Page 1-3, 1.2.1 & 1.2.2-I.G.4.B States that casks should be designed to protect spent fuel from mechanical damage during fuel insertion, removal, and handling operations. The cask basket should be designed to guide the spent fuel into the basket.

Comment- The .13 x 45 degree chamfer on the top of the basket is not considered an adequate guide for inserting a fuel bundle into the basket under 20-25 feet of water.

RESPONSE: **NuPac disagrees, a 1/8 chamfer is sufficient for loading fuel under water. The PNS IF-300 Cask has a fillet weld all around its fuel cell which is less than 1/8 chamfer and no problem with loading fuel into it (64 loads of PWR fuel and over 150 BWR loads) has been experienced. In addition, significant experience in the design and use of high density spent fuel storage racks justify the fuel lead-in on the 140-B basket.**

A.3 Page 1-4, 1.2.3 I.G.10.G States that the transporters should be provided with working platforms or decks where practical.

Comment- The design of the railcar does not appear to include either working platforms or decks for performing smear surveys, radiation surveys, etc. on the sides of the cask.

RESPONSE: There is a deck on each end of the car for impact limiter removal. There is no deck between the impact limiters so robotics can be used for radiation survey. Portable scaffolding will be used at the Utilities to provide access to the casks.

A.4 Page 1-4, 1.2.3 - I.G.17.F States that the transporter should be designed to channel any spilled contaminants to points off of the transporter for collection.

Comment- the design of the transporter does not include any method to channel contaminants to a collection point.

RESPONSE: This will be done in the final design phase.

A.5 Page 1-5, 1.2.5 - I.G.18.J States that the closure design should include features to keep the closure secure to the cask in the unlikely event of a tipping incident during in plant handling operations.

Comment - It is questionable that the present design of the closure holddown wedges will keep the closure secured in the unlikely event of a tipping incident.

RESPONSE: This will be investigated during final design phase. "Tipping" calculations have been performed to show a positive margin of safety. It is possible to leave 4 bolts in place (one in each quadrant) to prevent the lid from coming off. This method is not the preferred method, but can be employed if our existing design proves to be non-feasible.

A.6 Page 1-8, 1.3.1 - P.S.2.C States that casks and ancillary equipment shall be designed in accordance with ALARA radiation exposure principles. These principles shall be applied using a total system basis considering all operations of loading, transport, and unloading.

Comment - A number of operations do not seem to be consistent with ALARA principles. Examples of this include:

a. Installation and operation of the different valve tools.

b. Installation and torque application of the closure lid bolts.

c. Installation and removal of the cask uprighting fixture, if it can be done.

RESPONSE: **These items have been addressed but were not apparent in the PDR. Additional emphasis will be applied during the final design phase. ALARA considerations such as use of auxiliary shielding will be investigated if necessary.**

NuPac is confident that the cask uprighting fixture can be installed and removed. Design improvements to minimize time to install and remove the uprighting fixture will be investigated in the final design phase.

A.7 Page 1-8, 1.3.1 - P.S.2.D States that all cask operations from transporter/cask receipt through transporter/cask release shall be capable of being accomplished using remote, remote-automated, and contact or "hands-on" techniques.

Comment - The following design features of this cask do not appear to be very conducive to the use of remote or remote-automated handling equipment

a. Impact limiter installation and removal

b. Uprighting fixture installation and removal

c. Cask tiedown clamp installation and removal

d. Release of the longitudinal restraint wedges

e. Installation and operation of the cask valve tools.

RESPONSE: **Detail design for remote-automated operations will be done in final design based on yet to be supplied DOE specifications for interfaces for remote-automated techniques. (see SOW page c-B-4 item 2-D).**

A.8 Page 1-8, 1.3.1 - P.S.2.E States that all system components that potentially can come in contact with radioactive material shall be designed to limit surface contamination and weeping of the cask surface and for ease of decontamination.

Comment- the following design features of this cask do not appear to prevent surface contamination

a. Open threaded holes in the cask lid and the cask body

b. The valve openings or the unsealed threaded valve cap penetrations.

RESPONSE: **NuPac's 15 years experience in rail cask operations at reactor and fuel storage facilities uniquely qualify us to provide designs and surface controls to MINIMIZE contamination and weeping. This experience will be applied during the final design at which time the expressed concerns will be addressed.**

A.9 Page 1-8, 1.3.1 - I.G.16.A States that cask design should incorporate features to allow for cavity draining, drying, sampling, leak testing, and spent fuel cool down using contact, remote, and remote automated methods.

Comment - It seems to me that remote or remote-automated installation and operation of the cask valve tools will be extremely difficult. Also, I do not consider filling and then draining the cask to be a reasonable method for cooling down hot fuel assemblies, if cool down is necessary. In addition, it would be very difficult to do that operation in a hot cell using the existing valves. It would seem that there would be a fill valve at the top and then drain from the bottom.

RESPONSE: **Cask cool down requirements will be investigated during the final design phase. How this is to be accomplished will depend on the cool down method to be used at the MRS/Repository such as heated water, steam, or gas. A cool down operation may not be required for Dry Hot Cell operation, however the cask must be vented to relieve internal pressure prior to unbolting the lid.**

A.10 Page 1-8, 1.3.1 - I.G.18.B States that casks should have a surface capable of being sealed to a hot cell enclosure for loading/unloading operations. A study shall be performed and a recommendation by the contractor on the location and operation of this surface during the preliminary design phase.

Comment - There is no evidence of a recommendation by the Contractor of the location and operation of the sealing surface.

RESPONSE: **NuPac's cask sealing surface design recommendations were submitted in a letter to DOE on October 17, 1988. Reference to this letter and a discussion of the sealing surface design will be included in the Final Design Report.**

A.11 Page 1-10. 1.3.3 - I.G.14.A States that removable impact limiters should be compatible with contact, remote, and remote-automated handling methods.

Comment - It is not apparent whether these impact limiters can be removed and installed other than by contact handling.

RESPONSE: **Our intent is that remote and/or remote-automated handling methods be used on basic cask operations. The final details as to how this will be accomplished will be addressed during final design.**

A.12 Page 1-10, 1.3.3 - I.G.14.E States that impact limiters should include features to allow for periodic in service examination of energy-absorbing materials which may degrade during the cask lifetime.

Comment - It is assumed that the foam installation opening covers are not permanently attached to the impact limiter body. If that is not true, then access will need to be provided.

RESPONSE: **Foam installation covers are permanently installed. The foam vent covers can be removed for inspection.**

A.13 Page 1.10, 1.3.3 - How does an operator know that the impact limiter ring is in the cask lid groove?

RESPONSE: **This will be addressed during final design and may be done by use of point match marks on the cask Note: the engagement has a depth of 1 1/2".**

A.14 Page 1-10, 1.3.3 - Do you show that the impact limiter remains on during the hypothetical accident drop conditions? I could not find any indication that at the end of the drop analysis or at the beginning of the thermal analysis that the impact limiter is shown to remain attached to the cask. You rely on that for thermal protection for the seals.

RESPONSE: **The impact limiters and attachments are designed such that the impact limiter will remain attached to the cask during accident drop conditions. This will be verified during scale drop testing.**

A.15 Page 1-10 - How do you evacuate the volume between the O-rings?

RESPONSE: **This is accomplished with a vacuum pump, through the test port.**

A.16 Page 1-12 - The narrative identifies rupture discs but the drawing shows only one, which is it?

RESPONSE: At the present time only one rupture disc is used.

A.17 Page 1-28 - In Section 1.3.19, First bullet, it is stated that it must be possible to visually inspect the seal surface after loading fuel into the basket but prior to installing the lid. This will be quite difficult under 20-25 feet of water, especially after the cask is loaded and the pool water has a lot of suspended particulate. I would think it would make more sense to clean and inspect the seal surface before loading and then protect the surface during loading. Also, how do you intend to monitor debris as the cask is being loaded and then be able to remove it, as you state?

RESPONSE: Seal surface protectors will be used at the loading sites. Seals (o-rings) will be inspected at the loading site while the head is out of the pool. After fuel loading the procedure will have a step requiring an inspection for and removal of debris. This is the current practice used with the IF-300 and debris has been removed both at the loading site and GE Morris Facility (such things as broken glass, pens, self reading dosimeters, etc. have been found).

A.18 Page 1-20 In the last bullet you refer to personnel at the repository wearing protective clothing during handling operations. It is intended that the use of remote and remote automated equipment be used at the repository to the maximum extent possible because those operators are going to be handling casks most of the time. Even working in a 2 mrem per hour field could result in a yearly exposure of up to 4 rem, which is way too much.

RESPONSE: The requirement for use of protective clothing will apply when contact work is required.

A.19 General comment on Section 1.3.19 - There are a number of things that NuPac is going to do, many of which are identified in the performance specifications and Interface Guidelines. Why weren't these things identified first and then used as criteria for the designers? Also, how can I feel comfortable that these items will get done before it is too late, when they were not done at the appropriate time, for the preliminary design. I do not feel that NuPac will have more time to change these things in a final design than they did to initiate the preliminary design.

RESPONSE: NuPac has performed many analyses and reviews which are not included in the PDR. These reviews were and are being done to address the concerns expressed here and to address comments resulting from internal NuPac reviews. Cask operational experience not utilized during the early phases of the prelimenary design is now being applied which will make the cask more useable.

A.20 General comment on Section 1 - It would be helpful if in the appendix to this section or another more appropriate section, you included available NuPac procedures, like the load test procedure.

RESPONSE: Specific NuPac procedures will be included in the final design report.

B. Comments on the Preliminary design Drawings in Section 1

B.1 Cask Body - What holds the wire spacer in place? Can it drop due to differences in thermal expansion? Is ASTM A182 XM-19 the same as FXM-19 as far as ASME is concerned?

RESPONSE: The wire is tack welded in place during fabrication. The ASTM A182 XM-19 and the ASME FXM-19 are identical materials.

B.2 Cask Body - I.G.17.E States that all bolt holes for attaching closure head, valve covers, etc., and access ports should be designed to limit residual contamination and to prevent "hydraulic lock" of the fasteners.

Comment - The design of the cask lid and lid attachment method does nothing to limit residual contamination in the threaded valve covers and threaded lift penetrations or prevent "hydraulic lock" of the fasteners.

RESPONSE: The "hydraulic lock" problem is well understood by NuPac as well as the decontamination problems. These concerns are being addressed and details as to how they will be handled will be included in the final design package.

B.3 Cask Lid - I.G.18.C States that cask closure designs should be operable using contact, remote, and remote automated concepts.

Comment - The design of the cask closure does not lend itself to remote and remote-automated operations. As the cask lid lifting fixture is the cask lifting yoke, this device does not lend itself for use when the cask is sealed to the hot cell enclosure.

RESPONSE: A special cask lid removal device will be designed for Hot Cell Operation. A specification of interface requirements from DOE is needed to complete the application of remote-automated concepts.

B.4 Cask Lid - I.G.18.E States that the closure lid alignment, installation, and connection should be easily and quickly accomplished...

Comment - the present means for aligning the cask lid allows installation in two orientations. However, the valve penetrations are on one side of the lid. if automated techniques are used at the repository for gas sampling and leak checks, the valves need to be on the same side every time.

RESPONSE: The final design will allow the head to be set in only <u>one</u> location by keying off the guide pins located at different angles.

B.5 Cask Lid and Cask - I.G.18.H States that alignment marks visible from above a cask in a vertical position must be placed on the cask body and closure head.

Comment - There are no alignment marks on the cask body or the closure lid.

RESPONSE: Alignment marks will be shown in final design drawings.

B.6 Cask lid - I.G.16.B States that the number of auxiliary penetrations should be minimized and all should have double-closure protection and leak-test capabilities and be operable using contact, remote, and remote-automated techniques.

Comment - The rupture disc and vent plug do not have double containment. In fact, when the vent debris cover is removed the cask is vented to the atmosphere. It also is not apparent what the techniques are for remote and remote-automated operation.

RESPONSE: The leak test capabilities exist in the present design. The valve design is the same as the drain fill. The debris shield is the second closure. The rupture disc <u>can not have</u> a double closure. The techniques for remote and remote-automated operation will be addressed during final design.

B.7 Cask Lid - I.G.16.C States that all penetrations and valving should be designed to limit the accumulation of particulate residue.

Comment - The drain port has the capability to accumulate about 10 cu. in. of particulate residue which could result in a high does rate at the drain valve. I do not consider that to be minimized Also, how does that get cleaned? the design of the rupture disc, and the vent valve also have potential traps for particulate residue which could then weep during transit.

RESPONSE: **The method of draining the cask cavity will be changed to utilize pressurized gas to force the water out. This method will minimize residue build up.**

B.8 Cask Lid - I.G.16.E States that auxiliary penetrations serving different purposes should have dissimilar fittings to prevent errors in hookup, sampling. etc.

Comment - The vent and the spool plug penetrations on the cask lid have the same fitting configuration. In addition, the drain fitting configuration is only different in thread pitch but has the same diameter. An operator might possibly think that it was just a tight fit and try to put the wrong one on anyway.

RESPONSE: **The differences in penetration connections will be clarified during final design.**

B.9 Cask Lid - The valve debris covers need to be retained or they will get lost.

RESPONSE: **NuPac disagrees - A small cover connected with a safety chain could be damaged while the cask is going in or out of fuel pool. Administrative controls can be applied to prevent loss of the covers.**

B.10 Cask lid - Are the lid bolts chrome plated? It is not good practice to have 304 stainless steel bolts in threaded hole in 304. this applies to:

a. debris covers to lid
b. actuator to spoon valve

RESPONSE: **- No, these are cadmium plated low alloy steel bolts**

- NuPac is very aware of galling between stainless steel and will address this during final design.

B.11 Cask Lid - Is there to be a sequence to tightening the closure lid bolts? If so, at least it should be stated.

RESPONSE: Yes, this will be discussed in detail in the final design phase.

B.12 Cask Lid - I.G.18.K States that bolt or nut heads must have verticle and/or lateral access for a socket wrench, torque multiplier or automated tightening device.

Comment - The present design meets these interface guidelines, However, there are not any provisions for handling the fasteners using automated methods.

RESPONSE: Automated methods have been considered and will be clarified in final design.

B.13 Impact Limiter - On sheet 1, add A276 to material listing.
Need to have a brazing note on drawing.
Do not see tracks for the sunshield.
Does not appear to be room under the impact limiter for the dolly.
How is the impact limiter supported on the rail?
It seems that an elaborate lifting fixture is needed to install, remove, pick up, etc. The impact limiter. Suggest making it so that the impact limiter can be picked up by some common lifting device. Sheet 1 identifies ASTM A260 and other sheets identify ASTM A269, which is it? the ASME Code welded tube is A688. Need to show other materials on sheet 1 of the two drawings, like A240, A276, etc. if the fabricator uses ASTM A276 for bar stock, it is not an ASME Code P-8 material and the welding may have to be qualified details.

RESPONSE: The specifications as to <u>how</u> various operations are performed are sometimes beyond the scope of preliminary design. We are confident that the NuPac design can perform as stated. The specific details of these operations will be clarified during final design.

C. Section 3

C.1 Page 3-55 Section 3.5.1 - In the last paragraph you identify that the borated-silicone is self extinguishing and no deleterious gaseous char products have been reported. You do not make the same statement for the polyurethane foam. Is that material self extinguishing also?

RESPONSE: Yes, the material is self extinguishing per 14 CFR 25.853a testing. Carbon monoxide is the primary chargaseous product of concern; however, in an open environment deleterious concentrations probably would not be of concern.

D. Section 7

D.1 Page 7-2 Section l7.1.1 - Inspection of the fuel assemblies can only provide fuel bundle serial number and exterior fuel bundle condition. All other items identified in this section are paper checks that should be done well in advance of the shipping campaign.

RESPONSE: **Agree, section 7 has been rewritten for the Preliminary Design Report (PDR).**

D.2 Page 7-2 Section 7.1.2 - Need to remove the sunshield before removing the impact limiters. Also, it is easy to just say "attach the uprighting fixture to the railcar" but doing it will be something else. How does the uprighting fixture attach to the railcar, and what equipment is necessary to get it in place.

RESPONSE: **Agree, section 7 has been rewritten for the Preliminary Design Report (PDR). Specific details as to "how" something may be done will be clarified during final design.**

D.3 Page 7-3 Section 7.1.2.2 - How do you purge the cask with only the vent opening?

RESPONSE: **Section 7 has been rewritten for the Preliminary Design Report (PDR) and contains a brief outline of various operational procedures. Detailed procedures, such as for cask purging, etc., will be written during final design.**

D.4 Page 7-3 Section 7.1.2.3 - Why do you wash the exterior of the cask after you open the vent port?

RESPONSE: **Section 7 has been rewritten for the Preliminary Design Report (PDR). See the response for D.3.**

D.5 Page 7-3 Section 7.1.2.4 - This step covers cask lid removal which makes the contaminated cask open to the atmosphere and the operators. In Section B.1.1.3 it identifies that the cask lid is removed after the cask is placed in the pool using the cask lifting fixture. Which is correct?

RESPONSE: **The cask lid will be removed in the pool or Hot Cell. The only time it will be removed outside the pool will be at a maintenance facility or if a problem arises at the reactor and special radiation and contamination procedures would have to be used. NuPac is well aware of the radiation field in large casks after use based on IF-300 operating experience.**

D.6 Page 7-3 Section 7.1.2.5 - If Section B.1.1.3 is correct, which it probably is, then this Section is totally incorrect. Then the question is, when are the things that were done in Section 7.1.2.5 done?

RESPONSE: **Section 7 has been rewritten for the Preliminary Design Report (PDR). See the response to D.3.**

D.7 Page 7-3 Section 7.1.2.6 - Some of the facilities use demineralized water to flush and I do not believe that these facilities would want to put their demin system in the same line with contaminated water under pressure. It would seem that filling the cask should be done from the top with and overflow to determine when the cask is full.

RESPONSE: **NuPac is very aware of facility requirements and that they vary site to site. The IF-300 fills from the bottom and filling starts with the vent valve open and vented to a HEPA filter or suitable air vent for venting airborne gas. A check valve has been required at some facilities on the demineralized water supply.**

D.8 Page 7-3 Section 7.1.2.7 - Again, if Section B.1.1.3 is correct, then the sealing surface protector cannot be installed at this time.

RESPONSE: **Section 7 has been rewritten for the Preliminary Design Report (PDR) and will include proper time for installing seal surface protector device on the cask (in pool after head removal).**

D.9 Page 7-4 Section 7.1.2.11 - Do not put vacuum grease on the adjoining sealing surfaces on the cask lid. This will not provide any benefit and will only attract particulate that is suspended in the pool water. Particulate that ends up between the seal and the sealing surface will probably result in failing the leak test.

RESPONSE: **NuPac is very aware of the bad effect of using excess grease on the seals. The use of grease will be minimized and will be addressed in the Operating Manual during final design.**

D.10 Page 7-4 Section 7.1.2.12 - How do you ensure the cask lid locking equipment is in place and is secured under 20-25 feet of water?

RESPONSE: Visual indicating flags would show position.

D.11 Page 7-4 Section 7.1.2.13 - I.G.16.G States that the cavity draining should include a capability for visual or remote verification.

Comment - This feature is not identified.

RESPONSE: - If vacuum drying is used the vacuum gage is the way of verifying the cask is dry.
- If the cask is drained by applying gas pressure (20 psig) to vent, there are ways (dependent on the reactor site) which can be used to note the change from liquid to gas, such as draining back to pool and observing (looking) for gas bubbles. This method has been used on the IF-300 at most locations.

D.12 Page 7-4 Section 7.1.2.14 - The instructions here state to torque bolts to 1300-1400 ft.-lbs. While the drawing identifies a torque of 1200-1450 ft.-lbs. Which is correct?

RESPONSE: Section 7 has been rewritten for the Preliminary Design Report (PDR) using a torque of 1200-1450. Note: Torque has no effect on sealing the cask because O-rings are bore seals.

D.13 Page 7-4 Section 7.1.2.15, 16, & 17 - These sections describe the operations for vacuum drying the cask interior. First the drain port plug is closed, then the vent port tool is installed, and then the vacuum pump is installed and the cask cavity pressure is reduced to below 1 psia by a vacuum pump capable of achieving a pressure of 1 psia. First, I don't know how that will happen. Then, in accordance with section B.1.5.3.3, for drying the cask, the vent assembly is removed and the cask vent port closed. The vacuum pump is then operated and the vacuum drying takes place through the drain valve consistent with Figure B.1.5-1. There is an inconsistency. In addition, are there any tests or verifications to assure that the cask cavity is dry?

RESPONSE: Section 7 has been rewritten for the Preliminary Design Report (PDR) and will revise the section on vacuum drying. The cask is considered dry when less than 1 cubic foot of water remains and verification is made when the drain line shows gas is being discharged instead of water.

D.14 Page 7-5 Section 7.1.2.16 - I.G.16.I States that the ...capability to perform a flowing gas sample should be available.

Comment - This feature is not apparent in the design.

RESPONSE: **NuPac believes gas sampling would be done using a vacuum bottle attached to a vent port. However a flowing gas sample technique will be part of the Operating Manual furnished in the final design phase (only the repository or MRS would do gas sampling).**

D.15 Page 7-5 Section 7.1.2.18 - If the vent port is closed then how is the inert gas put into the cask cavity?

RESPONSE: **Section 7 has been rewritten for the Preliminary Design Report (PDR) showing inerting being part of the draining cycle.**

D.16 Page 7-5 Section 7.1.2.19 - Is there a leak check done on the rupture disc port?

RESPONSE: **Yes, annually or at time of replacement, whichever is less.**

D.17 Page 7-5 Section 7.1.2.24 - Install the cask labels in accordance with 49 CFR 172 Subpart E. This is to be done prior to installation of the sunscreen/personnel barrier.

RESPONSE: **Section 7 has been rewritten for the Preliminary Design Report (PDR). See the response to D.3.**

D.18 Page 7-7 Section 7.2 - Cask unloading at the repository will be done in a hot cell using remote, remote automated equipment to the maximum extent possible. With the full cask, the unloading procedure will be significantly different. There is no way that the cask lid will be removed unless the cask is sealed to the hot cell enclosure. How do you propose to remove the cask lid in the hot cell? The present lid lifting system cannot possibly be used at the repository where the top of the cask must be sealed to the hot cell enclosure.

RESPONSE: **A special head removal system will be designed and furnished for the Hot Cell based on interface requirements which will be provided by DOE. This will be done in the final design phase.**

E. Section 8

E.1 Section 8 does not address maintenance and testing of auxiliary equipment. That should be included in the section.

RESPONSE: Detailed maintenance and testing of ancillary equipment will be part of the Maintenance Manual furnished in the final design phase. Lifting equipment will use ANSI STD. 14.6 for test requirements and any DOE supplied requirements. (Note: Lifting gear is a reactor technical specification item and these will have to be addressed prior to supplying this equipment to a specific reactor).

E.2 Page 8-1 - Acceptance testing requirements are also defined in DOE Ord and they should be addressed.

RESPONSE: Acceptance test requirements will be contained in the Opertions and Maintenance Procedures.

E.3 Page 8-2, 8.1.2.1 - In the first paragraph, 90.054 pounds should be 95,054.

RESPONSE: Correct, will change "90.054 pounds" to "95,054 pounds".

E.4 Page 8-19, 8.2.1 - DOE Orders require periodic load testing of lifting equipment and lifting attachments.

RESPONSE: All such equipment will be inspected and/or tested in accordance with regulatory requirements.

E.5 Page 8-22, 8.2.2.3 - Is there any check to assure that the rupture disc is function properly?

RESPONSE: No the rupture disc is factory certified, visually inspected and leak tested annually or at time of replacement.

F. Section B.1

F.1 Page B.1.5 Section B.1.1 - Do not consider it time effective to have to change the trunnion stirrups twice during every loading operation. Also, is there a provision on the lifting fixture that precludes an operator form attempting to lift the cask, especially in the pool, with only one stirrup engaged and the other stirrup against the side of the trunnion?

RESPONSE: **Agree. This will be changed in final design and provisions will be added to prevent lifting of the cask with only one stirrup engaged.**

F.2 Page B.1.5 Section B.1.1 - What do the wedges do when the cask is set down in the pool, the lifting fixture disengaged from the cask and the lid lifted off the cask? I think there is some slack in the closure lid bolts and the lid will drop some, do the wedges follow? If they do, they may interfere putting the cask lid back on or reengaging the stirrups with the trunnions.

RESPONSE: **The wedges are pneumatically moved into the lock and unlock positions. This will be clarified during final design.**

F.3 Page B.1.6 Section B.1.1.1 - The lifting fixture will not be used at the repository for handling the cask closure lid. A different lifting fixture will have to be provided. The lifting fixture also may not be used to secure the lid in place during vertical transfer operations.

RESPONSE: **A special head removal system will be designed and furnished for the Hot Cell based upon interface requirements to be supplied by the DOE. This will be done in the final design phase.**

F.4 Page B.1.7 Section B.1.1.2.7 - With the lid blocking hardware attached to the lifting fixture in a fixed orientation, in the unlikely event that the cask tips, it would seem that the blocking feature would become ineffective.

RESPONSE: **The lid blocking mechanism prevents the lifting stirrups from disengaging. Thus, if the cask tips, the lid will be captured by the lift fixture. This will be clarified in the final design phase.**

F.5 Page B.1.9 figure B.1.9 - I assume this lifting fixture will function under water. It will, however, be nearly impossible to decontaminate when it is necessary to be shipped from one reactor site to another.

RESPONSE: Agree, complete decontamination to allow "free-shipment" may not be practical so reusable boxes will be furnished as part of the final design so that the yokes can be shipped LSA on exclusive use trucks. This is the way it is done for the IF-300 lifting equipment. The use of Type A containers will be investigated during the final design phase, which would permit these to be shipped in normal freight.

F.6 Page B.1.21 - B.1.2.1 - I.G.11.B States that transporter mounted tiedowns should, where practical, be integrated with the methods and equipment that will be used for laying down and uprighting the cask on its transporter.

Comment - It is recognized that the cask tiedowns are an integral part of the cask support structure. However, the equipment used for laying down and uprighting the cask is not an integral part of the cask support structure. This means that there is one additional piece of equipment to track and to move from utility to utility when a shipping campaign changes.

RESPONSE: Agree, but at the present time the railcar weight limitations do not permit this equipment to be part of the railcar.

F.7 Page B.1.21 - B.1.2.1 - I.G.11.F States that to simplify remote receiving operations, the direction of travel during removal of tiedown system components should be in the upward or outward direction, and access should be from above or from the side.

Comment - The direction of travel for the cask tiedown is upward and outward and there is access from above and from the side. However, I did not see any provisions for handling and operating the tiedown clamp remotely.

RESPONSE: This will be clarified during the final design phase.

F.8 Page B.1.46 - B.1.3.2 - P.S.2.F States that all removable ancillary components of the cask shall be located in readily accessible and low exposure areas and be attached using easily operable mechanisms.

Comment - It does not appear that the installation and removal of the cask uprighting fixture can be done using easily operable mechanisms. In fact, it appears that it is not even possible to install or remove the uprighting fixture. In addition, it does not appear that there are any provisions or equipment for handling the uprighting fixture.

RESPONSE: All of the concerns expressed in this comment have been addressed internally by NuPac and will be clarified during the final design phase.

F.9 Page B.1.51 - B.1.4.1 - I.G.19 States that all cask ancillary equipment normally transported with the cask should be operable and replaceable using contact, remote, and remote automated techniques.

Comment - It is questionable in my mind whether the sunshield, impact limiters, and cask tiedown clamps can be operated either remote or remote-automated.

RESPONSE: NuPac is confident that all these operations can be operated remotely or remote-automated. This design will be redefined in the final design phase to clarify our design based upon DOE furnished interface information.

F.10 Page B.1.7-16 Section B.1.7.8 Cask Lid - I.G.18.F States that the ... Closure lifting equipment should be designed to prevent inadvertent lifting of the cask and for quick and easy attachment to the components.

Comments - The design of the closure lifting equipment does not prevent inadvertent lifting of the cask even though the lifting fixture is designed to lift the cask. Also, it appears that it is also possible to lift only one side of the cask if one of the cask trunnion stirrups engages the trunnion.

RESPONSE: - The head lifting bolts will be re-designed during final design phase to have a ultimate load less than the cask weight so they will break prior to cask lift. (Note: this is the same requirements used on the IF-300 head lifting cables)

- Visual verification of trunnion engagement will be done and the method for verifying this step will be clarified in the final design phase and detailed instructions will be included in the operational procedures.

G. Section C.1

G.1 Page C.1.3 - Do not reference Yucca Mountain as the site for the repository as it is only under study, at this point. And do not use Oak Ridge, TN as the site of the MRS as it has been specifically excluded from being the MRS site. You only need to refer to the repository and the MRS, if there is one. In addition, it is not necessary to try to develop total cycle time and cask fleet size as fuel is going to be delivered from many locations. There are several studies going on that are trying to develop criteria to establish the cask fleet size. Your responsibility is to try and develop a cask design that will meet the facility turn around times identified in the RFP.

RESPONSE: **Section C.1 has been re-written to include NuPac's extensive experience in realistic cask turn around times based upon first hand use of rail-mounted casks.**

G.2 P.S.2.B States that the cask turnaround, the time between receipt and release shall be minimized with the design goal at the repository of less that 12 hours and less than 18 hours at utility reactors.

Comment - Figure 2 shows 30 hours loading time at a utility and there are a number of tasks not identified in the figure that are identified below that will add significantly to the time. It appears that this performance specification will not be met.

RESPONSE: **Same as response in G.1.**

G.3 The loading time shown in figure 2 does not include many items that need to be done prior to shipping. Some of these items that you have identified on page C.1.2. There are still others like smear and radiation surveys when the cask is removed from the pool, vacuum drying, and purging with inert gas. Some of these items and the ones mentioned on page C.1.2 will add 6-12 hours, or more to the loading time. In addition, I do not feel that you can reasonably estimate the unloading time at the MRS or the repository until more is known about the design of these facilities and the degree of remote and remote-automated equipment usage is better known. It will definitely be much different than the loading operation.

RESPONSE: **Same as response in G.1.**

GROUP NUMBER ELEVEN
COMMENTS AND REPSPONSES
REVIEWER: H.K. PETERSON

Comment:

The brevity of Section 5.0, Shielding Evaluation, undoubtedly reflects the preliminary nature of the design report. The shielding analysis considers the source to be evenly distributed throughout the cask internal cavity volume, which, in most cases, is a valid generalization. The final design should discuss some aspects that are not mentioned in the PDR. The additional aspects are:

a) The effect of axial peaking of the fission product distribution along the length of the fuel rod. (This peaking can be as high as 1.3 to 1.5 times the volume-smeared average density.)

RESPONSE: **The effect of axial peaking of the fission product distribution along the length of the fuel rod was accounted for by multiplying the radial dose rate results obtained with homogenized source region evenly distributed in the cask inner cavity by a factor of 1.08. This factor is for spent fuel aged 5 years or longer (Page 5-22 of the PDR). Use of this factor has been accepted by the NRC in the past for spent fuel storage systems. Normally the higher peaking (1.3 to 1.5) is obtained in the beginning-of-life irradiation of the fuel assembly. For higher burnups similar to the OCRWM cask designs, the fuel assembly is irradiated for 3 to 4 fuel cycles and the end-of-life axial peaking factor in such cases is just under 1.1 (Reference IF-300 Consolidated Safety Analysis Report, NEDO-10084-3). As an added conservatism in the shielding analysis, the gamma sources in the top and bottom nozzle regions of the fuel assembly due to activation of the hardware were also included in the active fuel region of the fuel assembly. This total source strength was used to calculate the dose rate in the cask axial directions.**

b) The effect of the fuel element end-box activation of Co-60 on the gamma dose on the outside of the cask.

RESPONSE: **The effect of fuel element end-box activation of Co-60 on the gamma dose on the outside of the cask was included in the shielding analysis presented in the PDR (page 5-15 2nd paragraph and Appendix 5.5.4). NuPac will verify during final design that end-box activation has been appropriately modeled in the shielding evaluation to determine whether modeling of end-box activation as a discrete source is required.**