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CONSOLIDATED DESIGN REPORT FOR FORT ST. VRAIN FUEL SHIPPING CASK

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CONSOLIDATED DESIGN REPORT
FOR FORT ST. VRAIN FUEL SHIPPING CASK

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NOTICE

GADR-55, Addendum I, Revision 1, is a superseding consolidation of the following:

GADR-55, Addendum I, issued August 1978
GADR-55, Addendum I, Revision A, issued 21 February 1979
GADR-55, Addendum I, Revision B, issued 30 March 1979
GADR-55, Addendum I, Revision C, issued 21 August 1979
GADR-55, Addendum I, Revision D, issued 11 October 1979

GADR-55, Revision 2, and GADR-55, Addendum I, Revision 1, comprise the complete design report for the model FSV-1 radioactive materials shipping package.

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NO CHANGE

INTRODUCTION

The complete design report for the model FSV-1 Spent Fuel Shipping Cask consists of the following volumes:

GADR-55, Revision 2 and

GADR-55, Addendum 1, Revision 1.

This design report is presented in separate volumes to better describe the two closure systems used with the same cask body. These closure systems are identified as follows:

NL Closure System (See Figure 1.)

Alternate Closure System (See Figure 2.)

The detailed description and the supporting analysis for the NL Closure System and the cask body is presented in GADR-55, Revision 2, "Consolidated Design Report for the Fort St. Vrain Fuel Shipping Cask". The detailed description and supporting analysis for the Alternate Closure System including the impact limiter is presented in GADR-55, Addendum 1, Revision 1, "Consolidated Design Report for the Fort St. Vrain Fuel Shipping Cask."

The General Atomic Company (GA) model FSV-1 Spent Fuel Shipping Cask is designed and fabricated to satisfy all of the requirements of Title 10, Code of Federal Regulations, Part 71, during the transport of spent fuel elements (see Figure 3) from the Fort St. Vrain, High Temperature Gas Reactor (HTGR). Six spent fuel elements, which are hexagonal graphite blocks containing fissile material, primarily U-233 and U-235 and fertile material, primarily thorium, are placed in the FSV-1 cask for each shipment. The FSV-1 cask consists of an inner container which provides the primary containment and a cask body which provides secondary containment, gamma shielding and structural integrity for the package. The principal materials of construction are stainless steel and depleted uranium. Silicone rubber seals are used for the inner and outer closures and the closure end of the FSV-1 cask is protected by a laminated plywood impact limiter (when the alternate closure system is used).

This alternate closure system consists of the following major components:

Fuel Container Lid

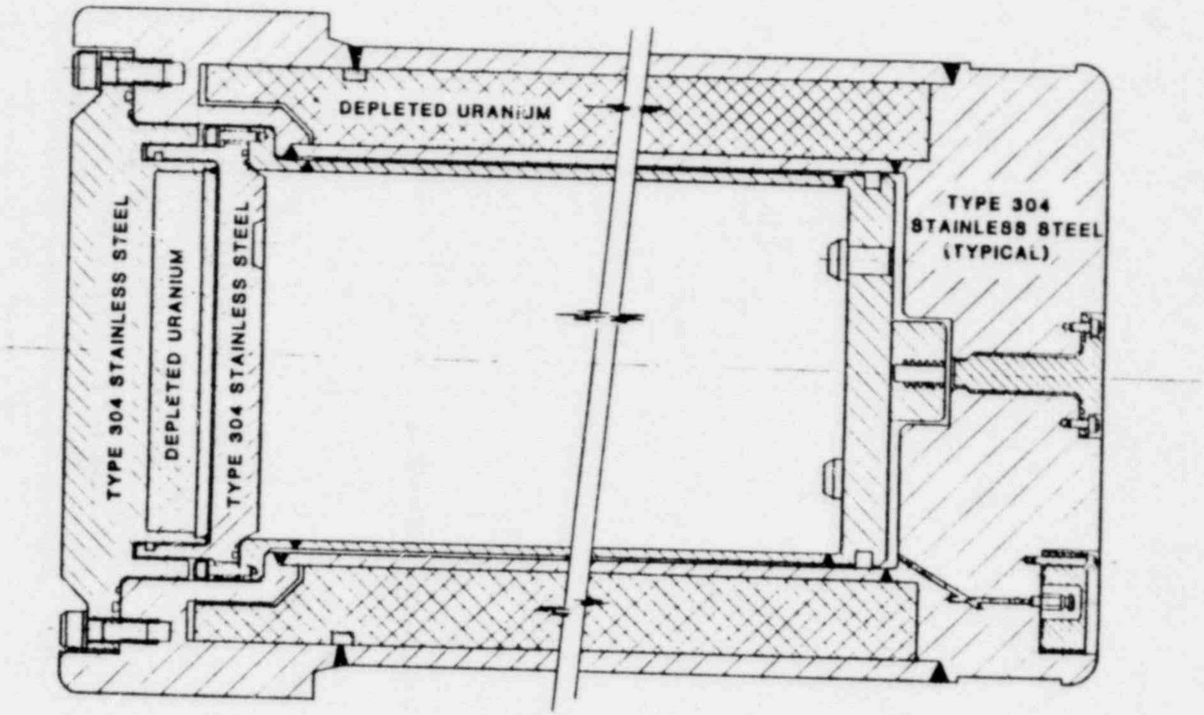
Shipping Cask Cover

Impact Limiter

The alternate closure system is shown on General Atomic Company (GAC) Drawings GADR-55-2-1, GADR-55-2-2, and GADR-55-2-3. The detailed description and the supporting analysis is presented in the following sections of Addendum I. These sections are numbered the same as the sections of GADR-55 and contain the additional analysis and description associated with the alternate closure system for the model FSV-1 cask. The alternate closure system is designed to satisfy the requirements of 10 CFR 71 as effective June 1978, except that the leakage rates and tests are designed to satisfy the requirements of ANS N14.5, "Leakage Tests on Packages for Shipment of Radioactive Materials," dated November 1974.

Reference throughout this report has been made to GAC manufacturing drawings designated as 90-H1501-XXX. These individual drawings are not a part of this report. Instead, GAC Drawings GADR-55-2-1, GADR-55-2-2, and GADR-55-2-3 have been included to provide the necessary design information.

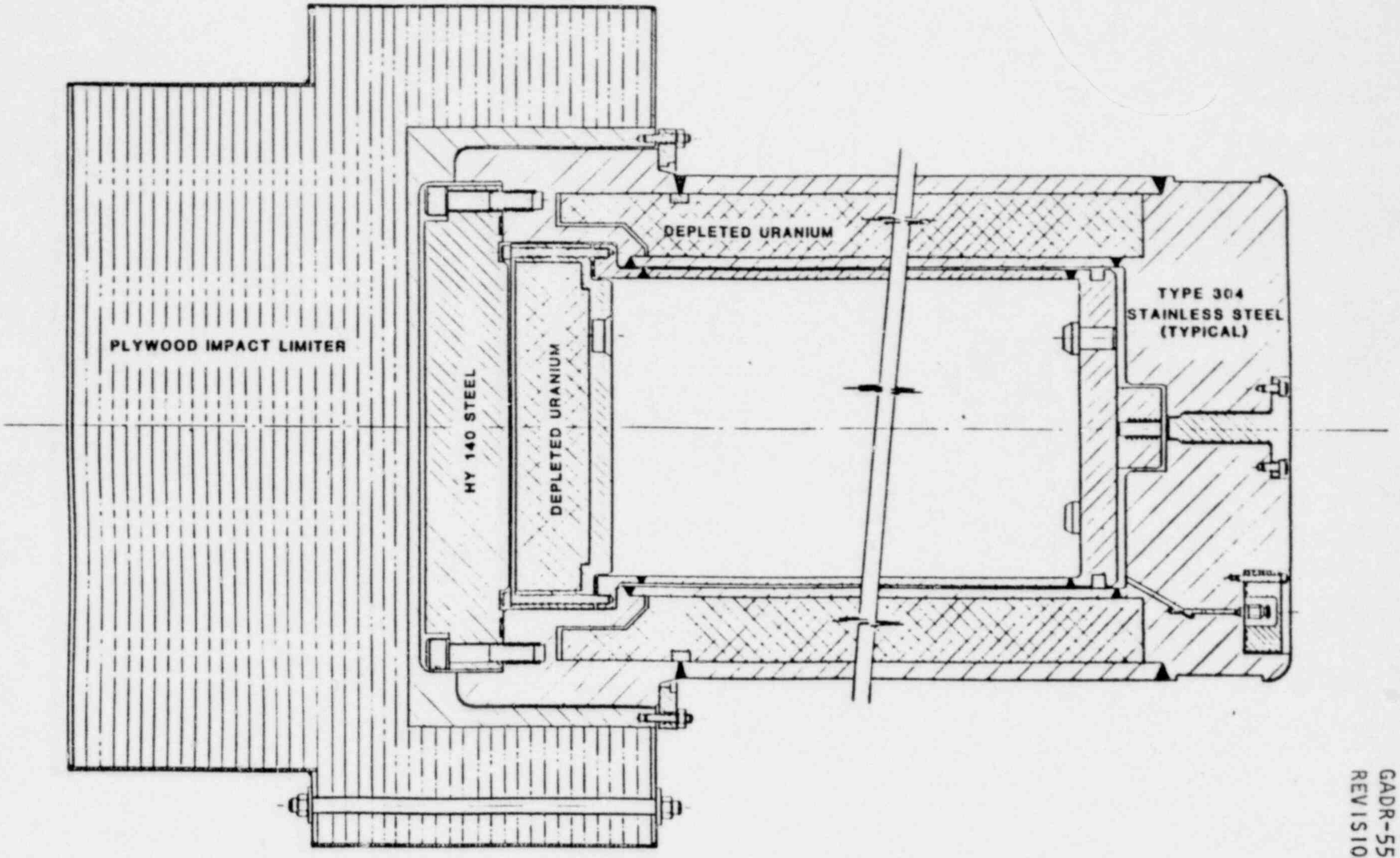
The primary objective of the alternate closure system is to reduce radiation exposure to operating personnel during opening and closing of the loaded cask. This has been accomplished by moving the depleted uranium shielding from the outer cask closure to the inner container lid. Thus the shielding is put in place at the earliest opportunity and removed at the latest possible step in the handling procedure. The revised hardware with improved shielding also simplifies the handling procedure. An impact limiter has been added to the closure system to further assure adequate structural integrity of the cask system when subjected to the hypothetical accident conditions.



MODEL FSV-1 CASK WITH NL CLOSURE SYSTEM

FIGURE 1

(For details refer to GADR-55)



MODEL FSV-1 CASK WITH ALTERNATE CLOSURE SYSTEM

FIGURE 2

(For details refer to GADR -55 addendum I)

SECTION I

SYSTEM DESCRIPTION

SYSTEM DESCRIPTION

A. PURPOSE

The purpose of the fuel shipping container and cask with alternate closures is to provide a radioactive material package for handling and transporting spent fuel from the reactor to a storage facility.

B. NORMAL OPERATING REQUIREMENTS

The fuel shipping container and cask with alternate closures and impact limiter is designed and constructed to satisfy the requirements of 10CFR-71 for normal conditions of transport.

C. ABNORMAL OPERATING REQUIREMENTS

The fuel shipping container and cask with alternate closures and impact limiter is designed to withstand conditions of hypothetical accident as delineated in 10CFR-71. This accident criteria includes free drop, puncture, thermal exposure, and water immersion conditions.

D. EQUIPMENT LIST

The following items of equipment will be used during the transfer of spent fuel from the Fort St. Vrain fuel storage wells to the fuel shipping container and cask.

Fuel Handling Machine (FHM).

Two (2) Reactor Isolation Valves (RIV).

Auxiliary Transfer Cask (ATC).

170-ton Overhead Crane.

Hot Service Facility (HSF).

Fuel Loading Port.

Fuel Shipping Container and Cask.

Fuel Shipping Cask Transport Trailer and Tractor.

50-Ton Overhead Crane.

HSF Jib-Hoist.

Fuel Shipping Cask Lifting Apparatus.

17-1/2 Ton Overhead Crane.

Fuel Handling Purge and Vacuum System.

Seal Adapter.

Adapter and Track Assembly

Restraint-Fuel Shipping Cask.

E. NORMAL OPERATING PROCEDURE

1. Transferring the Fuel Shipping Cask to the Refueling Floor.

   a. Inspect tractor and trailer and clean if necessary.

   b. Open truck bay door.

   c. Back tractor and trailer into truck bay in reactor building.

   *d. Disconnect brake hoses to set the trailer brakes and disconnect the light wires on left side of trailer.

   *e. Unlock trailer slide locks. Handle located on left side of trailer.

   *f. Back tractor to slide trailer rails to the closed position. Note that slide locks are engaged.

   g. Lower trailer legs and disconnect tractor.

   h. Drive tractor out of truck bay and close the truck bay door.

   i. Remove fuel loading port cover plate and seal adapter. Store on refueling floor. Use 17-1/2 ton overhead crane.

   j. Place temporary barricade around fuel loading port.

   k. Place temporary barricades around refueling floor hatches.

   l. Open hatches in refueling floor directly above truck bay. Use 17-1/2 ton overhead crane.

   m. Open sliding hatch in floor directly above truck bay.

   n. Remove fuel shipping cask front support tiedown and store on trailer.

   o. Remove the 6 nuts that hold the mounting ring to the impact limiter.

   p. Using the 17-1/2 ton overhead crane, remove the impact limiter and store it on the front of the trailer.

   q. Lower fuel shipping cask lifting apparatus on 50-ton overhead crane.

   r. Connect fuel shipping cask lifting apparatus to cask by engaging lifting pegs in the holes near the top of the fuel shipping cask. Adjust the lifting apparatus with the hand crank.

---

*Not required for fixed length trailer.

s. Raise the cask to about 20" and slide the impact limiter mounting ring to the base of the cask.

t. Raise and reposition 50-ton hook until cask is in the vertical position. Caution: Cask is bolted to trunnion on trailer.

u. Unbolt trunnion locking block from trailer and bolt to the inside left trunnion support using same bolts. Two (2) 1/2-13 HEX head bolts. Caution: Keep cask vertical.

v. Unbolt fuel shipping cask from trunnion. Four (4) 1-1/4-7 socket head bolts. Caution: Verify that crane is not lifting trailer.

w. Raise fuel shipping cask to a position above refueling floor and position directly over fuel loading port.

x. Rotate the fuel shipping cask to align the legs of the lifting apparatus with the guide plates in the fuel loading port. Note: Alignment mark on fuel shipping cask must match 10° off reactor north.

y. Lower fuel shipping cask into fuel loading port until cask is completely supported by the loading port.

z. Install restraints at the bottom of the fuel shipping cask.

aa. Disengage lifting apparatus from cask and temporarily store on refueling floor.

bb. Remove temporary barricades from around fuel loading port.

2. Preparing the Fuel Shipping Cask to Receive Fuel.

a. Screw three eyebolts into threaded holes in the top of the cask cover.

b. Position the 17-1/2 ton auxiliary crane hook with a three-leg sling, over the fuel shipping cask. Connect the legs of the sling to the eyebolts in the shipping cask cover.

c. Unbolt the fuel shipping cask cover. Twenty-four (24) 1-1/4 socket head bolts.

d. Remove the shipping cask cover to the hot service facility for decontamination, if required, and inspection of bolt threads and seals.

e. Using the jib hoist, pick up the seal adaptor and position the seal adaptor on top of the fuel shipping cask.

f. Using the 17-1/2 ton overhead crane, move a reactor isolation valve from storage and position it on top of the fuel loading port. Use alignment gage for positioning.

g. Connect purge and control lines to reactor isolation valve and open valve.

h. Inflate reactor isolation valve seals.

i. Remove the 12 bolts in the spent fuel container lid.

j. Install track and adapter guide onto shipping container lid. Engage the track on the two keys in the RIV.

k. Using the 170 ton overhead crane, move the auxiliary transfer cask from storage position to the top of reactor isolation valve located on the fuel loading port.

l. Open the shutter valve of the auxiliary transfer cask and lower the auxiliary transfer cask grapple to engage track and adapter assembly for lifting the shipping container lid.

m. Raise the container lid into auxiliary trasfer cask.

n. With the purge connection on the reactor isolation valve, purge the auxiliary transfer cask and backfill with air.

o. Close auxiliary transfer cask shutter.

p. Move the auxiliary transfer cask to its storage position and bolt in place.

3. Placing the Spent Fuel Elements in the Shipping Cask.

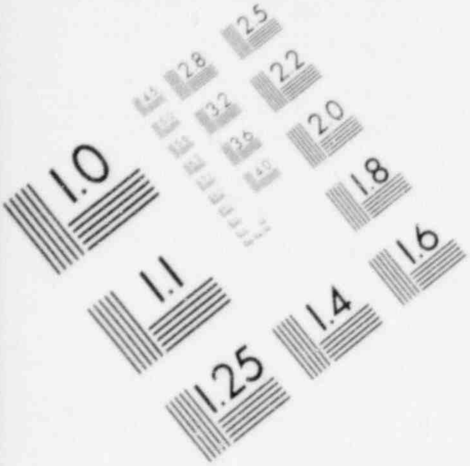
a. Mount the fuel handling machine with 6 spent fuel elements to the RIV on the loading port.

b. Evacuate fuel shipping cask through the reactor isolation valve and backfull with helium.

c. Open fuel handling machine cask valve.

d. Deposit 6 fuel elements into fuel shipping cask.

e. Close and seal the fuel handling machine cask valve.



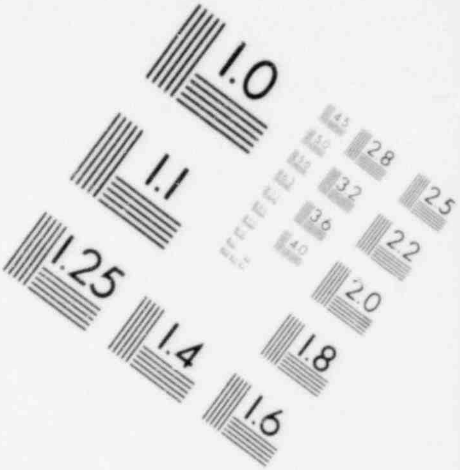
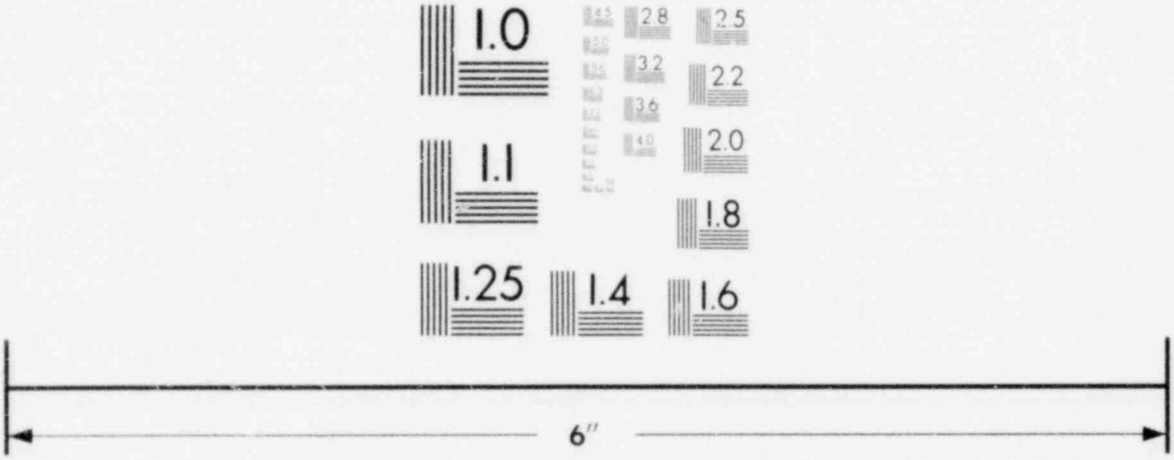
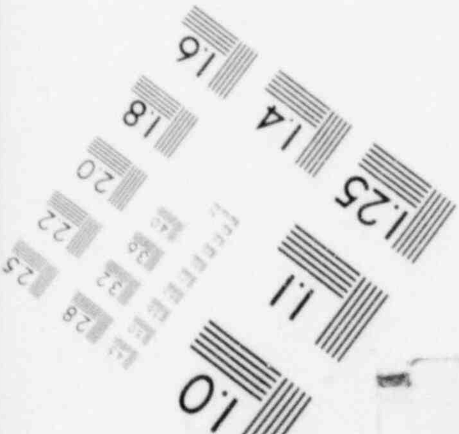
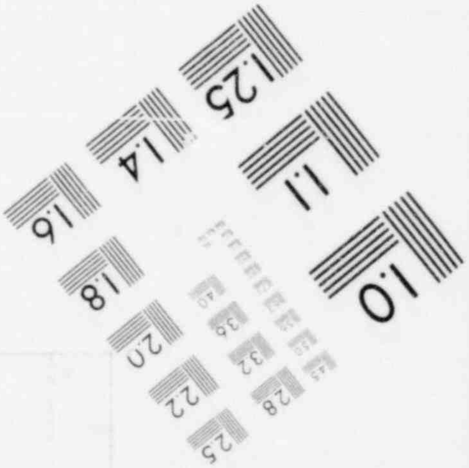


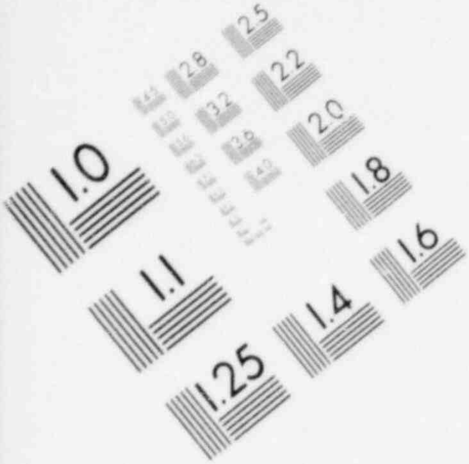
IMAGE EVALUATION
TEST TARGET (MT-3)



MICROCOPY RESOLUTION TEST CHART







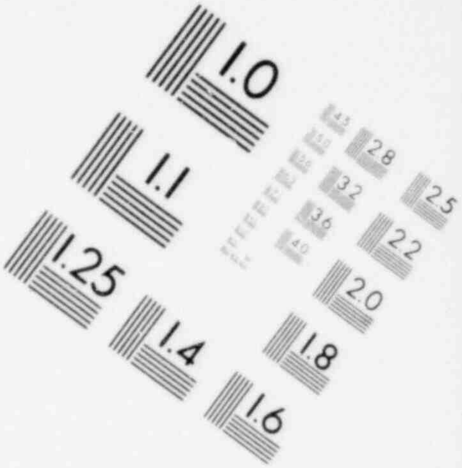
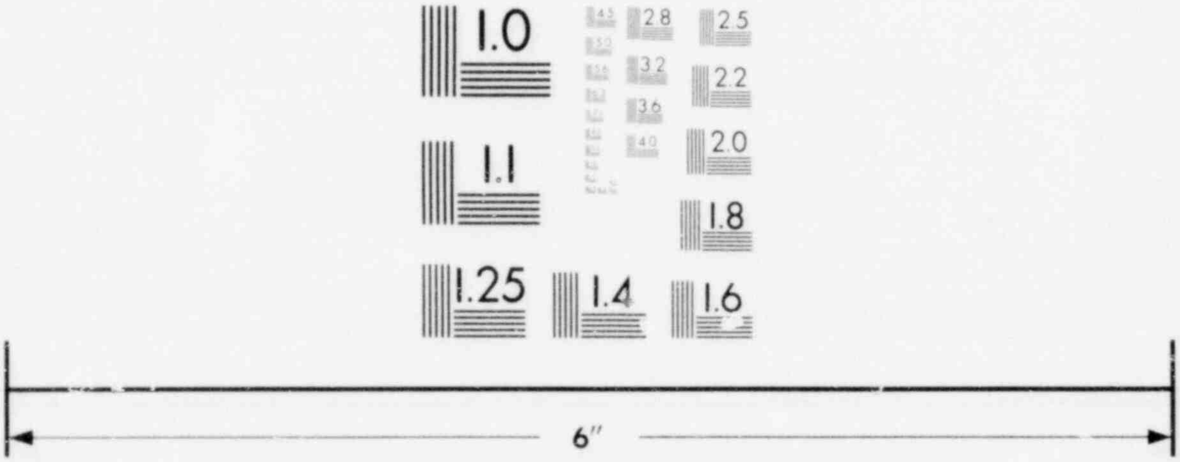
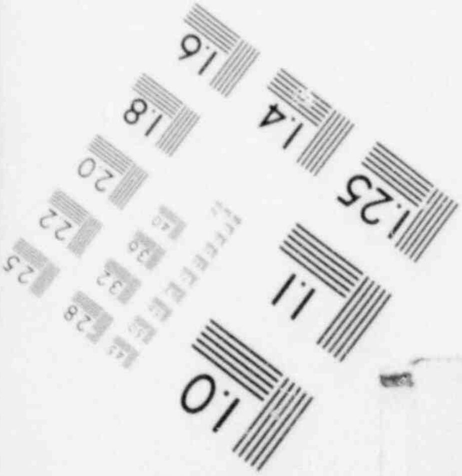
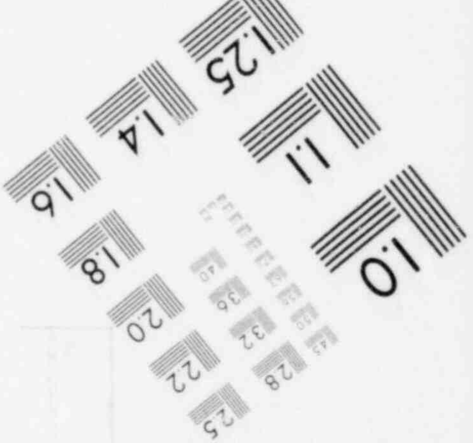


IMAGE EVALUATION TEST TARGET (MT-3)



MICROCOPY RESOLUTION TEST CHART





f. Evacuate the fuel shipping cask and backfill with air. Close the reactor isolation valve.

g. Remove the fuel handling machine to its storage position.

4. Installing the Container Lid.

a. Move the auxiliary transfer cask from its storage position and mount to the reactor isolation valve over the fuel loading port.

b. Open the reactor isolation valve.

c. Lower and deposit the fuel container lid.

d. Remove and store the auxiliary transfer cask.

e. Remove track and adapter assembly from the container lid.

f. Bold down the container lid using twelve 1/2 inch bolts. Torque to 15 to 20 ft-lbs.

g. Remove reactor isolation valve to its storage position.

5. Leakage Testing the Container Lid Seals.

a. Assembly verification testing. (Done before each use except when Step 5.b. is required.)

(1) Connect leakage test system with pressure gauge and shutoff valve to test port in container lid.

(2) Evacuate seal interspace to a pressure of 1 mm Hg. Close shutoff valve.

(3) Wait two minutes.* Maximum permissible pressure rise is 5.5 mm Hg (6.5 mm Hg on gauge).

---

* Test time is based on a total test cavity volume of 1 cubic inch (16.387 cm^3).

(4) If pressure rise is greater than the permissible rise, replace main flange and primary plug seals. Repeat Step 5.b.

b. Periodic verification testing (done after each third use or within 12 months and prior to use after each seal replacement).

(1) Connect leakage test system fitting with pressure gauge and shutoff valve to test port in container lid.

(2) Evacuate seal interspace to a pressure of 1 mm Hg. Close shutoff valve.

(3) Wait five minutes.* Maximum permissible pressure rise is 5.7 mm Hg. (6.7 mm Hg on gauge)

(4) If pressure rise is greater than the permissible rise, replace main flange and primary plug seals. Repeat Step 5.b.

c. Disconnect leakage test system from vacuum source.

d. Open shutoff valve to vent seal interspace and remove leakage test system.

e. Install the shipping plug in the test port.

f. Remove seal adapter from top of cask.

---

*Test time is based on a total test cavity volume of 1 cubic inch (16.387 cm^3)

g. Install cask cover and bolt in place. Torque 24 bolts to 80 to 120 ft-lbs.

h. Remove the three eyebolts from the fuel shipping cask cover.

6. Transfer of the Fuel Shipping Cask onto the Fuel Shipping Trailer.

a. Using the 50-ton building crane, pick up the fuel shipping cask lifting apparatus and move it to the fuel loading port.

b. Connect fuel shipping cask lifting apparatus to cask by engaging lifting pegs in the holes near the top of the fuel shipping cask. Adjust the lifting apparatus with the hand crank.

c. Remove the restraint from the bottom of the fuel shipping cask.

d. Raise the fuel shipping cask out of the fuel loading port and move it to the center of the hatchway in the refueling floor.

e. Lower the fuel shipping cask through the hatches until the fuel shipping cask is several feet above the trailer.

f. Position fuel shipping cask over the support on the trailer. Rotate fuel shipping cask to align the slot in the cask with the key in the support. Assure that the impact limiter mounting ring is in place on top of the rear cask support.

g. Lower the fuel shipping cask until the bottom engages the rear cask support on the trailer. Caution: Trunnion locking block is in place. Do not tilt fuel shipping cask.

h. Install bolts that hold fuel shipping cask to cask bottom support trunnion on trailer. Torque to 500-600 ft.lbs.

i. Remove bolts that attach trunnion locking block to trunnion support. Two (2) 1/2-13 HEX head bolts.

j. Bolt trunnion locking block to pad on trailer.

k. Continue to lower and position crane hook until the shipping cask head is within 20 inches of its rest position.

l. Slide the mounting ring to the top end of the cask.

m. Lower the shipping cask until it comes to rest on the cask top support structure.

n. Unlock and disengage cask lifting apparatus from the fuel shipping cask.

o. Move the cask lifting apparatus to its storage position.

p. Replace the top portion of the cask top support structure and install bolts.

q. Using the 17-1/2 ton overhead crane, install the impact limiter on the top end of the cask. Remove the sling.

r. Attach the mounting ring to the impact limiter with the 6 nuts.

s. Close hatch on refueling floor above truck bay.

t. Close sliding hatch above truck bay.

7. Fuel Shipping Truck Departure.

a. Open truck bay door.

b. Back tractor into truck bay and connect to trailer.

*c. Verify that brake hoses and light wires on left side of trailer are disconnected.

*d. Unlock trailer slide locks, handle located on left side of trailer.

*e. Drive tractor forward until trailer is extended and the shipping cask is moved forward to transit position. Note: Slide locks are engaged.

*f. Connect brake hoses and light wires located on left side of trailer.

g. Drive the fuel shipping tractor with trailer from the truck bay.

h. Close the truck bay door.

---

*Not required for fixed length trailer

F. MAINTENANCE PROGRAM

The shipping cask with the fuel container, and all auxiliary equipment will be maintained to assure that all items are in proper operating condition. A checklist will be developed which will list each component which requires specific maintenance actions. The checklist will include the method of maintenance check to be used, the acceptance criteria for each, and the required maintenance frequency. Each checkpoint will require sign-off by the individual making the check. Space will be provided on the maintenance checklist to enter the equipment identification, supervisor's name, and the date maintenance is completed.

The maintenance checklist will also include all auxiliary equipment, such as the lifting yoke, tie-down assemblies, and trailer. Maintenance of the trailer will be carried out in accordance with standard industry-recommended procedures and schedules.

The cask operating procedure will contain steps requiring a review of the equipment maintenance program checklists to verify that all required maintenance and periodic testing has been accomplished.

G. LEAKAGE TESTING

In accordance with Regulatory Guide 7.4, the guidance contained in ANSI N14.5, "Leakage Tests on Packages for Shipment of Radioactive Materials", was used to establish the maximum permissible leakage rate and the minimum leakage test sensitivity.

1. The containment system assembly verification test will be conducted prior to each use (except when the periodic verification test is required) as follows:

Component	Verification
Fuel Container main flange double seal	(a) (b)
Fuel Container primary plug seal	(a) (b)

(a) Checklist verification of proper assembly.

(b) Leakage test by evacuating the seal interspace to a pressure of 1 mm Hg. Observe that pressure does not rise above 6.5 mm Hg in two minutes (maximum permissible leakage rate is 1×10^{-3} atm cm^3/sec).

2. The containment system periodic verification test will be conducted after each third use, within 12 months after any use and prior to any use following the replacement of any primary seals.

Component	Verification
Fuel Container main flange seal	(a) (b)
Fuel Container primary plug seal	(a) (b)

(a) Checklist verification of proper assembly

(b) Leakage test by evacuating the seal interspace to a pressure of 1 mm Hg. Observe that pressure does not rise above 6.7 mm Hg in five minutes (maximum permissible leakage rate is 4.12×10^{-4} atm cm^3/sec).

3. The shipping cask seals that are not part of the containment system will be tested as part of the annual maintenance procedure as follows:

   a. Pressurize the shipping cask cavity to 10 psig through the lower purge valve connection. Reinstall the purge valve cover and apply soap solution around the purge valve cover and the lower cavity access port cover. No leak indications permitted.

   b. Remove the shipping plug from the cask cover. Evacuate the seal interspace to a pressure of 1 mm Hg. Observe that pressure does not rise above 6.5 mm Hg in two minutes (maximum permissible leakage rate is 1×10^{-3} atm cm^3/sec).

4. Calculations for permissible leakage rate.

   The maximum permissible leakage rate and the minimum sensitivity of the leakage test were determined by using the guidance provided in ANSI N14.5, "Draft American National Standard for Leakage Tests on Packages for Shipment of Radioactive Materials".

   a. Containment: The FSV-1 cask with alternate closure system is assumed to be a Type B (U) package.

   b. Gaseous fission product inventory:

      (1) Normal conditions of transport: negligible quantity (Ref. 3).

      (2) Accident conditions of transport: Kr 85 470 curies (Ref. 3).

   c. Parameters:

      (1) A_2 value for Kr 85 = 1000 curies (Ref. 1).

      (2) R_N = package containment requirements for normal conditions of transport, curies per second (Ci/sec).

      $R_N = 2.78 \times 10^{-10}$ Ci/sec (Ref. 2)

(3) R_A = package containment requirements for accident conditions of transport, curies per second (Ci/sec).

$$R_A = A_i \times 1.65 \times 10^{-9} \text{ Ci/sec} \quad \text{(Ref. 2).}$$

(4) Fuel container net volume:

$$235 \times 10^3 \text{ cm}^3$$

(5) Volume of test port in container lid and the test equipment, $V_p = 1.0 \text{ in.}^3$ (16.387 cm^3)

d. Normal conditions of transport:

Since the inventory of gaseous fission products during normal conditions of transport is negligible, the accident condition will establish the permissible leakage rate.

e. Accident conditions of transport:

(1) L_A = permissible leakage rate, atm cm^3/sec

$$L_A = \frac{R_A}{C_A}$$

C_A = specific activity of containment medium

$$C_A = \frac{470 \text{ Ci}}{235 \times 10^3 \text{ cm}^3} = 2.0 \times 10^{-3} \text{ Ci/cm}^3$$

$$R_A = 1000 \times 1.65 \times 10^{-9} = 1.65 \times 10^{-6}$$

$$L_A = \frac{1.65 \times 10^{-6} \text{ Ci/sec}}{2.0 \times 10^{-3} \text{ Ci/cm}^3} = 8.25 \times 10^{-4} \text{ cm}^3\text{/sec}$$

f. Containment system periodic verification:

The periodic leakage test is required to have a sensitivity to detect leakage that is 1/2 of the permissible leakage.

$$L_A = 8.25 \times 10^{-4} \text{ cm}^3\text{/sec}$$

$$1/2\ L_A = 4.12 \times 10^{-4} \text{ cm}^3\text{/sec}$$

Thus a "pressure rise" test with a nominal sensitivity of 1×10^{-4} atm cm^3/sec was selected.

(1) Duration of leakage test:

Using a test volume of 16.387 cm^3, a starting pressure of 1 mm Hg and an ending pressure of 7.6 mm Hg (Ref. 2), the volume of inleakage, V_i is:

$$V_i = 16.387\ \text{cm}^3 \left[\frac{7.6}{760} - \frac{1}{760}\right] = 1.42 \times 10^{-1}\ \text{cm}^3$$

t = test time in seconds is:

$$t = \frac{1.42 \times 10^{-1}\ \text{cm}^3}{4.12 \times 10^{-4}\ \text{cm}^3/\text{sec}} = 344.7\ \text{sec}$$

The allowable rate of pressure rise is:

$$\frac{6.6\ \text{mm Hg}}{344.7\ \text{sec}} = .01915\ \text{mm Hg/s}$$

The allowable pressure rise for a five minute test is:

$$.01915 \times 5 \times 60 = 5.7\ \text{mm Hg}$$

(2) Check of test sensitivity:

$$L_S = \frac{V_p\ T_S}{3600\ H}\left[\frac{P_2}{T_2} - \frac{P_1}{T_1}\right] \quad \text{(Ref. 2, Eq. B11)}$$

$$= \frac{16.387 \times 298}{3600 \times \frac{344.7}{3600}} \left[\frac{\frac{7.6}{760}}{298} - \frac{\frac{1}{760}}{298}\right]$$

$$L_S = 4.12 \times 10^{-4}\ \text{atm cm}^3/\text{sec}$$

g. Containment system assembly verification:

This test is used to verify that no gross seal defects exist prior to each shipment, therefore, a less sensitive test procedure is required. A test sensitivity of 1×10^{-3} atm cm^3/sec is assumed to provide a more reasonable test time although a 1×10^{-1} atm cm^3/sec test is allowed. (Ref. 2)

$$t = \frac{1.42 \times 10^{-1}\ \text{cm}^3}{1 \times 10^{-3}\ \text{cm}^3/\text{sec}} = 142\ \text{seconds}$$

The allowable rate of pressure rise is:

$$\frac{6.6\ \text{mm Hg}}{142\ \text{sec}} = .0465\ \text{mm Hg/sec}$$

The allowable pressure rise for a two-minute test is:

$$.0465 \times 2 \times 60 = 5.6\ \text{mm Hg}$$

SECTION I

Ref. 1. IAEA Safety Series, No. 6. 1973 revised.

2. ANSI N14.5. November 1974

3. GADR-55, Supplement A, page 9-5, 9-6 and 9-7.

SECTION II

PHYSICAL AND FUNCTIONAL DESCRIPTION

PHYSICAL AND FUNCTIONAL DESCRIPTION

A. GENERAL

The spent fuel container and fuel shipping cask with alternate closures is designed to transport six HTGR fuel elements weighing 300 pounds each, loaded in a single column. Design of all equipment is such that it will satisfy all requirements of 10CFR-71.

B. SPENT FUEL CONTAINER LID

The spent container lid is made of depleted uranium with .15 to .30 weight percent molybdenum which is enclosed in a welded type 304 stainless steel housing that has been coated with copper spray .002 to .005 inch thick. The lid is 20.5 inches in diameter, 5.71 inches thick and weighs about 1000 lbs. This lid forms the closure on the spent fuel container forming a cylindrical volume 16.62 inches in diameter by 187.62 inches in length. The container lid is aligned to the container with two dowel pins. It is attached to the container with twelve 1/2 inch diameter stainless steel bolts.

The lid is sealed to the container with a stainless steel spacer ring with integral molded dual concentric silicone elastomer seal rings. The inner concentric seal is the primary seal while the outer concentric seal forms a trapped volume useful for testing of the seal. A small diameter (.375 inch OD) seal located on the primary seal plug which seals above the gas sampling check valve is also a primary seal.

One gas passage penetrates the top end of the container lid and is used for both shipping container gas sampling and primary seal leak testing. Primary seal testing requires removal of a plug from the top of the container lid. A vacuum gauge and shutoff valve are then attached to the test port. A vacuum is drawn on the test port and the shutoff valve is closed. Pressure increase indicated on the vacuum gauge will indicate leakage past either the primary seal system and/or the .375 dia. O-ring seal on the primary seal plug. A second function of the test port is for sampling of the container gas. For this task, the primary seal plug is removed to expose an all stainless steel cartridge check valve. This valve is installed to prevent flow from the inside of the container. A sampling plug is then installed which seals itself to the cask lid prior to mechanically displacing the ball within the check valve. The installed sampling plug then allows for monitoring of gas activity and pressure.

C. SHIPPING CASK CLOSURE

The shipping cask closure in conjunction with the shipping cask body form a secondary containment around the sealed spent fuel container. The cask closure is a 4.75 inch thick, 27.13 inch diameter heat treated ASTM A579 alloy steel which is nickel plated. The cask closure is held to the cask body with twenty-four 1 1/4 inch diameter alloy steel cap screws.

SECTION II

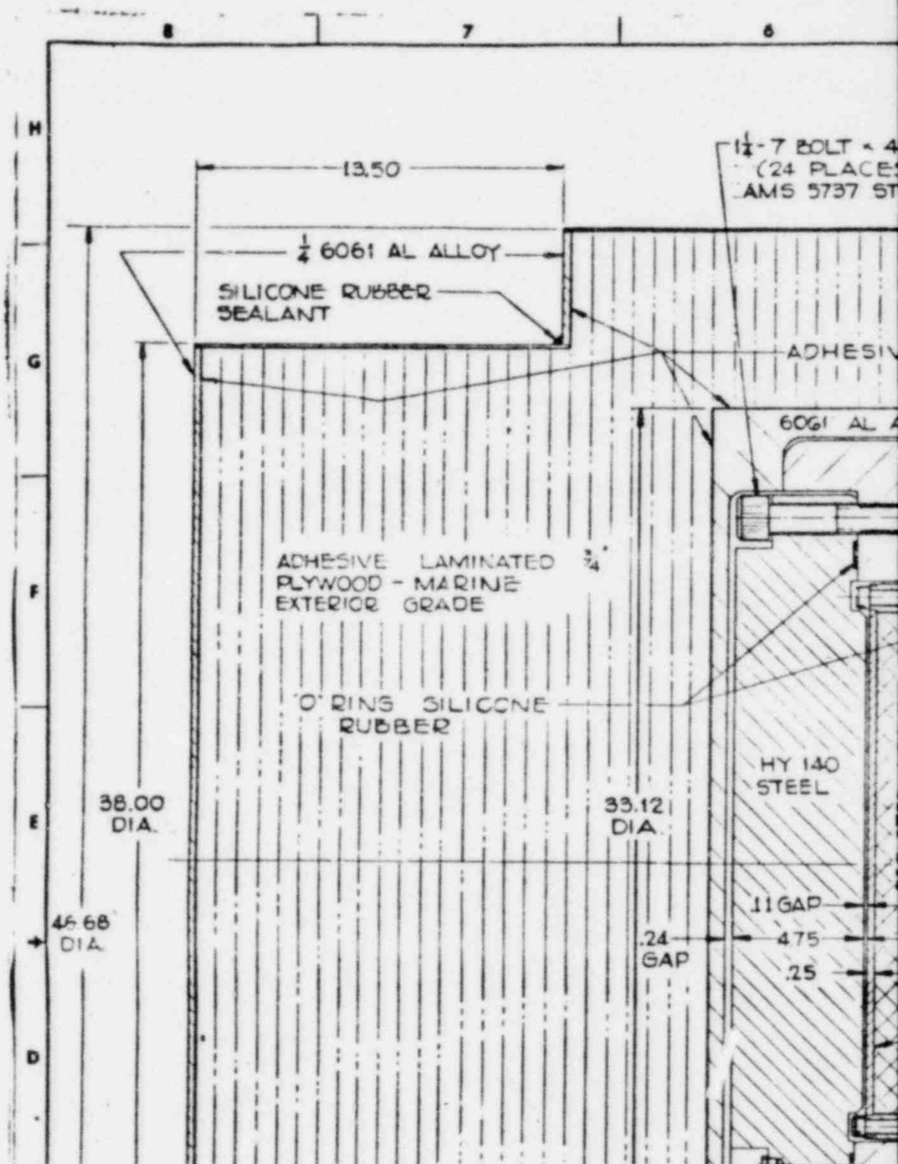
The shipping cask closure is sealed to the cask body with a stainless steel/dual concentric silicon elastomer seal design similar to that used on the spent fuel container lid. A single test port is routed from the top of the closure to the innerspace between the concentric seals to allow for seal leak testing similar to that done on the container lid seal.

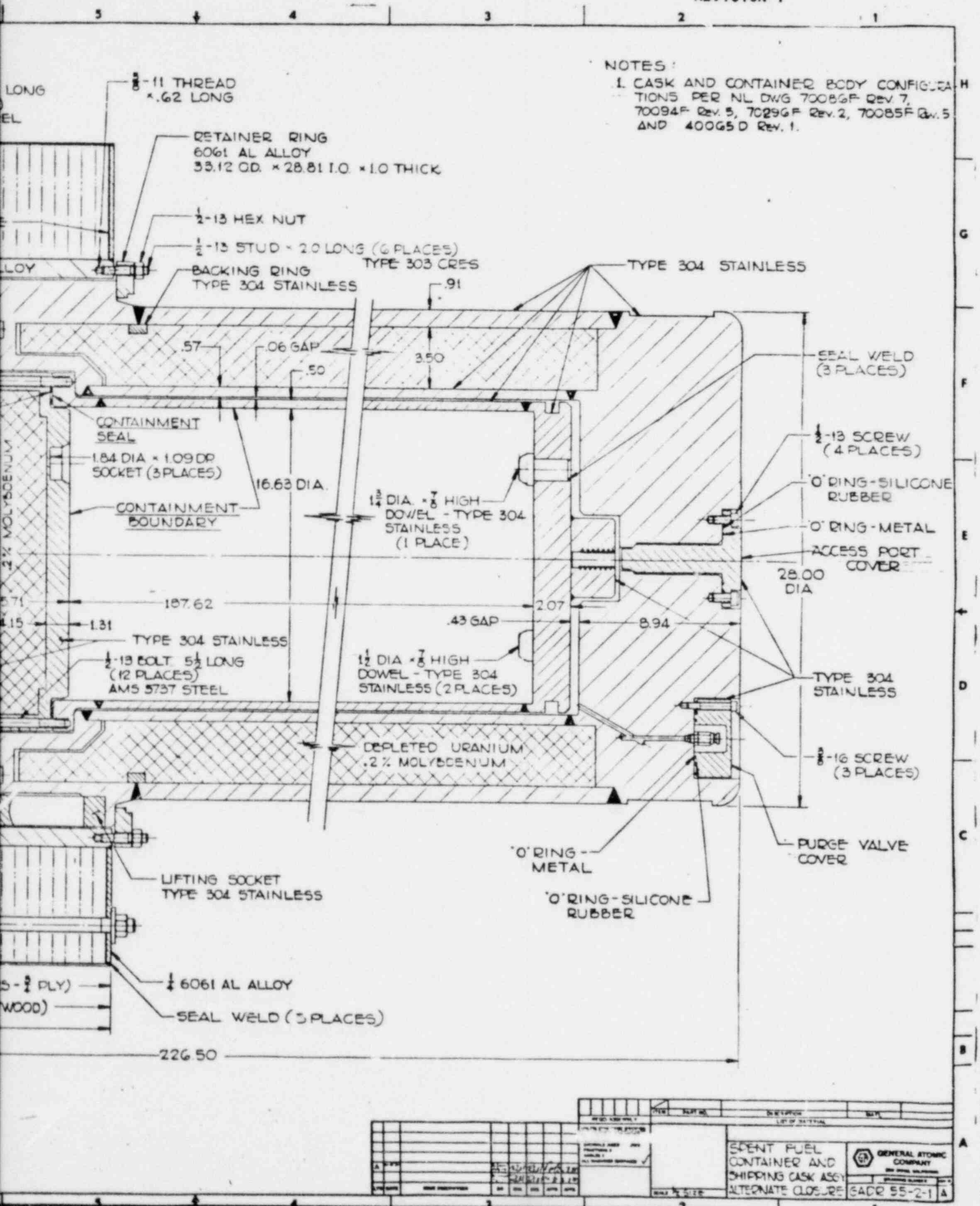
D. IMPACT LIMITER

An aluminum encased plywood impact limiter attaches to the top end of the cask and completely envelops the cask closure and container lid area. The impact limiter is designed to protect the cask closure area from both top end and side drops as well as drops through all intermediate angles. The limiter is made up of about 40 layers of 3/4 inch thick marine grade plywood and is encased in aluminum for weather protection and durability during handling. The impact limiter is clamped to the outer top end of the cask using a continuous mounting ring which is held to the impact limiter with six 1/2-inch diameter fasteners.

E. DRAWINGS

General Atomic Company: GADR-55-2-1, Issue A; GADR-55-2-2, Issue A; GADR-55-2-3, Issue A.


8
7
6
H
G
F
E
D
C
B
A
13.50
1½-7 BOLT × 4
(24 PLACES
AMS 5737 ST
¼ 6061 AL ALLOY
SILICONE RUBBER SEALANT
ADHESIV
6061 AL A
ADHESIVE LAMINATED ¾" PLYWOOD - MARINE EXTERIOR GRADE
'O' RINGS SILICONE RUBBER
HY 140 STEEL
38.00 DIA.
33.12 DIA.
46.68 DIA.
.11 GAP
.475
.25
.24 GAP
⅛ 6061 AL ALLOY
¾-10 BOLT (24 PLACES)
13.75 (18 LAYE
19.25 (25 LAYERS - ¾ PL
32.75 (43 LAYERS - ¾ PLYWOOD



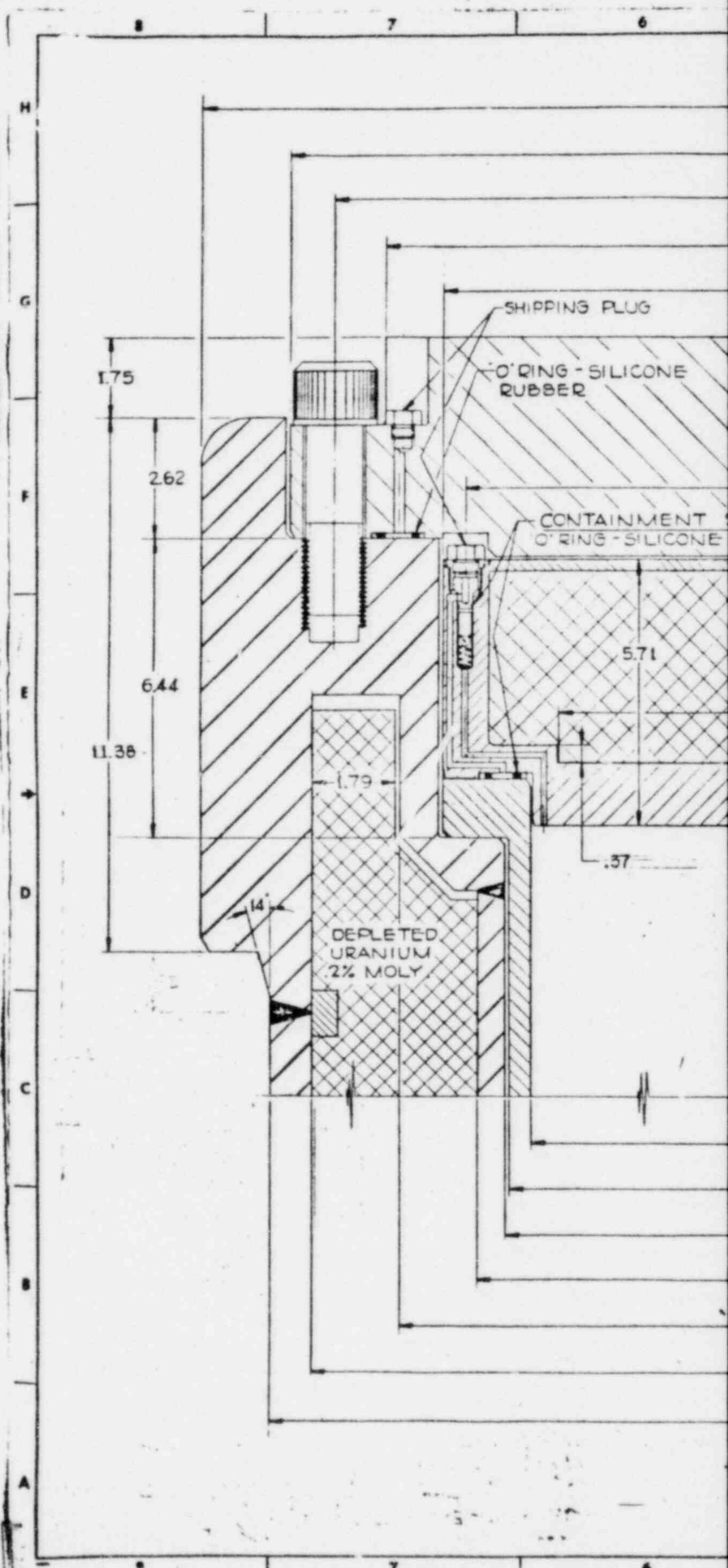
NOTES:
1. CASK AND CONTAINER BODY CONFIGURATIONS PER NL DWG 70086F Rev. 7, 70094F Rev. 5, 70296F Rev. 2, 70085F Rev. 5 AND 40065D Rev. 1.

SPENT FUEL
CONTAINER AND
SHIPPING CASK ASSY
ALTERNATE CLOSURE

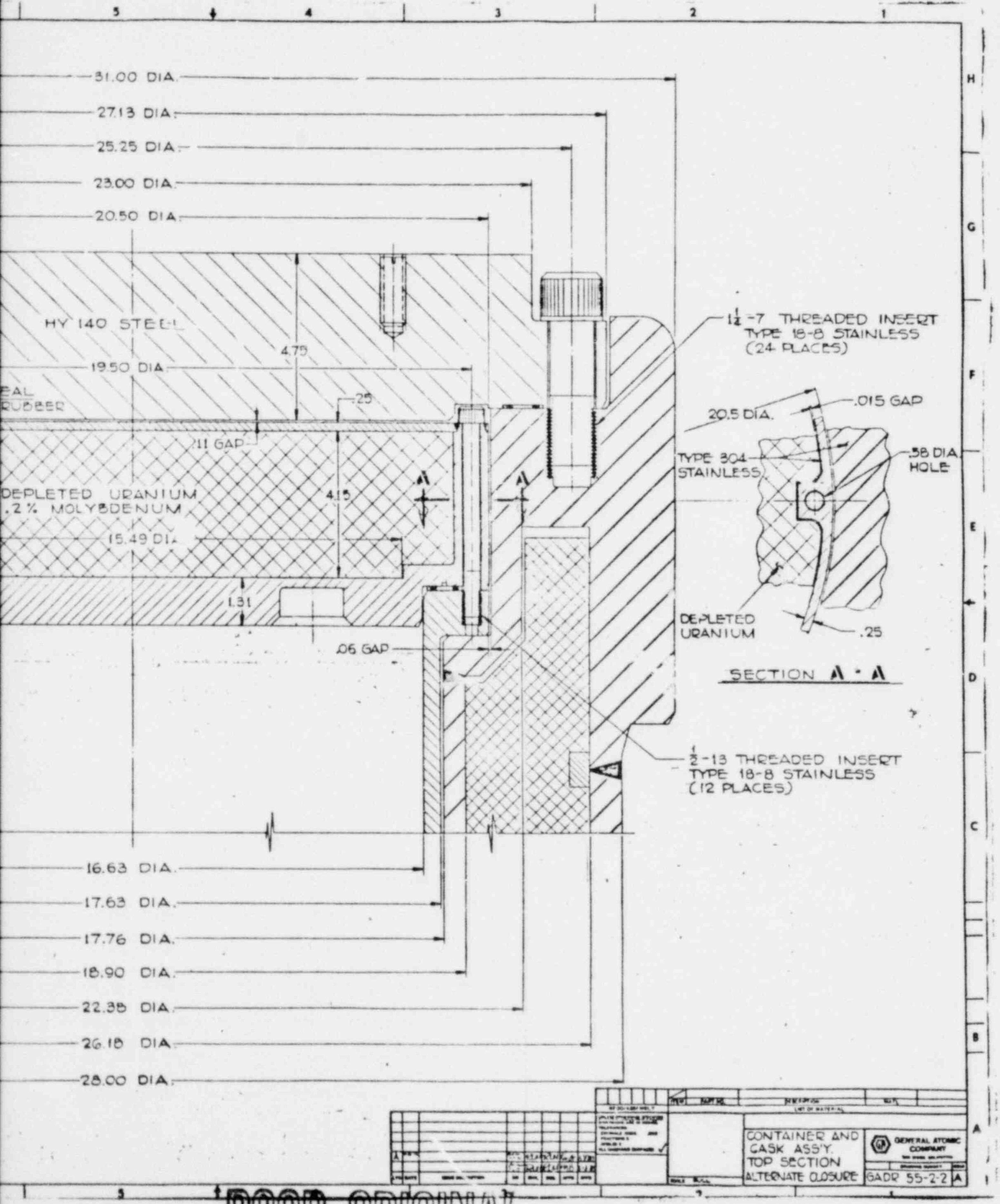
GENERAL ATOMIC COMPANY

GADR 55-2-1 A

POOR ORIGINAL



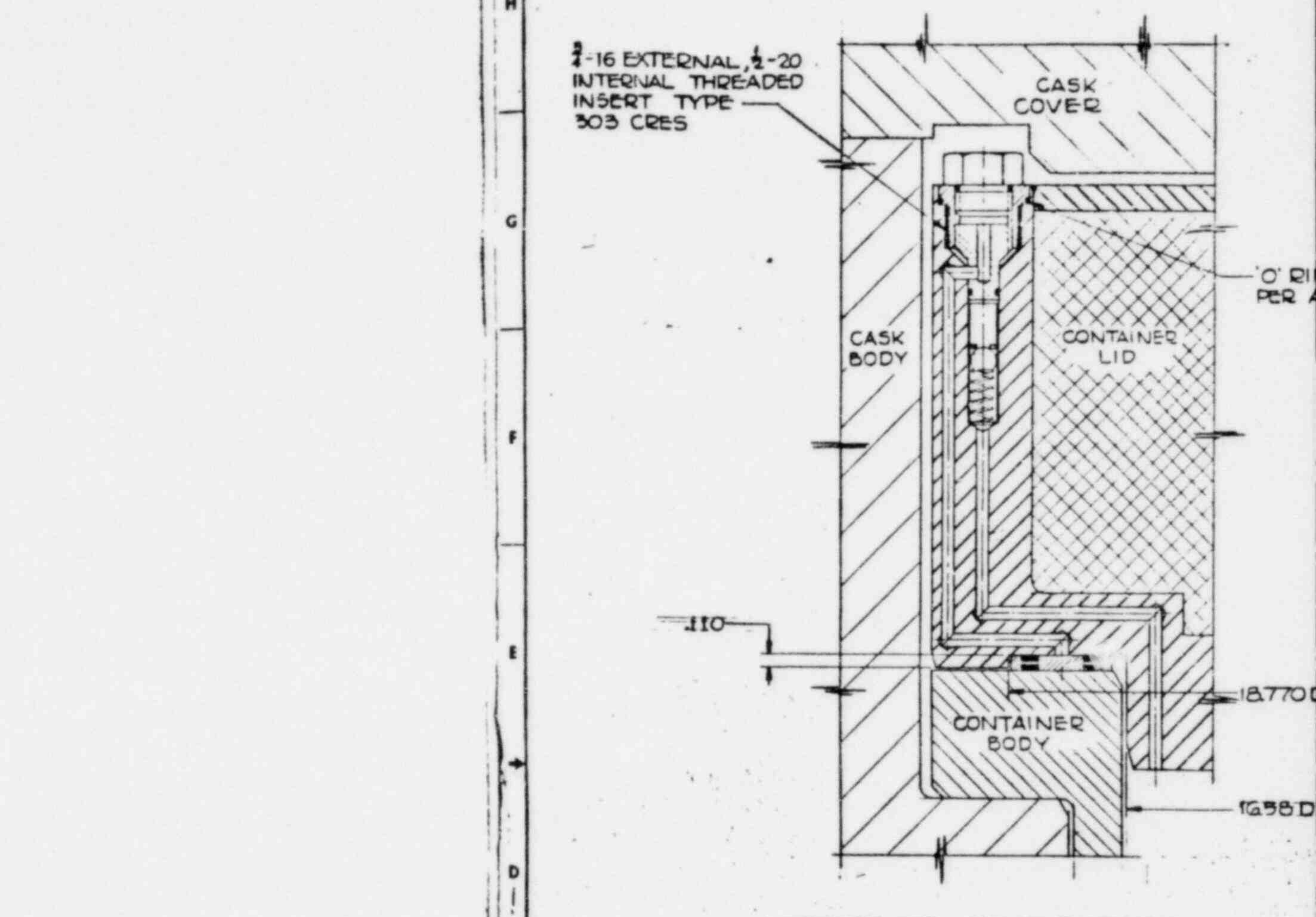
POOR ORIGINAL



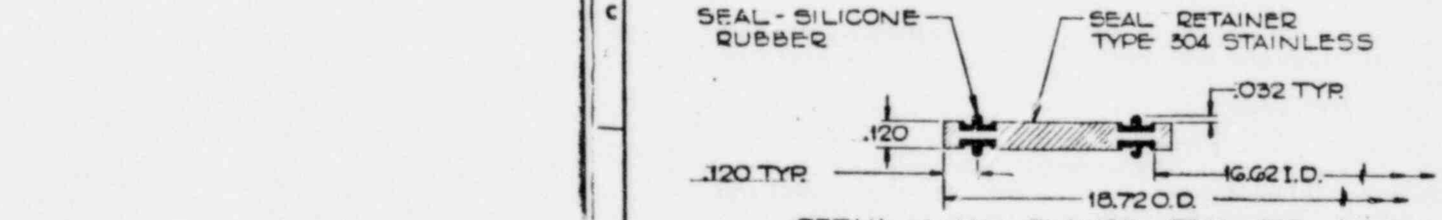
CONTAINER AND
CASK ASS'Y.
TOP SECTION
ALTERNATE CLOSURE

GENERAL ATOMIC
COMPANY

GADR 55-2-2 A

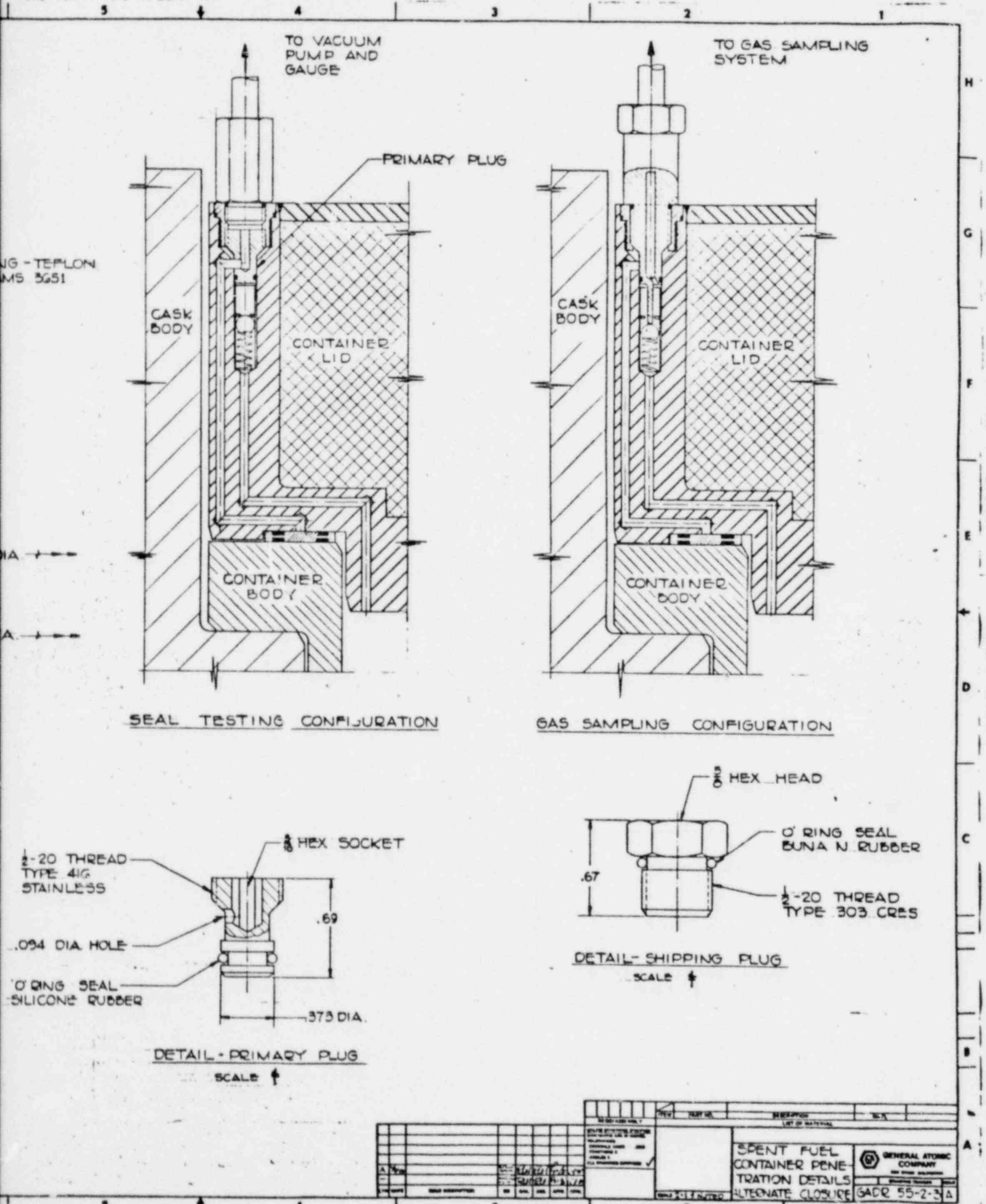


SHIPPING CONFIGURATION



DETAIL - MAIN FLANGE SEAL FOR CONTAINER
SCALE 4/1

POOR ORIGINAL



POOR ORIGINAL

SECTION III

PROPERTIES OF MATERIALS

PROPERTIES OF MATERIALS

Properties of materials used in the fabrication and assembly of the spent fuel containers and lid and the fuel shipping cask and cover are as follows:

A. "As-Cast" Depleted Uranium (.2% Mo)

1. Cylindrical Shield (compression)

Density: 18.9 grams/cc or .683 lb./in^3

Mechanical Properties:	Room Temperature	250°F
Ultimate Tensile Strength	60,000 to 100,000 psi	
Yield Strength	25,000 to 45,000 psi (tens)	73,000 psi (compr.
Reduction in Area	10% to 40%	
Elongation	8% to 15%	
Modulus of Elasticity	Approximately 24 (10)^6 psi	22.73 x 10^6
Poisson's Ratio	Approximately 0.21	
Shear Modulus	Approximately 12 (10)^6 psi	
Hardness	Rockwell B 65 to 90	

Melting Point: 2070°F

Thermal Expansion: 6.5 (10)$^{-6}$ in./in./°F

2. Container Lid (tension properties)

Same properties as above except:

	Room Temperature	300°F
Ultimate Tensile Strength	75,900 psi	59,200 psi
Yield Strength	41,500 psi	36,300 psi
Modulus of Elasticity	23.3 x 10^6 psi	21.1 x 10^6 psi

B. Stainless Steel Pipe, Type 304 per ASTM Spec. A-351, Grade CF-8

Physical Properties:	Room Temp.	250°F	300°F
Density	0.287 lb/in.^{3}		
Specific Gravity	7.94 grams/cc		
Melting Range	2550° to 2650°F		
Modulus of Elasticity	28 x 10^6 psi	27.4 x 10^6 psi	27.1 x 10^6 psi
Specific Heat (32° to 212°F)	0.12 Btu/lb/°F		

Thermal Conductivity:

At 200°F	9.4 Btu/hr/ft^2/°F/ft
At 1000°F	12.5 Btu/hr/ft^2/°F/ft

Mean Coefficient of Thermal Expansion:

32° to 212°F	9.6 in./in./°F x 10^{-6}
32° to 600°F	9.9 in./in./°F x 10^{-6}
32° to 1000°F	10.2 in./in./°F x 10^{-6}

Mechanical Properties:	Room Temp. (72°F)	250°F	300°F
Ultimate Tensile Strength	70,000 psi		
Yield Strength	30,000 psi	23,700 psi	22,500 psi
Elongation	35%		
Reduction of Area (approx)	60%		
Hardness	R_B 88		

C. Stainless Steel Forgings, Type 304 per ASTM Spec. A-182, Grade F-304

Physical Properties:

Same as B, above.

Mechanical Properties:

Ultimate Tensile Strength	70,000 psi
Yield Strength	30,000 psi
Elongation	40%
Reduction of Area	50%
Hardness (approx)	R_B 88

D. ASTM A579 Alloy Steel [HY140(T)]. (Ref. 9) (See also paragraph M)

Physical Properties:	Room Temp.	300°F
Density	0.285 lb/in^3	
Modulus of Elasticity	29.5 x 10^6 psi	28.5 x 10^6 psi
Ultimate Tensile Strength	150,000 psi	140,000 psi
Yield Strength	140,000 psi	130,000 psi
Elongation	15%	

E. 6061-T6 Aluminum Alloy (Ref. 7, Figures 3.0315 and 3.062)

Modulus of Elasticity at 300°F	10.4 x 10^6 psi
Ultimate Tensile Strength at 300°F	35,000 psi
Yield Strength at 300°F	30,000 psi
Elongation at 300°F	20%

F. Douglas Fir Plywood (Refs. 10 through 13)

Crushing Stress parallel to Grain	3500 psi
Crushing Stress perpendicular to Grain	1800 psi
Shear Stress allowable (Ref. 12, table 38)	1000 psi
Tensile Strength perpendicular to Grain (Ref. 13)	340 psi

The crushing stress remains nearly constant up to approximately 50% reduction of the original thickness. Beyond approximately 50% the crushing stress increases rapidly.

For the analysis in Section V, the lower of either the adhesive strength or the wood shear stress parallel to the grain was used for the shear stress allowable.

G. Uranium Welds

All uranium welding will be accomplished using single V-butt joints and inert dc tungsten arc welding. The inert gas used for shielding and trailing shields shall be of welding grade argon. The filler and base metals shall be depleted uranium. Prior to use, filler metal shall be free of oxides and other contamination.

Base metal shall be cleaned of oxides, oil, grease, and other weld contaminants. Each weld bead will be cleaned prior to the deposition of the next weld bead. Final layers of each weld will be liquid-penetrant inspected.

H. Stainless Steel Welds (Refs. 1 and 2)

All stainless steel welds will be in accordance with the "Rules for Construction of Nuclear Vessels" (Ref. 1). All of the welding procedures and welders will be qualified in accordance with "Welding Qualifications" (Ref. 2).

All stainless steel welds will be inspected per Ref. 1. Cracks, porosity, lack of fusion, undercutting, and overlapping will not be acceptable.

I. Seals (Refs. 3 and 4)

1. Gasket Assemblies, Gask-O-Seal, Parker Seal Company.
   Material: Parker Compound S455-70 Silicone rubber or equivalent.

   a) Cask Closure Head Seal - Specification Control Drawing No. 90-H1501-108. O.D. = 23.63"; I.D. = 21.34".

   b) Container Lid Seal - Specification Control Drawing No. 90-H1501-093. O.D. = 18.72"; I.D. = 16.62".

2. All metal "O" rings shall be self-energized for use in bolted flange assemblies. These "O" rings will be made of Inconel tubing. Service temperature is -320° to +1200°F. The following metal "O" rings have been selected for sealing the Fort St. Vrain spent fuel container and fuel shipping cask:

   a) Cask Base Closure Pin Seal - United Aircraft Products, Inc. Cat. No. U-6420-02813-SEA; O.D. = 2.81"; I.D. = 2.56"; Tube Diameter = 0.125".

   b) Cask Helium Connection Cap Seal - United Aircraft Products, Inc. Cat. No. U-6420-02630-SEA; O.D. = 2.62"; I.D. = 2.38"; Tube Diameter = 0.125".

3. All elastomer "O" rings shall be molded per AMS Specification 3304 of silicone rubber. Service temperature for this material is -100° to +500°F. The material will resist temperatures up to 700°F for short periods. The compression force used to install these "O" rings will be as recommended by the manufacturer (Ref. 4). The following silicone rubber "O" rings have been selected for sealing the Fort St. Vrain spent fuel container and fuel shipping cask:

   a) Cask Base Closure Pin Seal - Parco No. PRP-568-236; O.D. = 3.500"; I.D. = 3.25"; Diameter = 0.125".

   b) Cask Helium Connection Cap Seal - Parco No. PRP-568-233; O.D. = 3.125"; I.D. = 2.875"; Diameter = 0.125".

4. All "O" rings are installed in the removable parts of the spent fuel container and fuel shipping cask. This facilitates inspection and replacement and decontamination in the Fort St. Vrain hot service facility.

J. Fasteners (Refs. 5, 6, 7)

1. The bolts used in the assembly of the spent fuel container are high alloy steel per AMS 5737, which corresponds to SA-453, Grade 660 in Ref. 1. These bolts are heat treated to 130KSI min. ultimate tensile strength. The 1/2-inch size used in fastening the spent fuel container lid to the container has a minimum ultimate axial tensile strength of 18,400 lbs.

2. The bolts of the spent fuel container lid are threaded into "screw-lock" inserts made of Type 18-8 stainless steel (per AMS-7245B) wire having an ultimate tensile strength of approximately 200,000 psi. These "screw-lock" inserts meet military specification for locking torque and vibration. The internal thread conforms to thread form standards issued by the Department of Commerce (Ref. 6).

3. The bolts used in the assembly of the cover head to the fuel shipping cask shall be alloy steel per AMS 5737 with the following physical properties for the 1-1/4"-7 UNC size:

Tensile Strength, min.	130,000 psi.
Yield Strength, min.	95,000 psi.

4. The bolts of the cover head are threaded into inserts in the shipping cask head. These inserts are to prolong the life of the threads (since they can be replaced when worn).

K. Iron - Uranium Eutectic Prevention (Ref. 8)

Investigations have shown that uranium combines with stainless steel by solid state diffusion at temperatures above 1000°F. The iron-uranium eutectic melts at 1337°F so that if the two materials are in intimate contact at this temperature a molten alloy will be formed (Ref. 8).

Other investigations have shown that uranium in contact with stainless steel will penetrate the stainless steel by solid state diffusion in 24 hours at 1400°F. At 1355°F there was no attack on the stainless steel.

Recent tests of stainless steel - uranium - stainless steel assemblies wherein the surfaces of the stainless steel next to the uranium were spray coated with a 0.005-inch-thick coating of copper showed this coating to be an effective barrier to diffusion between the stainless steel and uranium at temperatures up to 1750°F (Ref. 8). All surfaces of stainless steel in contact with the depleted uranium shielding will be coated with 0.005-inch-thick copper coating for the Fort St. Vrain Fuel Shipping Casks.

L. Adhesives

The assemblies formed by laminating the plywood and then bonding the laminated plywood to the aluminum end cap are structurally important.

The plywood sheets have been laminated with Resorcinol resin to provide a waterproof joint that is stronger than the wood. Resorcinol is recommended by the American Plywood Association for structural assemblies fabricated in the field designed to withstand adverse environmental conditions.

An epoxy (Furane Epibond 1210/9861) is used between the aluminum end cap and plywood to provide a structural bond with a minimum shear strength of 1200 psi at 230°F for the maximum (130°F ambient) temperature condition. This particular epoxy was selected because it bonds well to diverse materials and retains sufficient strength at elevated temperatures.

Note:

In addition to the data shown above, material properties have been developed for use in the drop analysis of the modified cask (redesigned top closures and impact limiter). These properties consist of parameters defining the stress-strain curves and the strain rate sensitivity at elevated temperature of the following materials:

304 stainless (cask shells, container shell, primary closure)

.2% Mo - uranium alloy (lid and cylinder shield)

ASTM A579 alloy steel (top cask bulkhead).

For details of these materials data: See the stress analysis in Section V.

The original analysis for Addendum I was completed using 4340 Low Alloy Steel for the top cask bulkhead. Because the large billet of 4340 could not be heat treated properly to guarantee the required material conditions, the material was changed to ASTM A579 [HY140(T)]. Table III-1 compares the properties of the two materials. Third column lists test data from the actual material that was used for fabrication of the parts. An analytical check, using the data in column 2, showed the alternate material to be adequate for all conditions covered in this document.

TABLE III-1

FSV-1 SHIPPING CASK ALTERNATE CLOSURE SYSTEM
COMPARISON OF 4340 AND ASTM A579 CASK COVER MATERIAL

Physical Properties	4340	ASTM A579 (Nominal)	ASTM A579 (Actual)
Density, lb/in^3	0.285	0.285	
Modulus of Elasticity, psi			
@ room temp.	-----	29.5×10^6	
@ 300°F	29.0×10^6	28.5×10^6	
Ultimate Tensile Strength, psi			
@ room temp.	175,000	150,000	171,700
@ 300°F	-------	140,000	164,500
Yield Strength, psi			
@ room temp.	165,000	140,000	160,500
@ 300°F	150,000	130,000	154,300
Elongation, %			
@ room temp.	17	15	16.5
@ 300°F	18		13.

REFERENCES

1. *ASME Boiler and Pressure Vessel Code Section III - Nuclear Vessels, The American Society of Mechanical Engineers*, United Engineering Center, N.Y., 1965.

2. *ASME Boiler and Pressure Vessel Code Section IX - Welding Qualifications, The American Society of Mechanical Engineers*, United Engineering Center, N.Y., 1965.

3. "Metallic O-Rings," United Aircraft Products, Inc., Bulletin No. 596191B, Dayton, Ohio, July 15, 1959.

4. "O-Ring Design Handbook," Plastic and Rubber Products Company, Ontario, California.

5. "Bolt, External Wrenching, Self-Retained by Washer," Standard Pressed Steel Company, Jenkintown, Pa., Part Number and Specification 69241, Sheets 1, 2, and 3, March 6, 1968.

6. "Heli-Coil Screw-lock Inserts," Heli-Coil Corporation, Danbury, Connecticut, Bulletin 900.

7. Aerospace Structural Metals Handbook, Dept. of Defense.

8. Clifford. C. B., "Design and Fabrication of a Prototype Laminated Uranium Metal Shipping Cask for Large Shipment of Cobalt-60," USAEC Research and Development Report No. KY-521, Union Carbide Corporation, Nuclear Division, Paducah, Ky., April 3, 1967.

9. Alloy Digest. HY-130 and HY-140(T) Steel Alloy, Filing Code: SA-280. Published by Engineering Alloys Digest Inc., September 1972.

10. Memo: FSV-ME:MKN:42:79, Nichols to Ketchen dtd 4/3/79, "Summary of Plywood Evaluation Tests for the FSV-1 Shipping Cask Impact Limiter."

11. (DELETED)

12. Roark: "Formulas for Stress and Strain", 5th Edition.

13. C. L. Mantell: "Engineering Materials Handbook", 1958, McGraw.

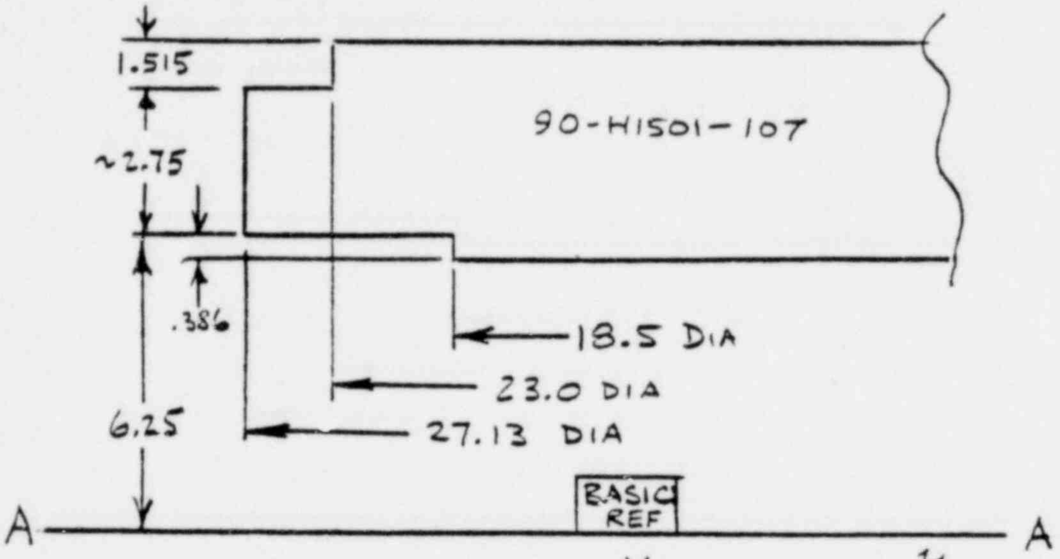
SECTION IV

WEIGHT CALCULATIONS

CALCULATIONS FOR	WTS & MOMENTS - SPENT FUEL CONTAINER & SHIPPING CASK				
EQUIP. NO.	H1501	PROJ. NO. 90		CALC. NO.	PAGE 4-1 OF 4-7
PREPARED BY	M. NICHOLS	DATE	5/11/78	REF. DOCUMENTS:	
REVIEWED BY	P. Anderson	DATE	5-22-78		
APPROVED BY		DATE			

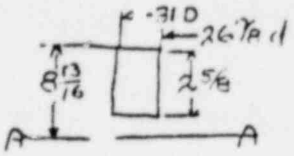
A. CASK CLOSURE HEAD (90-H1501-107)

ASSUME BOLTS ARE IN PLACE AND NEGLECT HOLES AND BOLT HEADS



				V		y		Vy
TOP	23d	$\pi d^2/4 (1.515)$	=	629.4 in³	×	−9.76	=	−6143.
MIDDLE	27.13d	$\pi d^2/4 (2.75)$	=	1589.7 in³	×	−7.63	=	−12130.
BOTTOM	18.5d	$\pi d^2/4 (.386)$	=	103.8 in³	×	−6.06	=	−629.
				2322.9				−18,902.
				× 0.283				× 0.283
			WT =	657.4 LB			M =	−5349. IN-LB

B. <u>CASK</u> - WTS



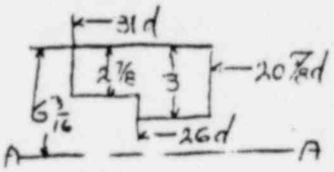
31d $+752\,in^2$

26⅞d -568

$184 \times 2\frac{5}{8} = 483\,in^3 \times -7\frac{1}{2}'' = -3622$

$.29$ $\quad$ $.29$

wt = 140 lbs $\quad$ M = −1050 in lbs



31d $+752\,in^2 \times 2\frac{7}{8} = 2160\,in^3 \times -4\frac{3}{4}'' = -10{,}250.$

26d $+530 \times \frac{1}{8} = 66 \times -3\frac{1}{4} = -216.$

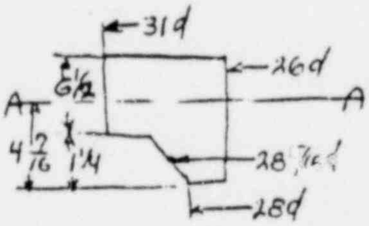
$+2226$ $\quad$ $-10{,}466$

−20⅝d $-335 \times 3 = -1005 \times -4\frac{11}{16} = +4850$

$+1221\,in^3$ $\quad$ $-5616.$

$.29$ $\quad$ $.29$

wt = 354. lbs $\quad$ M = −1628 in lbs



31d $752 \times 6.5 = 4880 \times -\frac{1}{16} = -305.$

28$\frac{5}{16}$d $630 \times 1\frac{1}{4} = 787 \times +3\frac{13}{16} = +3000.$

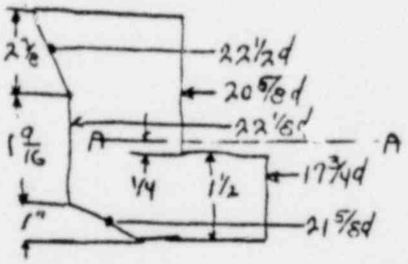
$+5667$ $\quad$ $+2695$

−26d $-530 \times 7\frac{3}{4} = -4100 \times +\frac{9}{16} = -2300$

$+1567\,in^3$ $\quad$ $+395.$

$.29$ $\quad$ $.29$

wt = 455 lbs $\quad$ M = +114 in lbs



22½d $397\,in^2 \times 2\frac{7}{8} = 942\,in^3 \times -2\frac{1}{4} = -2120$

22⅛d $385 \times 1\frac{9}{16} = 601 \times -\frac{9}{32} = -169$

21⅝d $367 \times 1 = 367 \times +1\frac{1}{4} = +458$

$+1910$ $\quad$ -1831

−20⅝d $-335 \times 3\frac{7}{16} = -1154 \times -1\frac{15}{32} = +1670$

−17¾d $-247 \times 1\frac{1}{2} = -370 \times +1 = 370$

-1524 $\quad$ $+1300$

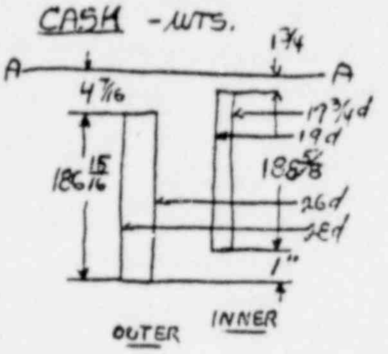
$+386$ $\quad$ -531

$.29$ $\quad$ $.29$

wt = 112 lbs $\quad$ W = −154 in lb

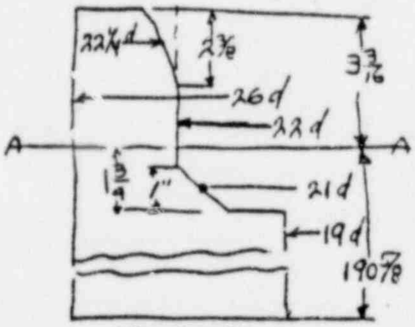
NATIONAL LEAD CO. NUCLEAR DIVISION
WILMINGTON PLANT

CASK - WTS.



28d 613 in²
-26d -530
83 in² × 186 15/16 = 15,500 in³ × +97 29/32 = +1,511,000.
× .29 × .29
(outer) wt 4500 lbs M = +434,000

19d 283.5 in²
-17¾d -247
36.5 in² × 188 5/8 = 6870 in³ × +96.06 = +660,000
× .29 × .29
(inner) wt = 1990 lbs M = 191,200 "lb

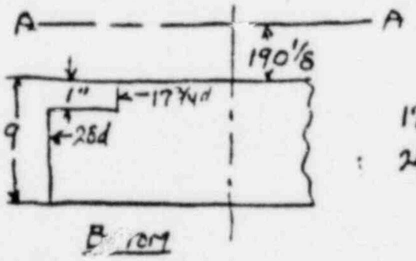


26d 530 in² × 193 13/16 = +102,750 in³ × +93 23/32 = +9,630,000.

-19d -283.5 × 188 7/8 = -53,582 × +96 3/16 = -5,150,000
-21d -346 × 1 = - 346. × +1¼ = - 432
-22d -380 × 1 9/16 = - 594 × -1/32 = + 19
-22¼d -369 × 2 7/8 = - 925 × -2 = + 1850

-55,365 -5,148,563
+47,385 +4,481,437
× .683 × .683

URANIUM wt 32,400 lbs M = +3,060,000"



17¾d 247 in² × 1 = 247 in³ × +190 5/8 = +47,100
28d 613 × 8 = 4904 × +195 1/8 = +960,000
+5151 +1,007,100

wt = × .29 = 1494 lbs M = × .29 = 292,000 in-lb

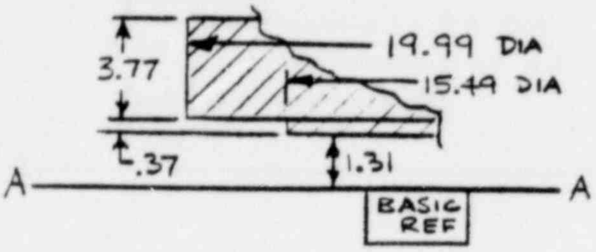
POOR ORIGINAL

CALCULATIONS FOR SPENT FUEL CONTAINER LID			
EQUIP. NO. H1501	PROJ. NO. 90	CALC. NO.	PAGE 4-4 OF 4-7
PREPARED BY M. Nichols	DATE 4/26/78	REF. DOCUMENTS:	
REVIEWED BY P. Anderson	DATE 5-22-78		
APPROVED BY	DATE		

C. CONTAINER WTS

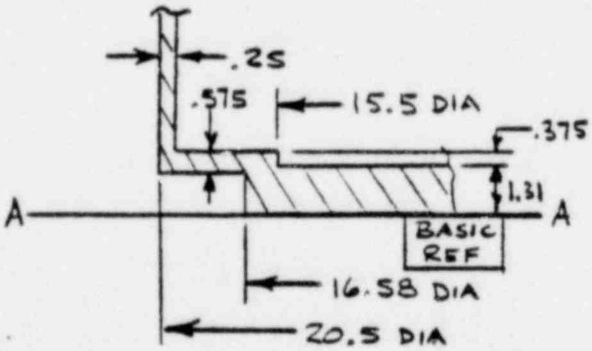
CONTAINER LID - WTS AND MOMENTS (90-H1501-033)

DEPLETED URANIUM (90-H1501-091)



				V	y	Vy
TOP	19.99 d	313.8 in²	× 3.77 =	1183.2 in³	× -3.565 =	-4218.1
BOTTOM	15.49 d	188.4	× .37 =	69.7	× -1.4975 =	-104.4
HOLES	-18(.94)(3.77)(.75)		=	-47.8	× -3.565 =	+170.5
				1205.1		4152.
				× .683		× .683
				WT. = 823.1 LBS		M = -2835.8 IN-LB

S.S. HOUSING (90-H1501-089, 090)



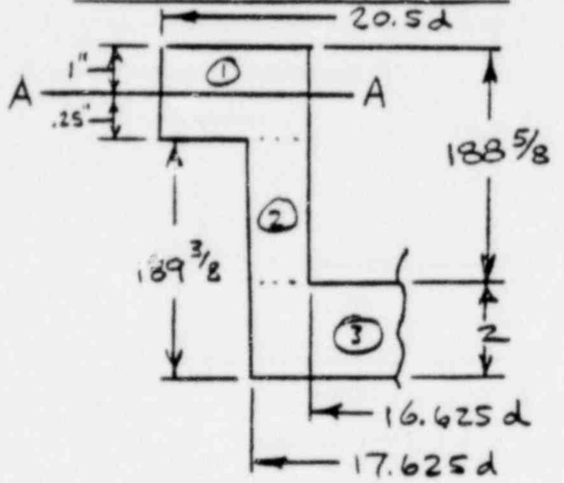
				V	y	Vy
TOP PLATE	20.5d	330 in²	× .25 =	82.5 in³	× -5.585 =	-460.9
CYLINDER	20.25 π × .25		× 4.46 =	70.9	× -3.355 =	-238.
BOTTOM PLATE	16.58d	215.9 in²	× 1.31 =	282.8	× -.655	-185.3
RING AT BOTTOM	20d	314.2	× .575 =	180.6	× 1.3975	-252.4
	-15.5d	188.7	× .575 =	-108.5	× 1.3975	+151.6
BOLTS & SLEEVES	16(3.77)(.75)(.92)		=	41.6	× -3.355	-139.6
				550.		-1124.6
				× .29		× .29
				WT = 159.5 LBS		M = -326.1 IN-LB

TOTALS FOR LID (90-H1501-088)

WT = 982.6 LBS M = -3162 IN-LB

CALCULATIONS FOR WTS & MOMENTS - SPENT FUEL CONTAINER & SHIPPING CASK			
EQUIP. NO. H1501	PROJ. NO. 90	CALC. NO.	PAGE 4-5 OF 4-7
PREPARED BY M. NICHOLS	DATE 5/11/78	REF. DOCUMENTS:	
REVIEWED BY P. Anderson	DATE 5-22-78		
APPROVED BY	DATE		

CONTAINER BODY (90-H1501-32)



	V	y	Vy
① $\frac{\pi}{4}(\overline{20.5}^2-\overline{16.625}^2)(1.25)$ =	141.2 in^3	X −.375 =	−53
② $\pi/4(\overline{17.625}^2-\overline{16.625}^2)(187.375)$ =	5040.4 in^3	X +93.94 =	473,495
③ $\pi/4(17.625)^2(2)$ =	488. in^3	X +188.625 =	92,040
	5669.6		565,482
	X .29		X .29
	WT = 1644.2 LB		M = 163,990 IN-LB

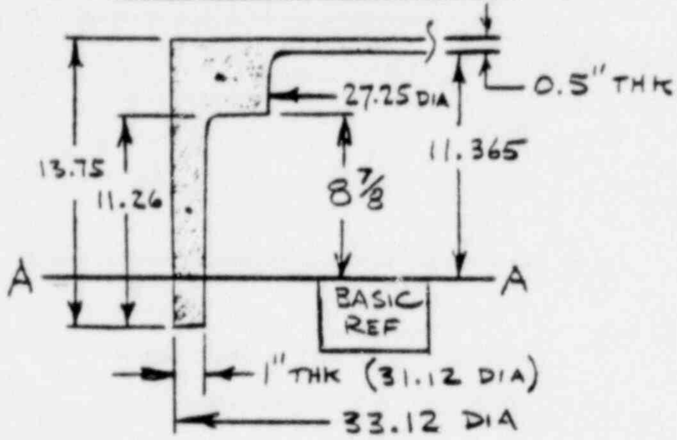
CONTENTS OF CONTAINER

300# × 6 = 1800 LB × 93.844 = 168,919 IN-LB

CALCULATIONS FOR	IMPACT LIMITER - SPENT FUEL SHIPPING CASK				
EQUIP. NO.	H 1501	PROJ. NO.	90	CALC. NO.	PAGE 4-6 OF 4-7
PREPARED BY	M. Nichols	DATE	6/19/78	REF. DOCUMENTS:	
REVIEWED BY	P. Anderson	DATE	6/19/78		
APPROVED BY		DATE	REV PER CN 4114		

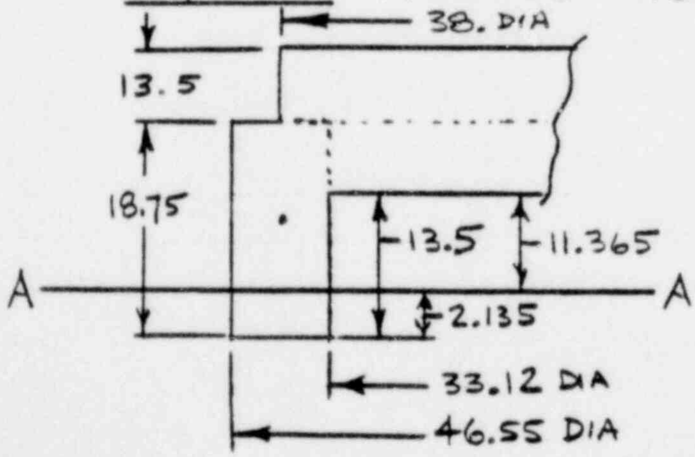
D. IMPACT LIMITER - WTS AND MOMENTS

UPPER END COVER (90-H1501-095)



			V		y	Vy
OUTER	32.12 d	$\pi d(11.26)(1)$	= 1136.2	in³	× -3.245	= -3687.
TOP	27.25	$\pi d^2/4 (0.5)$	= 291.6	in³	× -11.615	= -3387.
REMAINDER	27.25	$\pi(30.185)(2.935)(2.49)$	= 693.0	in³	× -10.12	= -7013.
			2120.8			-14087
			× .098			× .098
			WT = 207.8 LB			M = -1380.5 IN-LB

PLYWOOD (90-H1501-110)



			V		y	Vy
OUTER	39.835 d	$\pi d(6.715)(18.75)$	= 15,757	in³	× -7.24	= -114078.
TOP	38 d	$\pi d^2/4 (13.5)$	= 15,311	in³	× -23.365	= -357,742
INNER	33.12 d	$\pi d^2/4 (5.25)$	= 4523	in³	× -13.99	= -63,277
			35,591			-535,097.
			× .0208			× .0208
			WT = 740.3 LB			M = -11,130. IN-LB

CALCULATIONS FOR IMPACT LIMITER - SPENT FUEL SHIPPING CASK			
EQUIP. NO. H1501	PROJ. NO. 90	CALC. NO.	PAGE 4-7 OF 4-7
PREPARED BY M. Nichols	DATE 6/19/78	REF. DOCUMENTS:	
REVIEWED BY P. Anderson	DATE 6-19-78		
APPROVED BY	DATE REV PER CAI [illegible]		

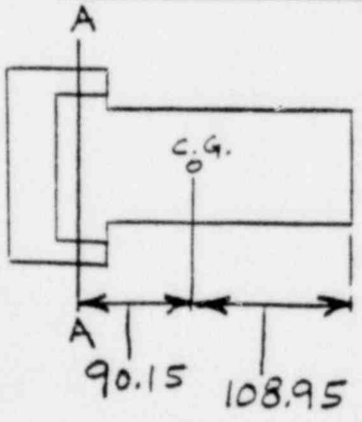
ALUMINUM SHEATH (90-H1501-110)

			V	y	Vy
BOTTOM PLATE	39.835d,	πd(6.715)(0.25)	= 210.1 in³	x+2.26 =	+ +474.8
TOP PLATE	46.55d	πd²/4 (0.25)	= 425.5 in³	x-27.24 =	-11,590.
CYLINDER	46.63d	πd(.06)(32.75)	= 287.9 in³	x-13.99 =	-4027.
MTG RING (90-H1501-106)	30.97d	πd(.63)(2.16)	= 132.4 in³	x 2.8 =	+370.7
	31.34d	πd(.37)(1.78)	= 64.8 in³	x 3.3 =	+214.
			1120.7 in		-14,553
			x .098		x .098
			109.8 LB		-1427

TOTALS FOR IMPACT LIMITER ASSEMBLY WT = 1057.9 LB M = -13,938

$$C.G. = \frac{-13,938}{1057.9} = 13.18 \text{ ABOVE A-A or } 17.18 \text{ BELOW TOP}$$

E. SUMMATION



	WT	MOMENT
HEAD	657.	- 5349.
CASK	140.	- 1050.
	354.	- 1628.
	455.	+114.
	112.	-154.
	4500.	+ 439,000.
	1990.	+ 191,200.
	32,400.	+ 3,060,000.
	1494.	+ 292,060.
CONT LID	983.	- 3162.
CONT BODY	1644	+ 163,990.
CONTENTS	1800	+ 168,919.
IMPACT LIMITER	1058	- 13938

POOR ORIGINAL

CASK TOTAL (LOADED) 47,587 LB 4,290,002 IN-LB

DISTANCE FROM A-A = 4,290,002/47,587 = 90.15"

C.G. IS 108.95" FROM BOTTOM OF CASK

SECTION V

STRESS ANALYSIS

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Stornford	DATE 16 June, 1978	REF. DOCUMENTS:	
REVIEWED BY	DATE		
APPROVED BY	DATE		

SECTION V INDEX

(Continued)

SECTION V INDEX (Continued)

A. DESIGN CRITERIA

The design criteria presented in Regulatory Guide 7.6 (Revision 1, March 1978) were used in the structural analysis of the cask cover and the container lid to verify that the Normal Conditions of Transport and the Hypothetical Accident Conditions of Appendicies A and B respectively, to 10 CFR Part 71 are satisfied.

TABLE V-1 presents a summary of the significant conditions, analytical values and allowables from the structural analysis.

TABLE V-1

Summary of Analysis Values for Normal Conditions of Transport and Hypothetical Accident Conditions

Ref.	Condition	Component	Stress	T($^\circ$F)	Analysis Value	Allowable	Pg
Reg. Guide 7.8 Para. C.1.c and C.3.c	15 psig 600°F (Design)	container lid housing	primary membrane	600	σ = 1,849 psi	Sm = 16,400 psi	5-26
			primary membrane + bending	600	σ = 9,688 psi	1.5Sm= 24,600 psi	5-26
			primary & secondary	600	σ = 9,688 psi	3Sm= 49,200 psi	5-26
			fatigue	600	n = 1,100 cycles	N = 10^6 cycles	5-26
NORMAL CONDITIONS OF TRANSPORT							
10 CFR 71 Appendix A Para. 1	130°F day	container lid top plate	bending	300	σ =22,296 psi	1.5Sm= 30,000 psi	5-30
		container lid top plate outer weld	primary	300	σ = 4,399 psi	Sm= 20,000 psi	5-31
		container lid top plate inner welds	shear	300	T =10,358 psi	0.6Sm= 12,000 psi	5-31
			primary	300	σ = 9,593 psi	Sm= 20,000 psi	5-32
			fatigue	300	n = 600 cycles	N= 60,000 cycles	5-32

TABLE V-1 (cont'd.)

Ref.	Condition	Component	Stress	T(°F)	Analysis Value	Allowable	Pg
10 CFR 71 Appendix A Para. 4	vibration	container lid	fatigue	300	$\sigma = 1{,}450$ psi	endurance limit = 25,400 psi	5-186
Para. 6	1 foot bottom drop	container lid housing	primary membrane	300	$\sigma = 11{,}650$ psi	Sm= 20,000 psi	5-76
		container lid DU shielding	primary membrane	300	$\sigma = 12{,}970$ psi	$Sm=\frac{Su}{3}=$ 19,700 psi	5-76
		cask cover	primary membrane + bending	300	$\sigma = 11{,}420$ psi	$Sm=\frac{Su}{3}=$ 46,700 psi	5-76
			primary and secondary	300	$\sigma = 11{,}420$ psi	3Sm=Su=140,000 psi	5-76
	1 foot side drop	container lid	bearing	300	$\sigma = 3{,}255$ psi	Sm= 20,000 psi	5-120

TABLE V-1 (Cont'd)

Ref.	Condition	Component	Stress	T($^{\circ}$F)	Analysis Value	Allowable	Pg
HYPOTHETICAL ACCIDENT							
10 CFR 71 <u>Appendix B</u> Para. 1	30' free drop bottom impact	container lid	primary membrane + bending	300	σ = 27,860 psi	Su= 66,000 psi	5-74
		cask cover	primary membrane + bending	300	σ = 38,970 psi	Su=140,000 psi	5-74
	30' free drop top impact	cask cover	primary membrane + bending	300	σ = 18,440 psi	Su=140,000 psi	5-124
Para. 2	puncture	cask cover	primary membrane + bending	300	σ = 137,400 psi	Su=140,000 psi	5-116
			puncture <u>force</u>	300	W = 2.5 x 10^6 lb.	P_s=8.06 x 10^6 lb	5-117
10 CFR 71 Appendix A and Appendix B	Normal and Hypothetical Accident	cask cover	extreme total stress intensity	300	σ = 155,900 psi	Sa=400,000 psi	Note (a)
		container lid	extreme total stress intensity	600	σ = 37,600 psi	Sa=650,000 psi	Note (b)

Notes:

(a) Extreme total stress intensity is composite of maximum stress (18,440 psi) from top impact plus maximum stress (137,400 psi) due to puncture.

(b) Extreme total stress intensity is composite of maximum stress (9,688 psi) due to design condition and maximum stress (27,860 psi) due to bottom impact.

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 8 June, 1978	REF. DOCUMENTS:	
REVIEWED BY	DATE [illegible] 16 · 78		
APPROVED BY	DATE		

B. ANALYSIS OF
CONTAINER LID ASSY
FOR PRESSURE & BOLT LOADING

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Hornford	DATE 2 March 1978	REF. DOCUMENTS:	
REVIEWED BY John Gacho	DATE June - 78		
APPROVED BY	DATE		

STRESS ANALYSIS
OF
CONTAINER LID ASSEMBLY

TABLE OF CONTENTS

ITEM PAGE

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Hanford	DATE 2 March, 1978	REF. DOCUMENTS:	
REVIEWED BY John Gacho	DATE June 12 -78		
APPROVED BY	DATE		

LIST OF DRAWINGS

90 - H1501 - 088	CONTAINER LID ASSY
90 - H1501 - 089	HOUSING, CONTAINER LID
90 - H1501 - 090	CONTAINER LID
90 - H1501 - 093	GASKET ASSY, CONTAINER LID

POOR ORIGINAL

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Hornford	DATE 7 March, 1978	REF. DOCUMENTS:	
REVIEWED BY John Glocker	DATE June 12-78		
APPROVED BY	DATE		

STRESS ANALYSIS

90-H1501-088 CONTAINER LID ASSY

DISCUSSION

THE HOUSING, DWG. 90-H1501-089, OF THE CONTAINER LID ASSY, DWG. 90-H1501-088, FORMS THE PRIMARY END CLOSURE OF THE FUEL CONTAINER. THIS ITEM TOGETHER WITH THE 12 SCREWS HAS BEEN ANALYZED FOR AN INTERNAL DESIGN PRESSURE OF 15 PSI AND A DESIGN TEMPERATURE OF 600 °F, REF PG 8-15 & 8-16 (FIRE ACCIDENT COND.).

THE CONTAINER LID, DWG. 90-H1501-090, IS WELDED TO THE HOUSING AS SHOWN IN THE ASSEMBLY DRAWING 90-H1501-088. WHEN ASSEMBLED, THE HOUSING AND LID FORM A LEAK TIGHT CAN PROTECTING THE URANIUM SHIELDING AGAINST OXYDATION. THE LID HAS NO PRIMARY BOUNDARY FUNCTION. IT WILL, HOWEVER, BE EXPOSED TO A DIFFERENTIAL PRESSURE FROM THE AIR TRAPPED IN THE LID ASSY, DURING FUEL LOADING OPERATIONS, WHEN A VACUUM IS PULLED FROM OUTSIDE THE LID. AN INITIAL (BEFORE HEATING) INTERNAL PRESSURE OF 15 PSIG HAS BEEN ASSUMED.

SINCE SOME PRESSURE BUILD-UPS MAY OCCUR IN THE CONTAINER BECAUSE OF INTERNAL HEAT GENERATION IN THE FUEL ELEMENTS, ETC., EVEN WITHOUT A FIRE ACCIDENT, BOTH ITEMS HAVE BEEN CHECKED FOR A TOTAL OF 600 PRESSURE CYCLES. THIS IS BASED ON 3 CASKS, 40 LOADINGS PER YEAR OVER 40 YEARS. PER CASK $= \frac{1}{3} \times 40 \times 40 = 533$, SAY 600. ACTUALLY,

CALCULATIONS FOR FSU SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY O. L. Stanford	DATE 7 March 1978	REF. DOCUMENTS:	
REVIEWED BY John Glachs	DATE June 12-78		
APPROVED BY	DATE		

DISCUSSION, CONT'D.

THE HOUSING HAS FOR SIMPLICITY OF ANALYSIS BEEN CHECKED FOR 1100 CYCLES OF COMBINED PRESSURE AND BOLT LOADING, SEE DISCUSSION OF CONTAINER LID HOUSING ANALYSIS BELOW. THE ANALYSIS HAS BEEN MADE ACCORDING TO RULES IN THE ASME SECT. III CODE FOR NUCLEAR POWER PLANT COMPONENTS (REF. 1).

THE CONTAINER HOUSING AND LID MATERIAL IS TYPE 304 STAINLESS STEEL, SA-240. THE BOLT MATERIAL IS AMS 5735, WHICH CORRESPONDS TO SA-453, GRADE 660 (25 NI, 15 CR HIGH ALLOY STEEL) IN THE CODE.

MATERIAL PROPERTIES PER REF. 1:

MATERIAL	TEMP. (°F)	S_m (psi)	S_y (psi)	S_{ult} (psi)	E (10^6 psi)	ν
SA-240 (HOUSING & LID)	70		30,000	75,000		
	100	20,000				
	300	20,000	22,500		27.1	.3
	600	16,400	18,200		25.4	.3
SA-453 GR. 660 (BOLT)	70		85,000	130,000	29.0	.3
	100	28,300				
	600	27,000	*80,000		26.0	.3

ONLY OPERATING CONDITIONS (REF. 1, FIG. NB-3222-1) HAVE BEEN CONSIDERED IN THIS ANALYSIS. THE DESIGN CONDITION AS DEFINED IN REF. 1, NB-3112, IS IDENTICAL TO THE FIRE ACCIDENT OPERATING CONDITION.

POOR ORIGINAL

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.
EQUIP. NO. PROJ. NO. CALC. NO. PAGE OF
PREPARED BY D. L. Thornfield DATE 7 March, 1978 REF. DOCUMENTS:
REVIEWED BY John Gacho DATE June 12-78
APPROVED BY DATE

90-H 1501-089 CONTAINER LID HOUSING

A SAC MODEL (REF. 5) OF THE HOUSING AND PART OF THE CONTAINER CYLINDER AND FLANGE IS DESCRIBED ON PAGE 5-14. THE STRUCTURE IS MODELLED AS PLATES, CYLINDERS, AND RINGS. A HINGE DUMMY SIMULATES THE STRUCTURAL EFFECT OF THE SEAL (90-H1501-093), WHICH ACTS AS A PIVOT POINT FOR THE HOUSING AND CONTAINER FLANGES. THE SEAL ASSY IS DESIGNED FOR METAL TO METAL CONTACT. DUMMY COMPONENT ⑪ PROVIDES THE EFFECT OF THE LID WHICH IS ANALYZED ON PG. 5-28 & ON.

THE RADIAL SHEAR TRANSFERRED THROUGH DUMMY ⑦ TURNS OUT TO BE RELATIVELY LARGE, SO THAT SOME SLIPPAGE OF THE GASKET WILL OCCUR DURING BOLTING (SEE PG. 5-21). CONSEQUENTLY SAC RUNS WERE MADE FOR AN IDENTICAL MODEL EXCEPT FOR COMPONENT ⑦ BEING AN ISOLATOR (REF. 5, PG. 22) INSTEAD OF A HINGE. CRITICAL STRESSES, WHICH SHOULD BRACKET THE ACTUAL CONFIGURATION, HAVE BEEN LISTED IN THIS REPORT FOR BOTH MODELS.

STRESS INTENSITIES AND -RANGES IN THE HOUSING AND BOLTS WERE COMPUTED BY USE OF THE STRESS 3 CODE (REF. 6). THE BOLTS WILL BE REMOVED AND REINSTALLED TWICE DURING EACH LOADING CYCLE. CONSEQUENTLY A TOTAL NUMBER OF CYCLES OF 2 × 533 = 1066, SAY 1100, HAS BEEN USED IN THE FATIGUE ANALYSIS OF THE HOUSING AND BOLTS.

A STRESS CONCENTRATION FACTOR OF $K = 4.0$ (REF. 1, NB-3232.3 (c)) HAS CONSERVATIVELY BEEN USED WHEREVER A STRESS RAISER EXISTS.

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK, CONTAINER LID.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. L. [illegible]	DATE 7 March, 1978	REF. DOCUMENTS:	
REVIEWED BY John [illegible]	DATE June 12 78		
APPROVED BY	DATE		

90- H1501-089 CONTAINER LID HOUSING, CONT'D.

THE BOLT FATIGUE ANALYSIS IN REF. 6 IS BASED ON THE METHOD DESCRIBED IN ARTICLE N-416(b) OF THE 1965 EDITION OF THE ASME CODE, SECTION III. THE METHOD HAS BEEN REVISED IN LATER EDITIONS OF THE CODE. A HAND CALCULATION BASED ON THE COMPUTER OUTPUT HAS THEREFORE BEEN USED IN THIS REPORT TO DETERMINE THE FATIGUE LIFE OF THE BOLTS IN ACCORDANCE WITH CURRENT RULES IN REF. 1.

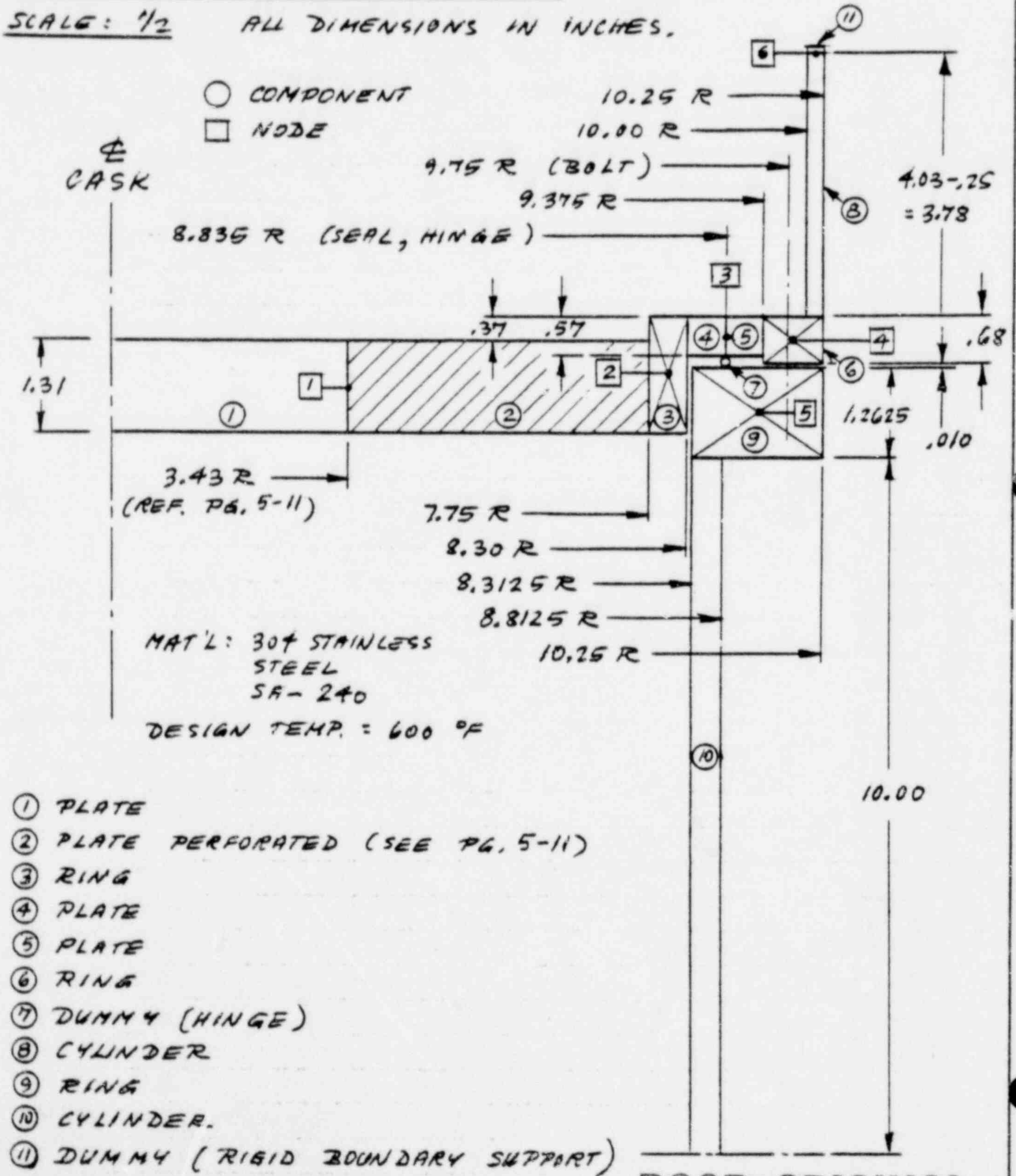
GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR SPENT FUEL CASK. CONTAINER LID.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. L. Stanford	DATE 27 Feb., 1978	REF. DOCUMENTS:	
REVIEWED BY John Gacho	DATE June 13-78		
APPROVED BY	DATE		

CAN AND FLANGE SAC MODEL (REF. 5)

SCALE: 1/2 ALL DIMENSIONS IN INCHES.



MAT'L: 304 STAINLESS STEEL SA-240

DESIGN TEMP. = 600 °F

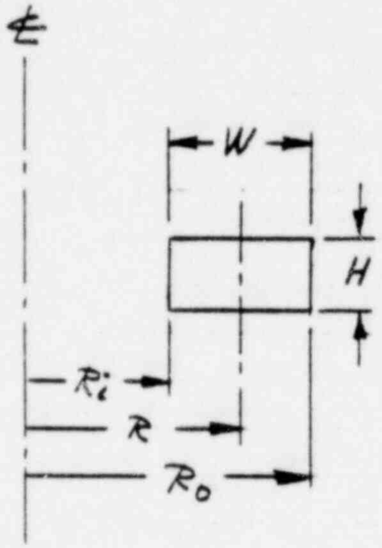
① PLATE
② PLATE PERFORATED (SEE PG. 5-11)
③ RING
④ PLATE
⑤ PLATE
⑥ RING
⑦ DUMMY (HINGE)
⑧ CYLINDER
⑨ RING
⑩ CYLINDER.
⑪ DUMMY (RIGID BOUNDARY SUPPORT)

POOR ORIGINAL

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 28 Feb., 1978	REF. DOCUMENTS:	
REVIEWED BY John [illegible]	DATE June 13-78		
APPROVED BY	DATE		

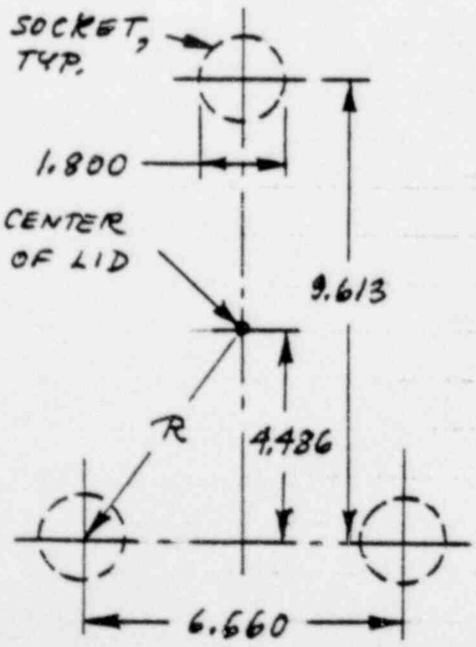
CONTAINER LID HOUSING

SAC MODEL GEOMETRY (INCHES)



COMP.	R_i	R_o	$R = \frac{R_i+R_o}{2}$	$W = R_o - R_i$	H
①	0	* 3.43	1.715	3.43	1.31
②	* 3.43	7.75	5.59	4.32	1.31
③	7.75	8.30	8.025	.55	1.68
④	8.30	8.835	8.5675	.535	.57
⑤	8.835	9.375	9.105	.54	.57
⑥	9.375	10.25	9.8125	.875	.68
⑦	8.835	8.835	8.835	0	.120
⑧	10.00	10.25	10.125	.25	3.78
⑨	8.3125	10.25	9.28125	1.9375	1.2625
⑩	8.3125	8.8125	8.5625	.50	10.00
⑪	10.00	10.25	10.125	.25	0

* PROPERTIES OF ②, PERFORATED PLATE :



CONSERVATIVELY CONSIDER DOWEL PIN SOCKETS AS BEING THROUGH HOLES OF 1.80 IN. DIA.

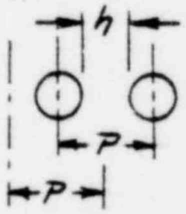
$R = \sqrt{\left(\frac{6.66}{2}\right)^2 + 4.486^2} = \underline{5.59 \text{ IN.}}$

$R_o = 7.75$ IN.

$R_i = R_o - 2(R_o - R)$

$= 7.75 - 2(7.75 - 5.59)$

$= 7.75 - 4.32 = \underline{3.43 \text{ IN.}}$



REF. 1 , A-8131 :

$P = \underline{4.32 \text{ IN.}}$ $h = 4.32 - 1.80 = \underline{2.52 \text{ IN.}}$

$\frac{h}{P} = \frac{2.52}{4.32} = .583$ $\left(\frac{P}{h} = \text{STRESS MULTIPLIER} = \frac{1}{.583} = 1.7143\right)$

REF. 1 , FIG. A-8131-1 :

$\frac{E^*}{E} = .59$, $\nu^* = .288$ $E = 25.4 \times 10^6$ psi @ 600 °F

$E^* = (.59)(25.4)10^6 = \underline{14.99 \times 10^6 \text{ psi}}$

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.			
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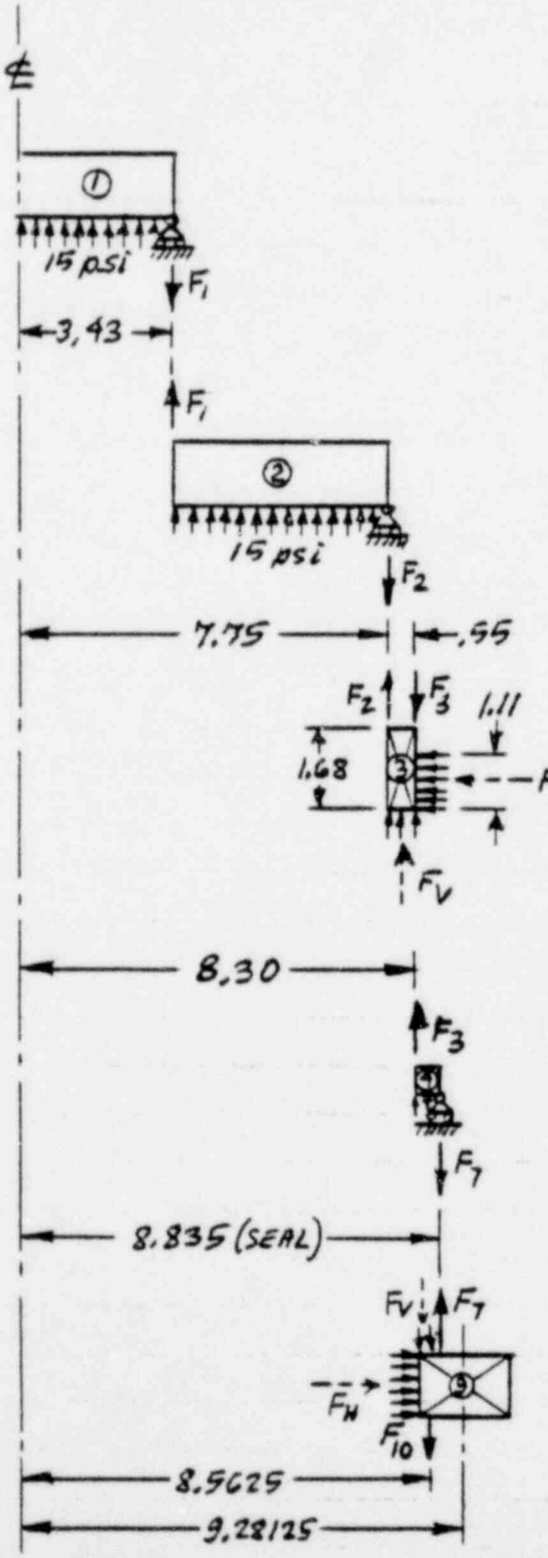
SAC MODEL. LOAD PATH CALCULATIONS.

UNIT LOAD 1: 15 psig PRESSURE



$$F_1 \, 2\pi (3.43) = (15)\pi(3.43)^2$$

$$F_1 = \frac{(15)(3.43)}{2} = \underline{25.725 \ \tfrac{LB}{IN}}$$

$$F_2 \, 2\pi (7.75) = (15)\pi(7.75)^2$$

$$F_2 = \frac{(15)(7.75)}{2} = \underline{58.125 \ \tfrac{LB}{IN}}$$

$$\sim (58.125)\frac{7.75}{8.025}$$

$$= \underline{56.133 \ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ③}$$

$$F_3 = \frac{15(8.30)}{2} = \underline{62.25 \ \tfrac{LB}{IN}}$$

$$\sim (62.25)\frac{8.30}{8.025}$$

$$= \underline{64.383 \ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ③}$$

$$F_V = (15)(.55) = \underline{8.25 \ \tfrac{LB}{IN}}$$

[CHECK: 56.133 + 8.25 = 64.383. O.K.]

$$F_H = (15)(1.11) = \underline{16.65 \ \tfrac{LB}{IN}}$$

$$\sim (16.65)\frac{8.30}{8.025}$$

$$= \underline{17.2206 \ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ③}$$

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SAC MODEL. LOAD PATH CALCULATIONS.

UNIT LOAD 1 = 15 psig PRESSURE, CONT'D.

$$\overset{\curvearrowright}{M_3} = (56.133)\left(\frac{.55}{2}\right) + (64.383)\left(\frac{.55}{2}\right) + (17.2206)\left(\frac{1.68}{2} - \frac{1.11}{2}\right)$$

$$= 15.437 + 17.705 + 4.908 = \underline{38.05 \ \tfrac{IN\,LB}{IN}}$$

$$F_7 = \frac{(15)(8.835)}{2} = \underline{66.2625 \ \tfrac{LB}{IN}}$$

$$\left[\begin{array}{l} W = \pi r^2 \omega = \pi (8.835)^2 (15) = \underline{3678 \ LB} \\ F_2 = \dfrac{W}{2\pi r} = \dfrac{3678}{2\pi (8.835)} = \underline{66.2625 \ \tfrac{LB}{IN}} \end{array}\right]$$

$$F_7 = 66.2625 \ \tfrac{LB}{IN} \sim (66.2625)\frac{8.835}{9.28125} = \underline{63.08 \ \tfrac{LB}{IN}} \text{ @ CENTER OF ⑨}$$

$$F_{10} = \frac{\pi (8.3125)^2 (15)}{2\pi (8.5625)} = \underline{60.52 \ \tfrac{LB}{IN}} \sim (60.52)\frac{8.5625}{9.28125} = \underline{55.84 \ \tfrac{LB}{IN}}$$

@ CENTER OF RING ⑨

$$F_V = 15 (8.835 - 8.3125) = 7.84 \ \tfrac{LB}{IN} \sim (7.84)\frac{8.57375}{9.28125}$$

$$= \underline{7.24 \ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ⑧}$$

[CHECK : 63.08 − 55.84 − 7.24 = 0 . O.K.]

$$F_H = (15)(1.2625) = 18.94 \ \tfrac{LB}{IN} \sim (18.94)\frac{8.3125}{9.28125}$$

$$= \underline{16.96 \ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ⑨}$$

$$\overset{\curvearrowright}{M_9} = (63.08)(9.28125 - 8.835) - (55.84)(9.28125 - 8.5625)$$

$$-(7.24)(9.28125 - 8.57375$$

$$= 28.148 - 40.132 - 5.122 = \underline{-17.11 \ \tfrac{IN\,LB}{IN}}$$

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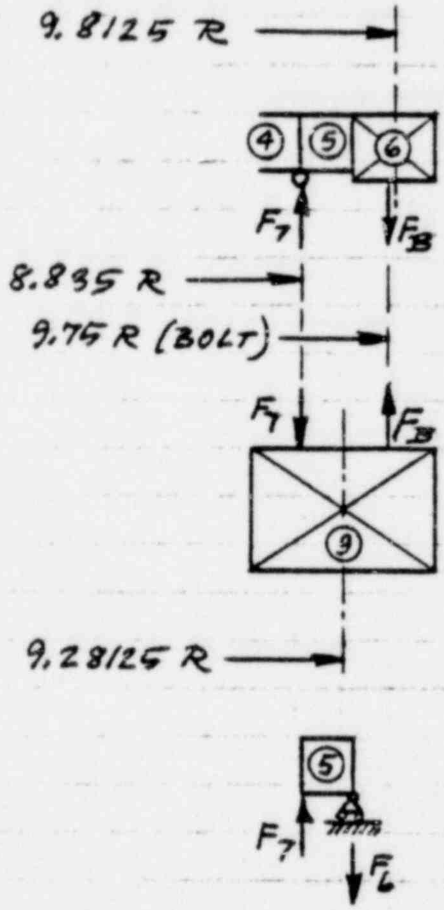
SAC MODEL. LOAD PATH CALCULATIONS.

UNIT LOAD 2 : 10,000 LB BOLT LOAD



12 BOLTS OF 10000 LB EACH :

$$F_B = \frac{(12)\ (10000)}{2\pi\ (9.75)} = \underline{1958.8\ \tfrac{LB}{IN}}$$

$$F_7 = \frac{(12)\ (10000)}{2\pi\ (8.835)} = \underline{2161.4\ \tfrac{LB}{IN}}$$

$$\sim (2161.4)\frac{8.835}{9.28125}$$

$$= \underline{2057.8\ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ⑨}$$

$$F_6 = \frac{(12)\ (10000)}{2\pi\ (9.375)} = 2037.2\ \tfrac{LB}{IN}$$

$$\sim (2037.2)\frac{9.375}{9.8125}$$

$$= \underline{1946.4\ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ⑥}$$

$$F_B = 1958.8\ \tfrac{LB}{IN} \sim (1958.8)\frac{9.75}{9.8125}$$

$$= \underline{1946.4\ \tfrac{LB}{IN}}$$

@ CENTER OF RING ⑥

$$\overset{\curvearrowright}{M_6} = (1946.4)(9.8125 - 9.375) - (1946.4)(9.8125 - 9.75)$$

$$= 851.53 - 121.65 = \underline{729.9\ \tfrac{IN\ LB}{IN}}$$

$$F_B = 1968.8\ \tfrac{LB}{IN} \sim 1958.8\ \frac{9.75}{9.28125} = \underline{2057.8\ \tfrac{LB}{IN}} \text{ @ CENTER OF RING ⑨}$$

$$\overset{\curvearrowright}{M_9} = -(2057.8)(9.28125 - 8.835) - (2057.8)(9.75 - 9.28125)$$

$$= -918.28 - 964.58 = \underline{-1882.9\ \tfrac{IN\ LB}{IN}}$$

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CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.

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CONTAINER LID HOUSING

BOLTS. STRESS-3 INPUT DATA

NEEDED TO REACT 15 psi PRESSURE AND COMPRESS SEAL: ~1000 LB / BOLT.

TORQUE $T = 20$ FT LB $= 20 \times 12 =$ 240 IN LB

13 UNC : COARSE THREADS ($\frac{1}{2}$ IN. DIA. SCREW)

$f = .15^{*}$ $K = .098585$ PER REF. 4

$P =$ AXIAL LOAD OF SCREW $= \frac{T}{K} = \frac{240}{.098585} =$ 2434 LB

STRESS AREA $= A =$ .1416 IN^2

CORRESP. DIA. $D = \sqrt{A \frac{4}{\pi}} = \sqrt{(.1416) \frac{4}{\pi}} =$ .4246 IN

UNIT BOLT LOAD PRE-STRESS : $\sigma = \frac{10{,}000 \text{ LB}}{.1416 \text{ IN}^2} =$ 70 621 psi

[ACTUAL PRE-STRESS : $\sigma = \frac{2434}{.1416} =$ 17 192 psi
< ALLOWABLE = 2S = 54000 psi @ 600°F]

* VALUE FOR AVERAGE BOLTS AND NUTS PER REF. 8, PG. 246.

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GENERAL ATOMIC COMPANY

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CONTAINER LID HOUSING

STRESS 3 MODEL (REF. 6)

UNIT LOAD FACTORS

NO. ↓	NO. → UNIT LOAD OPERATING CONDITION (LOAD SET)	1	2
		15 psig PRESSURE	10 000 LB BOLT LOAD
1	FIRE ACCIDENT	1.0	.2434
2	ZERO LOAD	0	0

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.

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SAC MODEL

CHECK OF HINGE ASSUMPTION (COMP. ⑦)

REF. SAC-OUTPUT FOR COMP. ⑦ OF HINGE MODEL:

$$S = \underset{\text{(END 1)}}{\text{RADIAL SHEAR}} = S_{PRESSURE} + (.2434)\,S_{BOLT}$$

$$= -16 + (.2434)(-934)$$

$$= -16 - 227 = \underline{-243\ ^{LB}/_{IN}}$$

REF. LOAD PATH CALCULATIONS, PG. 5-16 → 5-18:

$$F = \text{AXIAL COMPRESSION} = F_{7,PRESSURE} + (.2434)\,F_{7,BOLT}$$

$$= -66.2625 + (.2434)(2161.7)$$

$$= -66 + 526 = \underline{460\ ^{LB}/_{IN}}$$

$$|S| = 243 > (.2)\,F = (.2)(460) = 92\ ^{LB}/_{IN}$$

(SLIPPAGE WILL OCCUR)

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.			
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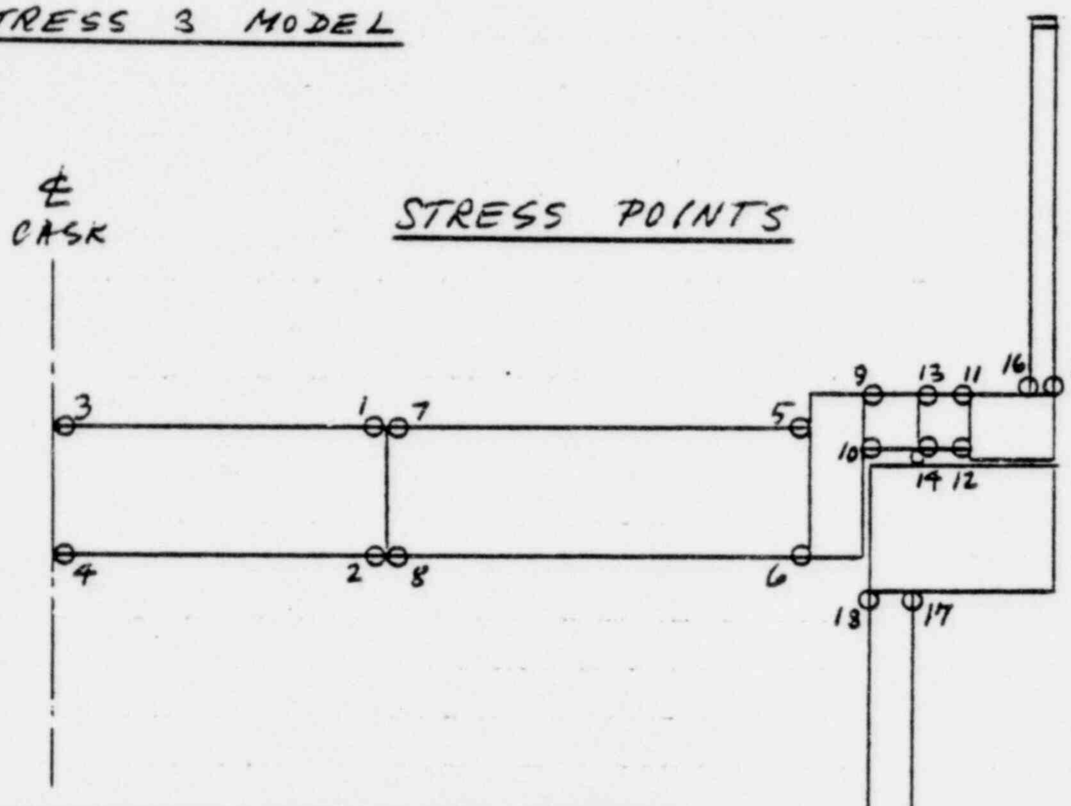
CONTAINER LID HOUSING

STRESS 3 MODEL

STRESS POINTS



POINT	COMP.	IDENT.	STRESS MULTIPLIER	STRESS CONCENTR. FACTOR (CONSERV.)
1	1	5 UPP	1.0	1.0
2	1	5 LWP	↕	↕
3	1	1 UPP		
4	1	1 LWP	1.0	1.0
5	2	5 UPP	1.7143	4.0
6	2	5 LWP	↕	↕
7	2	1 UPP		
8	2	1 LWP	1.7143	4.0
9	4	1 UPP	1.0	1.0
10	4	1 LWP	↕	4.0
11	5	5 UPP		4.0
12	5	5 LWP		4.0
13	5	1 UPP		1.0
14	5	1 LWP		4.0
15	8	1 OTC		1.0
16	8	1 INC		4.0
17	10	5 OTC		4.0
18	10	5 INC	1.0	1.0

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CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.			
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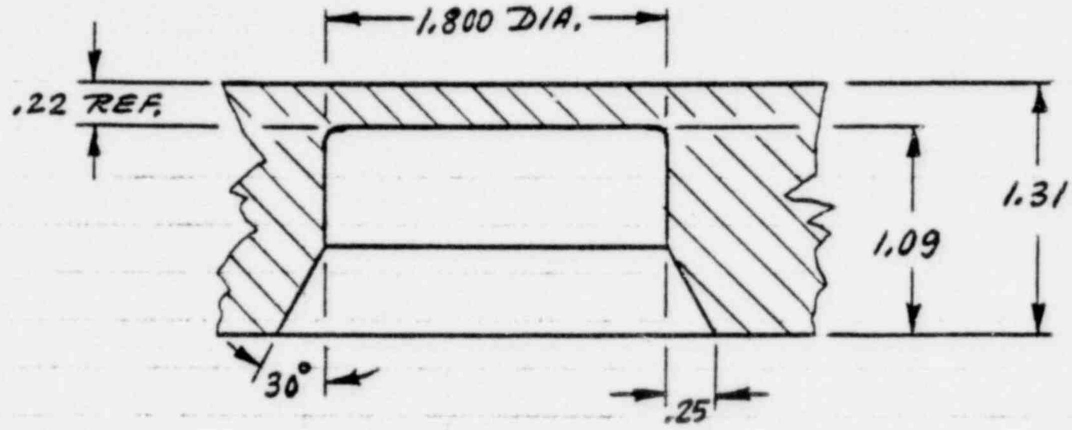
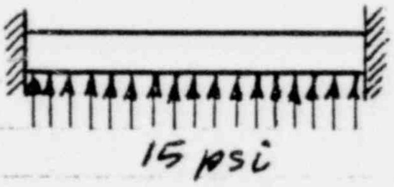
<u>90-H1501-089 CONTAINER LID HOUSING</u> (PRIMARY CLOSURE).

STRESS CHECK OF <u>BOTTOM PLATE</u> OF DOWEL PIN <u>SOCKET</u>:





CIRCUMFERENCE SHEAR:

$$W = \omega \pi a^2 = (15)\pi(.90)^2 = 38.17 \text{ LB}$$

$$\tau = \frac{W}{2\pi a t} = \frac{38.17}{2\pi(.90)(.22)} = \underline{31} \text{ } \underline{psi} \text{ (SMALL)}$$

BENDING PER REF. 3, PG. 195 (CASE 6):

$$\text{MAX. } S_r = \frac{3W}{4\pi t^2} = \frac{3(38.17)}{4\pi(.22)^2} = \underline{188} \text{ } \underline{psi} \text{ (SMALL)}$$

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CONTAINER LID HOUSING

SUMMARY OF CRITICAL STRESSES PER STRESS-3 OUTPUT. HINGE MODEL (COMP. ⑦)

ALL STRESSES (EXCEPT PEAK) TREATED AS PRIMARY.

HOUSING

PRIMARY MEMBRANE STRESS INTENSITY (POINTS 15 & 14):

$S = \underline{1794 \text{ psi}} < \text{ALLOWABLE} = S_m = 16400 \text{ psi} @ 600\,°F$

PRIMARY MEMBRANE + BENDING STRESS INTENSITY = LARGEST RANGE (POINTS 15 & 16):

$S = \underline{9262 \text{ psi}} < \text{ALLOWABLE} = 1.5\,S_m = 24600 \text{ psi} @ 600\,°F$

PEAK STRESS INTENSITY RANGE (POINT 16, LOAD SETS 1-2):

$2S_{alt} = \underline{37048 \text{ psi}}$

$$S_{alt}\frac{E_{curve}}{E_{mat'l}} = \frac{1}{2}(37048)\frac{26.0}{25.4} = \underline{18962 \text{ psi}}$$

ALLOWABLE : $N > 10^6$ CYCLES PER REF. 1, FIG. I-9.2
APPLIED : $n = 1100$

$$U = \frac{n}{N} < \frac{1100}{10^6} = \underline{.001} < 1.0 \quad . \quad \text{O.K.}$$

BOLT

FORCE REQUIRED TO COMPRESS A SINGLE SEAL: $30-150\ \frac{oz}{in}$ PER REF. 7, PARKER GASK-O-SEAL HANDBOOK OSD 5411 (1977), PG. 9.

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CONTAINER LID HOUSING, CONT'D.

90-H1501-093 GASKET ASSY HAS TWO BEADS,

GASKET COMPRESSION LOAD $\leq (2)(150) = 300 \frac{LB}{IN}$

PRESSURE LOAD $F_z = 66.2625 \frac{LB}{IN}$

TOTAL LOAD $\leq (300 + 66.2625)\, 2\pi\, (8.835) = 20\,332$ LB

$\therefore \sim \frac{20\,332}{12} = \underline{1694}$ LB/BOLT

BOLT STRESS AREA $= .1416$ IN^2

REF. 1, NB-3230:

$\sigma_t \leq \frac{1694}{.1416} = \underline{11\,966}$ psi < ALLOWABLE $= S_m = 27\,000$ psi @ 600 °F

PRESTRESS (REF. PG.) = MAX. SERVICE STRESS PER REF. 1, NB-3232.1:

$\sigma_t = \frac{2434}{.1416} = \underline{17\,192}$ psi < ALLOWABLE $= 2 S_m = 54000$ psi @ 600 °F

MAX. STRESS PER REF. 1, NB-3232.2 (REF. C.P.O.):

$\sigma_{MAX} = \underline{39\,786}$ psi < ALLOWABLE $= 3\, S_m = 81000$ psi @ 600 °F

$[\sigma_{MAX} < 2.7\, S_m = (2.7)(27{,}000) = 72\,900 \text{ psi}]$

PEAK STRESS INTENSITY RANGE PER C.P.O.: $2\, S_{alt}$

$$S_{alt} \frac{E_{CURVE}}{E_{BOLT}} = \frac{1}{2} K [\sigma_{MAX} - 0] \left(\frac{E_{CURVE}}{E_{BOLT}}\right) = \frac{1}{2}(4)(39786)\frac{30.0}{26.0}$$

$= \underline{91\,814}$ psi

ALLOWABLE : $N = 1200$ CYCLES PER REF. 1, FIG. I-9.4
APPLIED : $n = 1100$

$$U = \frac{n}{N} = \frac{1100}{1200} = \underline{.917} < 1.0. \quad \text{O.K.}$$

CALCULATIONS FOR FSU SPENT FUEL SHIPPING CASK. CONTAINER LID.			
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CONTAINER LID HOUSING, CONT'D.

SUMMARY OF CRITICAL STRESSES PER STRESS-3 OUTPUT, CONT'D.

ISOLATOR MODEL (COMP. ⑦)

ALL STRESSES (EXCEPT PEAK) TREATED AS PRIMARY.

HOUSING

PRIMARY MEMBRANE STRESS INTENSITY (POINTS 13 & 14):

$S = \underline{1849}$ psi < ALLOWABLE $= S_m = 16400$ psi @ 600 °F

PRIMARY MEMBRANE + BENDING STRESS INTENSITY = LARGEST RANGE (POINTS 15 & 16):

$S = \underline{9688}$ psi < ALLOWABLE $= 1.5\, S_m = 24600$ psi @ 600 °F

PEAK STRESS INT[illegible]TY RANGE (POINT 16. LOAD SETS 1-2):

$2\, S_{alt} = \underline{38752}$ psi

$$S_{alt} \frac{E_{curve}}{E_{MAT'L}} = \left(\frac{1}{2}\right)(38752)\frac{26.0}{25.4} = \underline{19\,834} \text{ psi}$$

ALLOWABLE : $N > 10^6$ CYCLES PER REF. 1, FIG. I-9.2

APPLIED : $n = 1100$

$$U = \frac{n}{N} < \frac{1100}{10^6} = \underline{.001} < 1.0 \quad . \quad \text{O.K.}$$

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CONTAINER LID HOUSING, CONT'D.

ISOLATOR MODEL (COMP. ⑦), CONT'D.

BOLT

STRESSES SAME AS FOR HINGE MODEL EXCEPT AS SHOWN BELOW:

MAX. STRESS PER REF. 1, NB-3232.2 (REF. C.P.O.):

$\sigma_{max} = \underline{41\,368\ psi} <$ ALLOWABLE $= 3\,S_m = 81\,000$ psi @ 600 °F

$[\sigma_{max} < 2.7\,S_m = (2.7)(27\,000) = 72\,900$ psi$]$

PEAK STRESS INTENSITY RANGE PER C.P.O.: $2\,S_{alt} = K[\sigma_{max} - 0] = (4)[41\,368 - 0]$

$$S_{alt}\frac{E_{CURVE}}{E_{MAT'L}} = \frac{1}{2}K[\sigma_{max} - 0]\frac{E_{CURVE}}{E_{MAT'L}} = \frac{1}{2}(4)(41\,368)\frac{30.0}{26.0} = \underline{95\,463}\ \underline{psi}$$

ALLOWABLE: $N = 1100$ CYCLES PER REF. 1, FIG. I-9.4

APPLIED: $n = 1100$

$$U = \frac{n}{N} = \frac{1100}{1100} = \underline{1.0}.\quad O.K.$$

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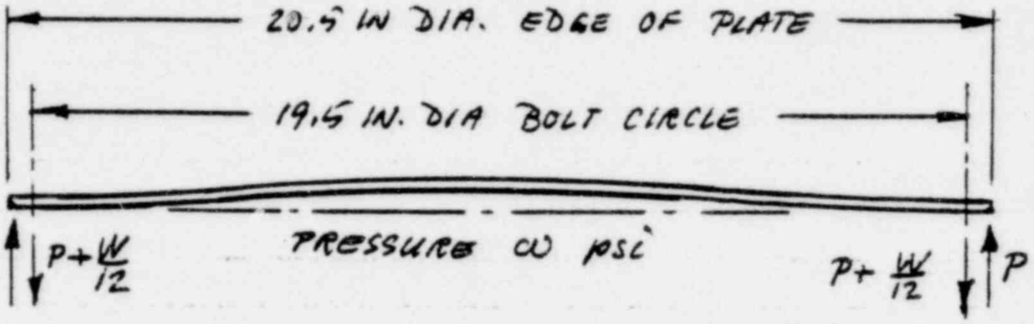
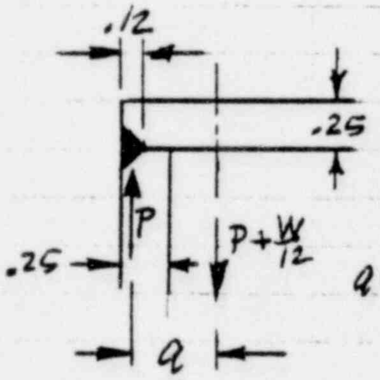


EDGE REACTIONS SHOWN ARE PER BOLT.

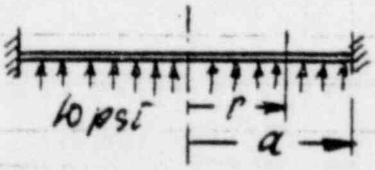


$a = .5 - \frac{.12}{2} = .44$ IN.

EDGE DETAIL
TYP. 12 PLACES

CHECK FOR A UNIT FINAL PRESSURE (UNDER DEFLECTED LID) OF $\omega = 10$ psi.

REF. 3, CASE 6, PG. 195:



MAX. S_r (@ EDGE): $S_r = \frac{3W}{4\pi t^2}$

$W = \omega \pi a^2 = (10)\pi(10.25)^2 = \underline{3301 \text{ LB}}$

MAX $S_r = \frac{(3)(3301)}{4\pi(.25)^2} = \underline{12,608 \text{ psi}}$

(ALLOWABLE $= 1.5\ S_m = (1.5)(20,000)$
$= \underline{30,000}$ psi @ 300°F)

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90 - H 1501 - 090 CONTAINER LID, CONT'D.

MAX. DEFLECTION @ CENTER : $y = \frac{3W(m^2-1)a^2}{16\pi E m^2 t^3}$

$m = \frac{1}{\nu} = \frac{1}{.3} = 3.333$

$m^2 = 11.111$

$y = \frac{(3)(3301)(10.111)(10.25)^2}{16\pi(27.1)(10^6)(11.111)(.25)^3} = \underline{.0445 \text{ IN.}}$

[$y = .0445 < \frac{1}{2}t = \frac{1}{2}(.25) = .125$. COMMON CASE FORMULAS APPLY, REF. 3, PG. 192].

TRAPPED GAS VOLUME BEFORE DEFLECTION OF LID (MAX. GAPS = .025 IN.):

$V_1 \sim (.025 + .025)\left[\frac{\pi}{4}(20.00)^2\right] + (.025)\,\pi\,(20.00)(4.40)$

$= 15.71 + 6.91 = \underline{22.62 \text{ IN}^3}$

VOLUME UNDER DEFLECTED LID : $\Delta V = \int_0^a 2\pi r\, y\, dr$

$y = \frac{3W(m^2-1)}{16\pi E m^2 t^3}\left[\frac{(a^2-r^2)^2}{a^2}\right]$

$= K\left[a^4 + r^4 - 2a^2r^2\right]$

$K = \frac{3W(m^2-1)}{16\pi E m^2 t^3 a^2} = \frac{3(3301)(10.111)}{16\pi(27.1)(10^6)(11.111)(.25)^3(10.25)^2} = 4.029 \times 10^{-6}$

$\Delta V = 2\pi K \int_0^a r\left[a^4 + r^4 - 2a^2r^2\right] dr$

$= 2\pi K\left[a^4\frac{a^2}{2} + \frac{a^6}{6} - 2a^2\frac{a^4}{4}\right]$

$= 2\pi K\frac{a^6}{6} = \underline{\frac{1}{3}\pi K a^6} = \underline{\frac{W(m^2-1)a^4}{16 E m^2 t^3}}$ (IN^3)

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<u>90-H1501-090 CONTAINER LID</u>, CONT'D.

FOR $w = 10$ psi : $\Delta V = \dfrac{(3301)(10.111)(10.25)^4}{16\,(27.1)(10^6)(11.111)(.25)^3} = \underline{4.8936 \text{ in}^3}$

INITIAL PRESSURE $= p_1$ psi $\qquad V_1 = 22.62 \text{ in}^3$

AFTER DEFLECTION OF LID:

$p_2 = 10$ psi $\qquad V_2 = V_1 + \Delta V$

$= 22.62 + 4.8936$

$= 27.5136 \text{ in}^3$

$$p_1 = p_2 \frac{V_2}{V_1} = (10)\frac{27.5136}{22.62} = \underline{12.16} \text{ psi}$$

ACTUAL p_1 FOR UNDEFLECTED LID @ 300 °F BASED ON 15 psia @ 70 °F :

$$p_{70} = 15 \text{ psi} = \left(\frac{R}{V}\right) T_{70}$$

$$p_{300} = \left(\frac{R}{V}\right) T_{300} = \left(\frac{p_{70}}{T_{70}}\right) T_{300}$$

$T_{70} = 70 + 460 = 530$ °R $\qquad T_{300} = 300 + 460 = 760$ °R

$$p_{300} = \left(\frac{15}{530}\right)(760) = \underline{21.51} \text{ psi}$$

AFTER DEFLECTION OF LID : $p = (21.51)\dfrac{10.00}{12.16} = \underline{17.68} \text{ psi}$

= DESIGN PRESSURE

STRESSES AND DEFLECTIONS ARE PROPORTIONAL TO p:

MAX. $S_r = \left(\dfrac{17.68}{10.00}\right)(12608) = \underline{22,296 \text{ psi}} < 1.5\,S_m = 30,000$ psi @ 300 °F

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK. CONTAINER LID.			
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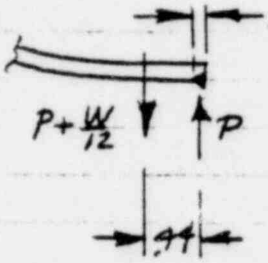
PREPARED BY P. L. [illegible]	DATE 22 Feb., 1978	REF. DOCUMENTS:	
REVIEWED BY John Glacho	DATE June 12-78		
APPROVED BY	DATE		

90- H1501-090 CONTAINER LID, CONT'D.

$$W = (3301)\left(\frac{17.68}{10.00}\right) = \underline{5837 \text{ LB}}$$

MAX. y (CENTER) : $(.0445)(1.768) = \underline{.0787 \text{ IN.}} < \frac{1}{2}t = .125$ IN.
(COMMON CASE FORMULAS APPLY, REF. 3 PG. 192)



$$S_r = \frac{6M}{t^2} \;;\quad M = \frac{S_r t^2}{6} = \frac{(22296)(.25)^2}{6} = \underline{232 \ \frac{\text{IN LB}}{\text{IN}}}$$

LENGTH OF CIRCUMFERENCE : $L = \pi D = \pi(20.5) = 64.4$ IN.

TOTAL $M = (64.4)(232) = 14960$ IN LB

PER BOLT : $\frac{14960}{12} = \underline{1246 \text{ IN LB}}$

$$(P)(.44) = 1246 \;;\quad P = \frac{1246}{.44} = \underline{2833 \text{ LB}}$$

STRESS IN OUTER CIRCUMFERENCE WELD :

$$\sigma_C = \frac{P}{\left(\frac{L}{12}\right)(.12)} = \frac{(12)(2833)}{(64.4)(.12)} = \underline{4399 \text{ psi}} < S_m = 20{,}000 \text{ psi}$$

$$P + \frac{W}{12} = 2833 + \frac{5837}{12} = 2833 + 486 = \underline{3319 \text{ LB}}$$

STRESS IN .85 IN. DIA. SHEAR WELD AROUND SCREW HOLE :

$$\tau = \frac{3319}{\pi(.85)(.12)} = \underline{10{,}358 \text{ psi}} < \text{ALLOWABLE} = (.6)(20{,}000) = 12{,}000 \text{ psi}$$

(REF. 1, NB-3227.2)

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK, CONTAINER LID.			
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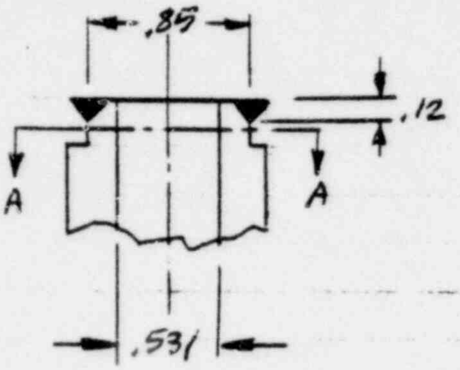
90- H 1501 - 090 CONTAINER LID, CONT'D.



SECTION A-A:

$$AREA = \frac{\pi}{4}(.85^2 - .531^2) = .3460 \text{ IN.}^2$$

$$\sigma_t = \frac{3319}{.3460} = \underline{9,593} \text{ psi} < S_m = 20,000 \text{ psi}$$

FATIGUE CHECK OF CIRCULAR SHEAR WELD:

ASSUME $K = 4$, STRESS INTENSITY RANGE = $(K)(2\tau - 0)$

$$2 S_a = (4)(2\tau) = (4)(2)(10,358) = 82,860 \text{ psi}$$

$$S_a = 41,430 \text{ psi} . \quad S_a \frac{26.0}{27.1} = 39,800 \text{ psi}$$

$N = 60,000$ CYCLES PER REF. 1, FIG. I-9.2

$n = 600$

$$U = \frac{n}{N} = \frac{600}{60,000} = \underline{.010} < 1.0 . \quad \text{O.K.}$$

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CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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CASK COVER HEAD AND BOLTS FOR INTERNAL PRESSURE

THE OUTER COVER HEAD AND ITS 24 BOLTS ($1\frac{1}{4}$" DIA.) ARE STRUCTURALLY ADEQUATE FOR THE INTERNAL 15 psi PRESSURE CONDITION BY COMPARISON WITH THE CONTAINER LID INSTALLATION.

YIELD STRENGTH OF ONE $\frac{1}{2}$" BOLT FOR THE CONTAINER LID (REF. PG. 5-21):

$$F_y = (A_{stress})(f_y)$$

A_{stress} = STRESS AREA = $.1416\ IN^2$

f_y = YIELD STRENGTH OF BOLT MAT'L = 130 000 psi (REF. PG. 3-5)

$$F_y = (.1416)(130\,000) = 18\,408\ LB$$

12 BOLTS : $(12)\,F_y = \underline{220\,900\ LB}$

YIELD STRENGTH OF ONE $1\frac{1}{4}$" BOLT FOR THE COVER HEAD:

$$F_y = (A_{stress})(f_y)$$
$$= (.9684)\,(95000) = 91\,998\ LB$$

24 BOLTS : $(24)\,F_y = \underline{2\,207\,900\ LB}$

CALCULATIONS FOR FSV SPENT FUEL CASK. CONTAINER LID.			
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PREPARED BY R. L. [illegible]	DATE 2 March, 1978	REF. DOCUMENTS:	
REVIEWED BY John Gleeck	DATE June 13-78		
APPROVED BY	DATE		

LIST OF REFERENCES

1. ASME CODE SECT. III, 1974 EDITION INCLUDING ALL ISSUED ADDENDA THROUGH WINTER 1974 ADDENDA.
2. DELETED (INFORMATION ALREADY INCLUDED IN THE TEXT OF THIS DOCUMENT)
3. R. J. ROARK : "FORMULAS FOR STRESS AND STRAIN," THIRD EDITION 1954.
4. "BOLT TORQUE FACTORS" BY ROBERT H. LIPP. DESIGN NEWS MAGAZINE MARCH 8, 1971 ISSUE.
5. GAMD-9710. SAC MANUAL. PREPARED BY H. D. SHATOFF. DTD. 15 DECEMBER 1969.
6. GAMD-9644. STRESS 3 (VERSION 5) MANUAL. PREPARED BY H. D. SHATOFF. DTD. 20 AUGUST 1969.
7. PARKER GASK-O-SEAL HANDBOOK OSD 5411 (1977).
8. J. E. SHIGLEY : "MECHANICAL ENGINEERING DESIGN", McGRAW-HILL 1963.

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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C. IMPACT ANALYSIS

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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PREPARED BY D. L.	DATE 13 June, 1978	REF. DOCUMENTS:	
REVIEWED BY John Gacko	DATE June 16-78		
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INTRODUCTION TO IMPACT ANALYSIS

IT IS DOCUMENTED IN THE FOLLOWING SECTIONS THAT THE STRUCTURAL INTEGRITY OF THE CASK AS MODIFIED WILL BE RETAINED FOR A FREE 30 FT FALL ONTO A RIGID SURFACE.

IT IS ALSO SHOWN, THAT A 40 INCHES DROP ONTO A STEEL PIN WILL NOT PUNCTURE THE TOP COVER PLATE.

BECAUSE THE HEAD IS PROTECTED WITH A PLYWOOD IMPACT LIMITER WHILE THE CASK BOTTOM HAS NO SUCH PROTECTION, SEPARATE COMPUTER CODES WERE EMPLOYED FOR THE HEAD AND BOTTOM DROP CASES. STILL ANOTHER CODE WAS USED FOR THE 30 FT SIDE DROP WITH SIMULTANEOUS IMPACT OF CASK TOP AND BOTTOM.

THE HONDO CODE (A FINITE ELEMENT COMPUTER PROGRAM FOR THE LARGE DEFORMATION DYNAMIC RESPONSE OF AXISYMMETRIC SOLIDS, DEVELOPED BY SANDIA LABORATORIES) WAS EMPLOYED IN THE ANALYSIS OF A 30 FT BOTTOM DROP. THIS CASE IS BASED ON THE NORMAL IMPACT OF A METAL SURFACE ON AN IMMOVABLE GROUND. THE ACCURATE AND SOPHISTICATED HONDO CODE ALLOWS FOR STRAIN HARDENING AND STRAIN-RATE SENSITIVITY EFFECTS. IT DEVELOPS DISPLACEMENTS, VELOCITIES, ACCELERATIONS, AND STRESSES AS FUNCTIONS OF TIME IN SPECIFIED POINTS OF THE STRUCTURE.

(CONT'D.)

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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INTRODUCTION TO IMPACT ANALYSIS, CONT'D.

FOR THE HEAD AND SIDE DROP CASES IN-HOUSE CODES WERE DEVELOPED WHICH ACCOUNT FOR THE CRUSHING STRENGTH OF THE PLYWOOD IMPACT LIMITER AS A FUNCTION OF CASK ORIENTATION AT IMPACT.

BECAUSE OF THE LONG STROKE CRUSHING OF THE PLYWOOD THE HEAD DROP IS ESSENTIALLY A STATIC CASE, THAT DOES NOT REQUIRE A DYNAMIC RESPONSE ANALYSIS.

THE SIDE DROP CASE IS NOT AXI-SYMMETRIC AND THEREFORE DOES NOT LEND ITSELF TO ANALYSIS BY THE HONDO CODE.

THE HEAD DROP CODE WAS PRIMARILY DESIGNED TO VERIFY THE INTEGRITY OF THE PLYWOOD LIMITER. IT PROVIDES THE TOTAL AMOUNT OF DEFORMATION (CRUSHING) OF PLYWOOD FOR VARIOUS ANGLES OF THE CASK CENTERLINE WITH THE VERTICAL AT THE TIME OF IMPACT. THE ANALYSIS SHOWS THAT THE DEPTH OF CRUSHING IS SUFFICIENTLY SHALLOW TO ASSURE THE INTEGRITY OF THE CASK STRUCTURE ITSELF.

THE SIDE DROP CODE IS USED FOR A CASE OF SIMULTANEOUS IMPACT OF THE CASK BOTTOM AND THE HEAD IMPACT LIMITER. TAKING ACCOUNT OF THE CRUSHING STRENGTH OF THE LIMITER, THE VARIATION IN CASK CROSS-SECTION, AND THE

(CONT'D.)

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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INTRODUCTION TO IMPACT ANALYSIS, CONT'D.

EFFECTS OF STRAIN HARDENING, IT DEVELOPS THE INTERNAL BENDING MOMENT IN THE SIMPLY SUPPORTED BEAM.

ANY IMPACT AT AN ANGLE (EITHER HEAD OR TAIL FIRST) BETWEEN THE PERFECT VERTICAL CASE AND THE SIDE DROP CASE WILL BE CONSERVATIVELY COVERED BY THE EXTREME CASES. SEE "DISCUSSION AND SUMMARY" FOR THE BOTTOM 30 FT DROP ANALYSIS ("CONCLUSIONS OF HONDO ANALYSIS"), PG. 5-66 AND 5-67.

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CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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D. 30 FT BOTTOM DROP

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.
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PREPARED BY P. L. Thurford DATE 15 Jan., 1979 REF. DOCUMENTS:
REVIEWED BY lmc DATE 2-8-79
APPROVED BY DATE

HONDO ANALYSIS

30 FT. BOTTOM DROP

THE HONDO RUNS SIMULATE A CASK BOTTOM IMPACT ON IMMOVABLE GROUND BY ASSIGNING THE 30 FT. FREE FALL Z-VELOCITY TO ALL NODES, EXCEPT NODES 1 THROUGH 11 ON THE BOTTOM SURFACE, WHICH ARE GIVEN ZERO VELOCITY FROM TIME POINT 0 AND ON (REF. HONDO MODEL GEOMETRY ON PG. (5-78). FROM THESE INITIAL VELOCITY CONDITIONS THE DYNAMIC RESPONSE OF THE CASK IS DETERMINED BY THE CODE, AND SELECTED DISPLACEMENTS, VELOCITIES, ACCELERATIONS, AND STRESSES PRINTED OUT AT SPECIFIED TIME INTERVALS.

THE COMPUTED ANSWERS ARE BASED ON IDEALIZED MATERIAL PROPERTIES THAT CONSERVATIVELY SUBSTITUTE THE ACTUAL MATERIAL PROPERTIES WITHIN STRAIN AND STRAIN-RATE RANGES EXPERIENCED IN ALL REGIONS OF THE CASK.

$$v = v_0 + at$$

$$s = s_0 + v_0 t + \tfrac{1}{2} a t^2$$

$$a = 32\ \mathrm{FT/sec^2} = 384\ \mathrm{IN/sec^2} \qquad v_0 = 0 \qquad s_0 = 0$$

$$s = 30\ \mathrm{FT} = 360\ \mathrm{IN} \quad \mathrm{FOR} \quad \tfrac{1}{2} a t^2 = 360$$

$$\mathrm{OR:}\ t = \sqrt{\frac{2 \times 360}{384}} = \underline{1.3693\ \mathrm{sec.}}$$

$$v = 0 + (384)(1.3693) = \underline{525.8\ \mathrm{IN/sec}}$$

INITIAL Z-VELOCITY = $\underline{-525.8\ \mathrm{IN/sec}}$ FOR ALL NODES EXCEPT NODES 1 THROUGH 11.

CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER LID.			
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POOR ORIGINAL

VERTICAL IMPACT ANALYSIS

MATERIALS DATA FOR HONDO INPUT

DISCUSSION

THE FOLLOWING MATERIAL CHARACTERISTICS AT APPLICABLE TEMPERATURES ARE REQUIRED INPUT:

1. MASS DENSITY
2. STRESS AS A FUNCTION OF STRAIN UP TO A PERMANENT SET OF APPROXIMATELY .5% (WHICH CORRESPONDS TO APPROX. ONE INCH COMPRESSION OF THE CASK).
3. YIELD STRENGTH AS A FUNCTION OF STRAIN RATE (STRAIN RATE SENSITIVITY).

THE STRESS-STRAIN FUNCTION IS IDEALIZED INTO STRAIGHT LINES AND EXPRESSED BY PARAMETERS E, ν, t_0, E_t, AND β (SEE REF. 6, PAGE 66, FIG. 17). A STRESS-STRAIN CURVE FOR THE .2% MO-URANIUM ALLOY LID SHIELD MATERIAL WAS NOT AVAILABLE FROM THE SUPPLIER UNTIL AFTER THE ANALYSIS WAS MADE. THE IDEALIZED CURVE USED IN THE HONDO INPUT WAS THEREFORE BASED ON ESTIMATES DERIVED FROM SEVERAL AVAILABLE SOURCES OF INFORMATION REGARDING PURE URANIUM AND URANIUM ALLOYS WITH VARYING AMOUNTS OF MOLYBDENUM. AS SEEN ON PAGE 5-48 THE IDEALIZED CURVE IS CONSERVATIVE IN THAT $\sigma_y' < \sigma_y$. ALL HONDO RUNS MADE PRODUCED STRESSES IN THE LID SHIELD THAT WERE LOWER THAN σ_y' ($\sigma_y' = 30700$ psi FOR 300 °F AND $\dot{\varepsilon} = 10^{-3}$).

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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DISCUSSION, CONT'D.

THE STRAIN RATE SENSITIVITY FOR THE CAST 304 STAINLESS STEEL IS BASED ON A 3571 LB/IN^2 INCREASE IN YIELD STRENGTH PER DECADE INCREASE IN STRAIN RATE (APPLICABLE AT ROOM TEMPERATURE, SEE REF. 10, PG. 11). THE CASK STEEL TEMP. IS 250 °F → 300 °F WHICH CORRESPONDS TO 121 °C → 149 °C. THE ACTUAL STRAIN RATE SENSITIVITIES AT THESE TEMP'S ARE PROBABLY LOWER THAN AT ROOM TEMP., SEE REF. 1, PG. 13. THE STRAIN RATE ($\dot{\varepsilon}$) FOR A NORMAL TENSILE TEST IS $\sim 10^{-3}$. FOR STRAIN RATES BELOW 10^{-5} THE 304 STEEL YIELD STRENGTH IS ASSUMED CONSTANT AND EQUAL TO THE VALUE AT $\dot{\varepsilon} = 10^{-5}$.

FOR THE URANIUM-MOLY ALLOYS THE STRAIN RATE SENSITIVITY WAS ASSUMED SIMILAR TO THE ONE DEPICTED ON FIG. 17, REF. 5, PG. 338 FOR PURE α-URANIUM - EXTRAPOLATED DOWNWARD TO $\dot{\varepsilon} = 10^{-6}$. IN THE RANGE ABOVE $\dot{\varepsilon} = 10^{-6}$ THE YIELD STRENGTH IS ASSUMED GOVERNED BY THE POWER EQUATION (REF. 6, PG. 18):

$$t_y = t_0 \left[1 + \left(\frac{|\dot{\varepsilon}|}{D} \right)^{\frac{1}{P}} \right]$$

WHERE t_0 = THE YIELD STRENGTH AT $\dot{\varepsilon} = 10^{-6}$ (~ ZERO RATE. $\dot{\varepsilon} = 10^{-6}$ IN/IN/SEC CORRESPONDS TO A DOUBLING OF LENGTH IN 10^6 SEC'S = 278 HOURS, WHICH IS A VERY LOW RATE OF STRAIN).

THE "t_0" VALUE READ FROM THE IDEALIZED STRESS-STRAIN CURVE IS BASED ON $\dot{\varepsilon} = 10^{-3}$.

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DISCUSSION, CONT'D.

BECAUSE OF UNCERTAINTY REGARDING THE VALIDITY OR THE STRAIN RATE SENSITIVITY DATA, THE HONDO RUN WILL BE REPEATED WITH STRAIN RATE PARAMETERS p AND D INPUT AS ZERO (GIVES STRAIN RATE INSENSITIVE BEHAVIOR PER REF. 6, PG, 71). THE MODEL WHICH PRODUCES THE HIGHEST STRESSES IN THE LID WILL BE USED FOR ANALYSIS OF THE LID.

THE REQUIRED MATERIALS INPUT DATA ARE TABULATED ON PAGE 5-62.

TO CLARIFY THE RESULTS OBTAINED IN THE HONDO ANALYSIS A FURTHER DISCUSSION OF MATERIALS DATA AND PROCEDURES IS PROVIDED ON PAGE 5-97 A AND ON.

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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VERTICAL IMPACT ANALYSIS

MATERIALS DATA FOR HONDO INPUT

MAT'L IDENT. NO'S 1 & 5 (CASK SHELLS, CONTAINER SHELL, PRIMARY CLOSURE, TOP MEMBR.)

304 STAINLESS STEEL ------ @ $\left\{ \begin{array}{l} 250\,°F \\ 300\,°F \end{array} \right.$

ASTM A 351 SR CF-8

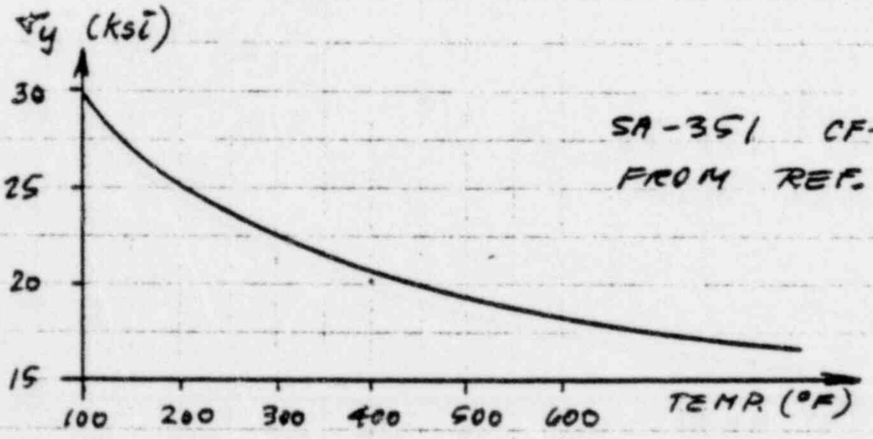
ASME CODE SECT. III DESIGNATION : SA-351 CF-8

$\rho = .290 \frac{LB}{IN^3}$

$g = 980.665\ cm/sec^2 \sim 980.665\overset{in/cm}{(.3937)} = 386.088\ IN/sec^2$

$\text{MASS DENSITY} = \frac{\rho}{g} = \frac{.290}{386.088} = \underline{.0007511 \frac{LB\ sec^2}{IN^4}}$

$E = \left\{ \begin{array}{l} \underline{27.4 \times 10^6\ psi} \ @\ 250\,°F \\ \underline{27.1 \times 10^6\ psi} \ @\ 300\,°F \end{array} \right\}$ PER REF. 2, TABLE I-6.0



SA-351 CF-8 YIELD STRENGTH DATA FROM REF. 2, TABLE I-2.2.

$\sigma_{y\,250°F} = 23.7$ ksi

$\sigma_{y\,300°F} = 22.5$ ksi

$\sigma_{y\,400°F} = 20.7$ ksi

$\frac{\sigma_{y\,250°F}}{\sigma_{y\,400°F}} = \frac{23.7}{20.7} = \underline{1.145}$

$\frac{\sigma_{y\,300°F}}{\sigma_{y\,400°F}} = \frac{22.5}{20.7} = \underline{1.087}$

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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MAT'L IDENTIFICATION NO'S 1 & 5, CONT'D.

IDEALIZED STRESS-STRAIN CURVES ARE DRAWN UPON FIG. 3.03112 (FROM REF. 7, CODE 1303, PAGE 13) BELOW, USING E-VALUES AND σ_y-RATIOS FROM PRECEDING PAGE.

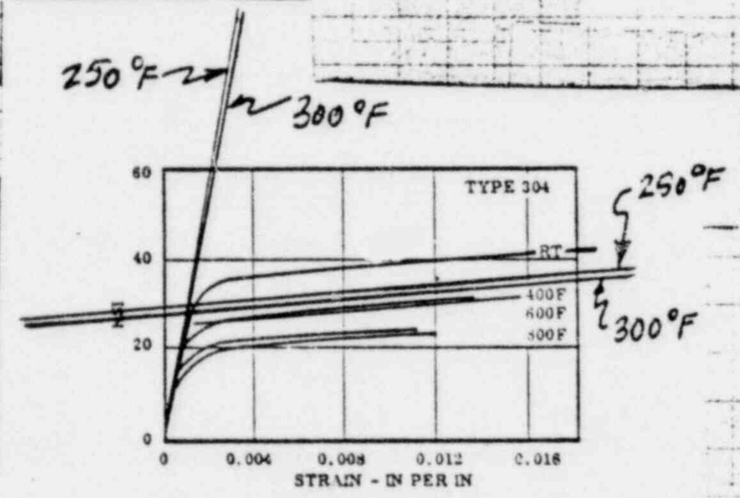

FIG 3.03112 STRESS - STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURES (23)

BY SCALING GRAPH:

FOR 250 °F ($E = 27.4 \times 10^6$ psi):

$t_0 = \underline{29\,500}$ psi

FOR 300 °F ($E = 27.1 \times 10^6$ psi):

$t_0 = \underline{28\,400}$ psi

HARDENING MODULUS IN BOTH CASES:

$$E_t = \frac{\Delta\sigma}{\Delta\varepsilon} = \frac{7368}{.018} = \underline{409\,300 \text{ psi}}$$

STRAIN RATE SENSITIVITY: $\Delta\sigma_y = 3571$ LB/IN² PER DECADE INCREASE IN $\dot{\varepsilon}$ FOR $\dot{\varepsilon} \geqq 10^{-5}$.
(REF. 10, PG. 11)

$$t_y = t_0 = \left\{ \begin{array}{l} \underline{29\,500} \text{ psi @ } 250\text{ °F} \\ \underline{28\,400} \text{ psi @ } 300\text{ °F} \end{array} \right\} \text{ FOR } \dot{\varepsilon} = 10^{-3}$$

$$t_y = \underline{t_0 + [3571][\log_{10}}\ \underline{(10^3 \dot{\varepsilon})]} \quad \text{FOR } \dot{\varepsilon} \geqq 10^{-5}$$

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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MAT'L IDENT. NO. 2 (URANIUM SHIELD, LID)

.2 % MO URANIUM ALLOY (CAST) @ 300 °F

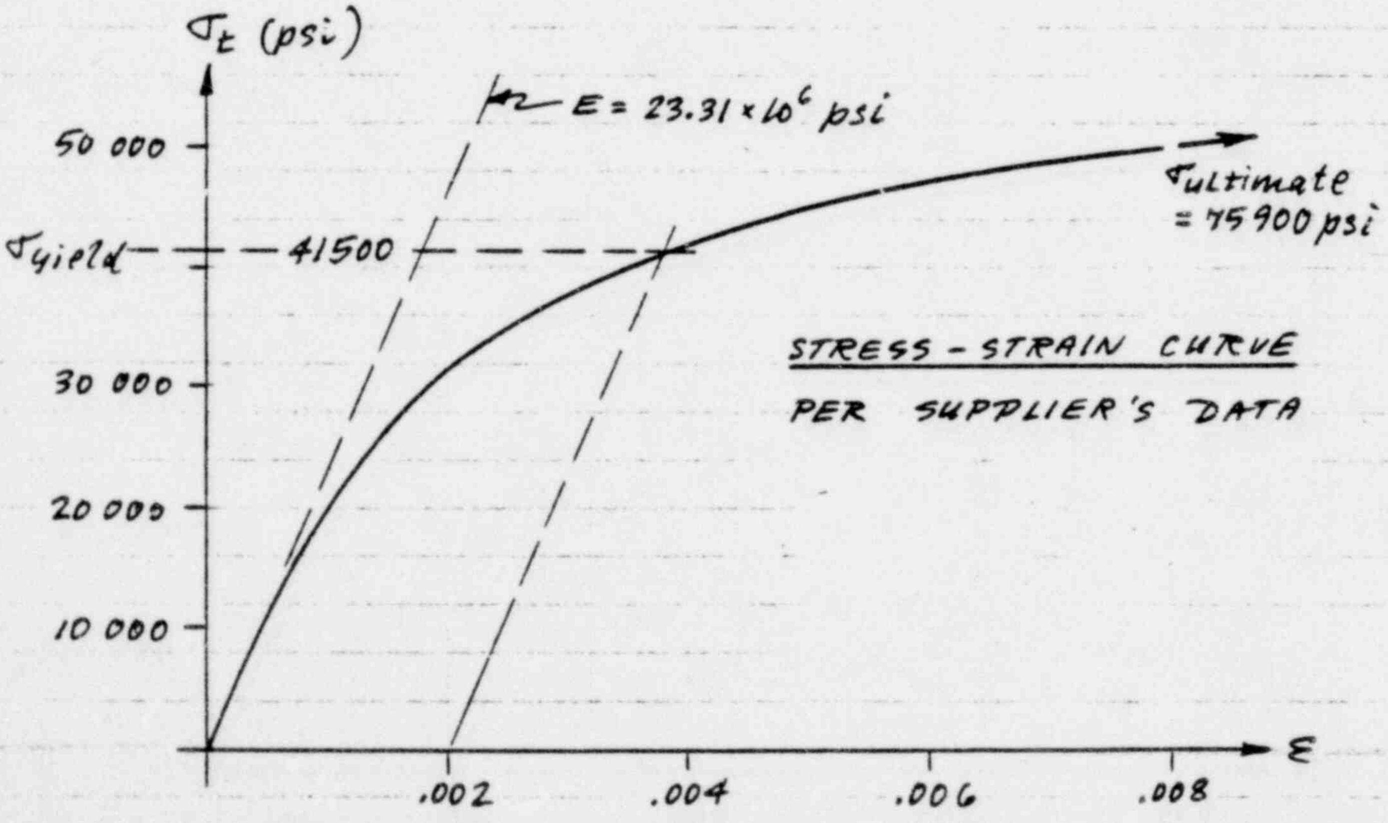
DENSITY PER SUPPLIER'S DATA :

$$\rho = \underline{18.81\ g/cm^3}$$

$$\rho = 18.81\ g/cm^3 \sim (18.81)(.03613) = \underline{.67961\ LB/IN^3}$$

$$\text{MASS DENSITY} = \frac{.67961}{386.088} = \underline{.0017602\ \frac{LB\ SEC^2}{IN^4}}$$

$\nu = .21$ PER REF. 4, PG. 3-1
(COMPARE WITH $\nu = .25$ LISTED FOR PURE URANIUM IN REF. 8, PG. 151).



.2 % MO-URANIUM ALLOY (CAST) LID SHIELD MATERIAL @ 70 °F IN TENSION. STRAIN RATE $\dot{\varepsilon} = 10^{-3}$.

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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MATERIAL IDENTIFICATION NO. 2, CONT'D.

ADJUSTMENT FOR 300 °F TEMP :

REF. 5, PG. 313 (FIG. 1) :
70 °F ~ 21 °C ~ 294 °K . READ: $E_{70} = 29.0 \times 10^6$ psi
300 °F ~ 149 °C ~ 422 °K . READ: $E_{300} = 26.2 \times 10^6$ psi

REF. 5, PG. 317 (FIG. 4) :
70 °F ~ 21 °C . READ: $\sigma_{yield} = 48$ ksi. $\sigma_{ult.} = 100$ ksi
300 °F ~ 149 °C . READ: $\sigma_{yield} = 42$ ksi. $\sigma_{ult} = 78$ ksi

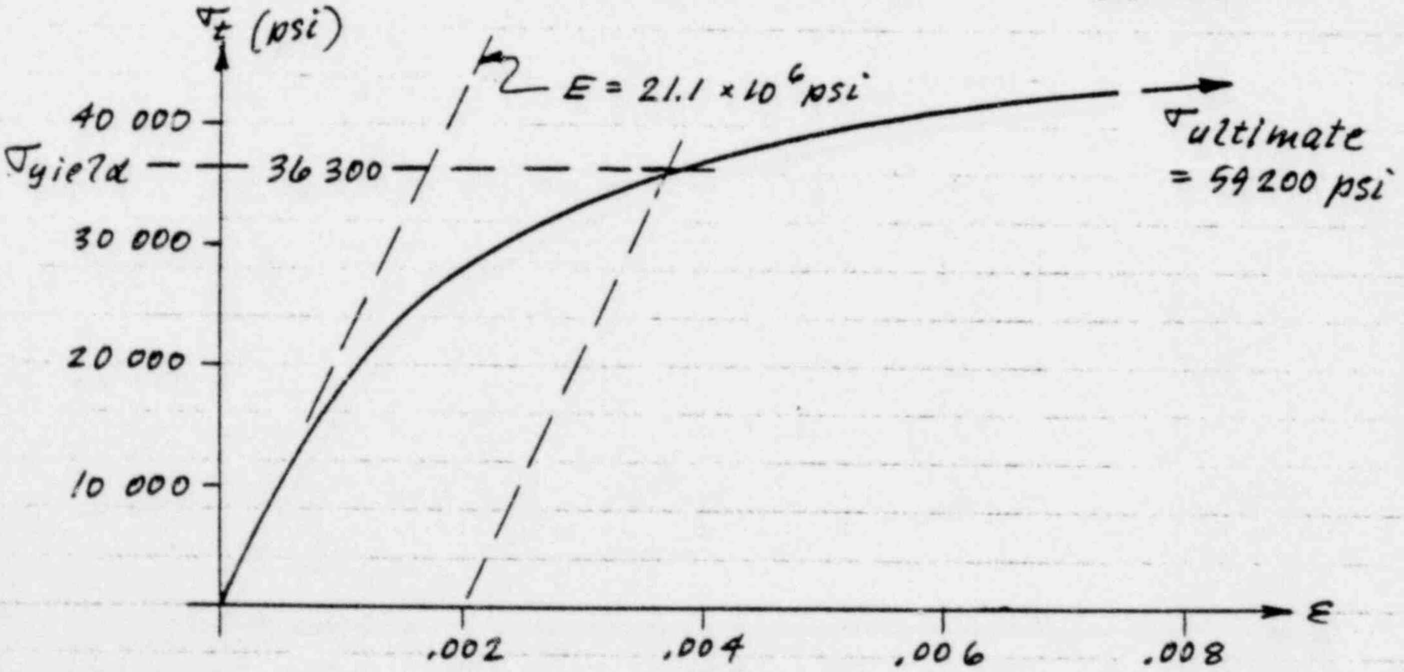
ADJUSTED DATA :

$$\sigma_y = (41500)\left(\frac{42}{48}\right) = \underline{36\,300 \text{ psi}}$$

$$\sigma_u = (75\,900)\left(\frac{78}{100}\right) = \underline{59\,200 \text{ psi}}$$

$$E = (23.31 \times 10^6)\left(\frac{26.2}{29.0}\right) = \underline{21.1 \times 10^6 \text{ psi}}$$

THE STRESS-STRAIN CURVE BELOW WAS CONSTRUCTED ON THE BASIS OF THE ADJUSTED VALUES OF σ_y, σ_u, & E.



SUPPLIER'S STRESS-STRAIN CURVE ADJUSTED FOR 300 °F TEMP.

$\dot{\varepsilon} = 10^{-3}$

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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PREPARED B. D. L. Lunford	DATE 16 Jan., 1979	REF. DOCUMENTS:	
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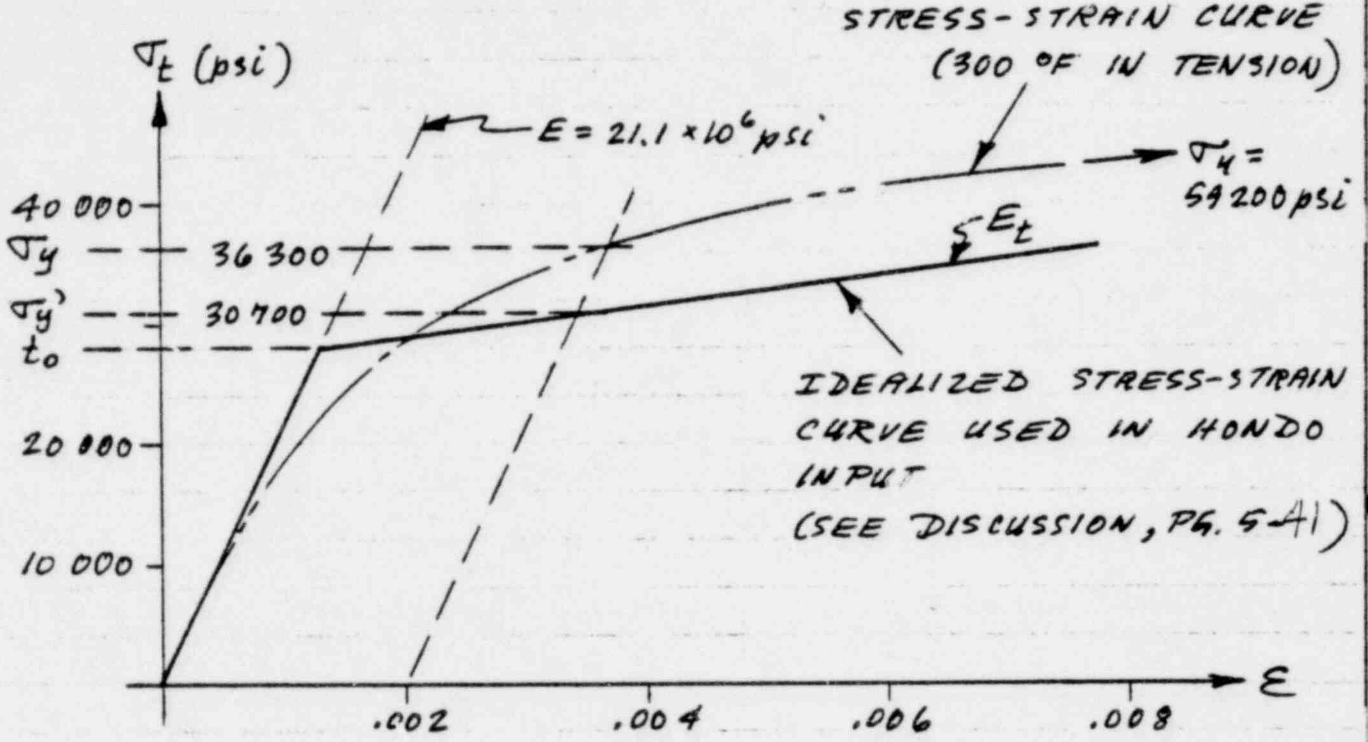
APPROVED BY	DATE		

MATERIAL IDENTIFICATION NO. 2, CONT'D.

VERTICAL IMPACT ANALYSIS
MATERIALS DATA FOR HONDO INPUT



.2 % Mo URANIUM ALLOY (CAST) @ 300 °F IN TENSION

STRAIN RATE $\dot{\varepsilon} = 10^{-3}$

E_t = 1.35×10^6 psi

t_o = 28 000 psi

$$\sigma_y' = t_o + (E_t)(\varepsilon) = 28\,000 + (1\,350\,000)(.002)$$
$$= 28\,000 + 2700 = 30\,700 \text{ psi}$$

σ_y' = 30 700 psi EXCEEDS STRESSES EXPERIENCED IN LID (REF. C.P.O.).

SLOPE OF E_t LINE IS ACCEPTABLE FOR THE 30 FT. DROP ANALYSIS SINCE STRESSES IN THE LID NEVER REACH THE IDEALIZED STATIC ($\dot{\varepsilon} = 10^{-3}$) YIELD STRENGTH σ_y'.

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSU FUEL SHIPPING CASK. CONTAINER LID.			
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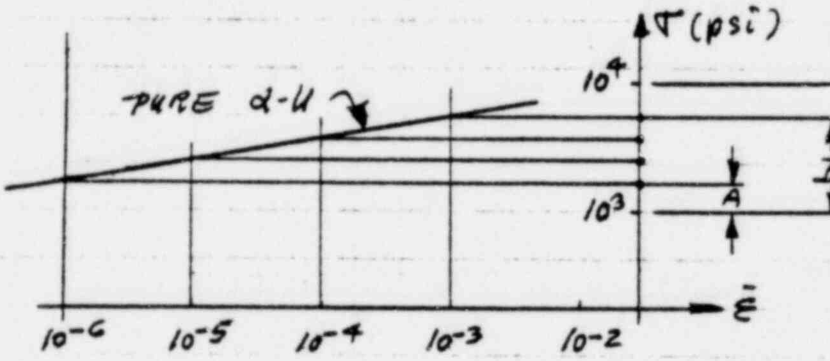
MAT'L IDENTIFICATION NO. 2, CONT'D.

STRAIN RATE SENSITIVITY CONSTANTS p & D

REFER TO REF. 5, PG. 338, FIG. 17 AND USE $t_0 = \sigma$ AT $\dot{\varepsilon} = 10^{-6}$ (BY EXTRAPOLATION).

ANALYSIS OF FIG. 17, REF. 5, PG. 338:



SCALED (ON A ½ SCALE):
$A = .31$
$B = .99$
$C = 1.36$

$\frac{1}{3}(B-A) = \frac{1}{3}(.99-.31) = \underline{.22667}$

$A + \frac{1}{3}(B-A) = .31 + .22667 = \underline{.53667}$

$A + \frac{2}{3}(B-A) = .31 + .45334 = \underline{.76334}$

$\log 1.6881 = .2274 \sim (.2274)(1.36) = .31 = A$
$\sigma_{10^{-6}} = \underline{1688}$ psi

$\log 2.481 = .3946 \sim (.3946)(1.36) = .53667 = A + \frac{1}{3}(B-A)$
$\sigma_{10^{-5}} = \underline{2481}$ psi

$\log 3.6415 = .56128 \sim (.56128)(1.36) = .76334 = A + \frac{2}{3}(B-A)$
$\sigma_{10^{-4}} = \underline{3642}$ psi

$\log 5.345 = .72794 \sim (.72794)(1.36) = .99 = B$
$\sigma_{10^{-3}} = \underline{5345}$ psi

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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MAT'L IDENTIFICATION NO. 2, CONT'D.

ANALYSIS OF FIG. 17, REF. 5, PG. 338, CONT'D.:

POWER LAW (REF. 6, PG. 18) :

$$t_y = t_0 \left[1 + \left(\frac{|\dot{\varepsilon}|}{D}\right)^{\frac{1}{p}} \right] \quad \text{OR} \quad |\dot{\varepsilon}| = D\left(\frac{t_y}{t_0} - 1\right)^p$$

FOR $|\dot{\varepsilon}| > 10^{-6}$

TAKING $t_0 = t_y$ FOR $\dot{\varepsilon} = 10^{-6}$: $t_0 = 1688$ psi

$$(1): \quad 10^{-5} = D\left(\frac{2481}{1688} - 1\right)^p$$

$$(2): \quad 10^{-4} = D\left(\frac{3642}{1688} - 1\right)^p$$

$$(3): \quad 10^{-3} = D\left(\frac{5345}{1688} - 1\right)^p$$

$$\frac{(1)}{(2)}: \quad 10^{-1} = \left(\frac{\frac{2481}{1688} - 1}{\frac{3642}{1688} - 1}\right)^p = \left(\frac{.4698}{1.1576}\right)^p = (.4058)^p$$

$$-1 = p \log(.4058)$$

$$p = \frac{-1}{-.3917} = \underline{2.553}$$

$$(1): \quad 10^{-5} = D\left(\frac{2481}{1688} - 1\right)^{2.553}$$

$$\frac{10^{-5}}{D} = (.4698)^{2.553} = .1453$$

$$D = \frac{10^{-5}}{.1453} = \underline{6.882 \times 10^{-5}}$$

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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MAT'L IDENTIFICATION NO. 2, CONT'D.

ANALYSIS OF FIG. 17, REF. 5, PG. 338, CONT'D.

$$\frac{(2)}{(3)}: \quad 10^{-1} = \left(\frac{\frac{3642}{1688} - 1}{\frac{5345}{1688} - 1} \right)^{p} = \left(\frac{1.1576}{2.1665} \right)^{p} = (.5343)^{p}$$

$$-1 = p \log (.5343)$$

$$p = \frac{-1}{-.2722} = \underline{3.6738}$$

$$(2): \quad 10^{-4} = D\,(1.1576)^{3.6738}$$

$$\frac{10^{-4}}{D} = (1.1576)^{3.6738} = 1.7110$$

$$D = \frac{10^{-4}}{1.7110} = \underline{5.8412 \times 10^{-5}}$$

FOR HONDO ANAL. USE AVERAGE VALUES:

$$p = \tfrac{1}{2}\left[2.553 + 3.6738\right] = \underline{3.113}$$

$$D = \tfrac{1}{2}\left[6.882 + 5.8412\right]10^{-5} = \underline{6.362 \times 10^{-5}}$$

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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APPROVED BY	DATE		

MAT'L IDENTIFICATION NO. 2, CONT'D.

FOR .2% MO URANIUM ALLOY @ 300 °F :

IDEALIZED $t_y = 28000$ psi FOR $\dot{\varepsilon} = 10^{-3}$ (PAGE 5-48)

$$|\dot{\varepsilon}| = D\left[\frac{t_y}{t_o} - 1\right]^p$$

$$10^{-3} = \left[6.362 \times 10^{-5}\right]\left[\frac{28000}{t_o} - 1\right]^{3.113}$$

$$15.718 = \left[\frac{28000}{t_o} - 1\right]^{3.113} = X^{3.113}$$

$$\log 15.718 = 3.113 \log X = 1.1964$$

$$\log X = \frac{1.1964}{3.113} = .3843$$

$$X = \frac{28000}{t_o} - 1 = 2.4228$$

$$\frac{28000}{t_o} = 3.4228 \qquad t_o = \frac{28000}{3.4228} = \underline{\underline{8180 \text{ psi}}}$$

$$t_y = t_o\left[1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{p}}\right]$$

$$\dot{\varepsilon} = 10^{-5}: \quad t_y = (8180)\left[1 + \left(\frac{10^{-5}}{6.362 \times 10^{-5}}\right)^{\frac{1}{3.113}}\right] = (8180)[1.552] = \underline{12695 \text{ psi}}$$

$$\dot{\varepsilon} = 10^{-4}: \quad t_y = (8180)\left[1 + \left(\frac{10^{-4}}{6.362 \times 10^{-5}}\right)^{\frac{1}{3.113}}\right] = (8180)[2.156] = \underline{17640 \text{ psi}}$$

$$\dot{\varepsilon} = 10^{-3}: \quad t_y = (8180)\left[1 + \left(\frac{10^{-3}}{6.362 \times 10^{-5}}\right)^{\frac{1}{3.113}}\right] = (8180)[3.423] = \underline{27800 \text{ psi}}$$

$$\dot{\varepsilon} = 10^{-2}: \quad t_y = (8180)\left[1 + \left(\frac{10^{-2}}{6.362 \times 10^{-5}}\right)^{\frac{1}{3.113}}\right] = (8180)[6.076] = \underline{49707 \text{ psi}}$$

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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<u>MAT'L IDENT. NO. 3</u> (URANIUM SHIELD, CYLINDER)

<u>.2 % MO URANIUM ALLOY (CAST) @ 250 °F</u>

DENSITIES PER REF. 8, PG. 191 $\begin{cases} \text{PURE CAST URANIUM}: \rho = 18.9 \text{ g/cm}^3 \\ \text{2\% MO URAN. ALLOY}: \rho = 18.4 \text{ g/cm}^3 \end{cases}$

.2 % MO URANIUM ALLOY : $\rho = 18.9 - \frac{1}{10}(18.9 - 18.4) = \underline{18.85 \text{ g/cm}^3}$

$\rho = 18.85 \text{ g/cm}^3 \sim (18.85)(.03613) = \underline{.68105 \text{ LB/IN}^3}$

MASS DENSITY $= \frac{.68105}{386.088} = \underline{.001764 \frac{\text{LB SEC}^2}{\text{IN}^4}}$

FOR POISSON'S RATIO USE SAME VALUE AS ON PG. 5-46 : $\nu = .21$ PER REF. 4, PG. 3-1.

<u>STRESS – STRAIN DATA</u>

THE CASK ITEMS OF THIS MATERIAL ARE PRIMARILY SUBJECT TO COMPRESSION LOADING. THE STRESS–STRAIN CONSTANTS WILL THEREFORE BE BASED ON THE COMPRESSION CURVE IN REF. 4, PG. 5-3 (COMPARE WITH FIGURE 8 IN REF. 5, PG. 324). THE AVERAGE CURVE ON PG. 5-3 OF REF. 4, WHICH IS FOR PURE URANIUM AT ROOM TEMP., HAS BEEN ADJUSTED FOR .2 % MO ADDITION AND 250 °F TEMP. AND SHOWN ON PAGE 5-56 TOGETHER WITH E AND E_t LINES FOR THE STRAIN RANGE OF UP TO .5 % PERMANENT SET.

CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER LID.			
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MAT'L IDENTIFICATION NO. 3, CONT'D.

REF. 8, PG. 151: $E = \left[25 - \frac{1}{10}(25 - 21)\right] \times 10^6$
$= 24.6 \times 10^6$ psi
FOR .2% MO URANIUM ALLOY @ ROOM TEMP.

REDUCTION OF E FOR 250 °F TEMP. PER REF. 5, PG. 313 (FIG. 1):
FOR 70 °F ~ 21 °C ~ 294 °K. READ: $E_{70} = 29.0 \times 10^6$ psi
FOR 250 °F ~ 121 °C ~ 394 °K. READ: $E_{250} = 26.8 \times 10^6$ psi

$$E = \left[24.6 \times 10^6\right] \frac{26.8}{29.0} = \underline{22.73 \times 10^6} \text{ psi}$$

REDUCTION OF σ_{yield} FOR 250 °F TEMP. PER REF. 5, PG. 317 (FIG. 4):
70 °F ~ 21 °C. READ: $\sigma_{yield} = 48$ ksi
250 °F ~ 121 °C. READ: $\sigma_{yield} = 43$ ksi

$$\text{FACTOR} = \frac{43}{48} = \underline{.8958}$$

INCREASE OF σ_{yield} FOR .2 % MO ADDITION PER REF. 8, PG. 151:
PURE URANIUM: $\sigma_{yield} = 25$ ksi
2% MO URANIUM ALLOY: $\sigma_{yield} = 55$ ksi
.2% MO URANIUM ALLOY: $\sigma_{yield} = 25 + \frac{1}{10}(55 - 25)$
$= 28$ ksi

$$\text{FACTOR} = \frac{28}{25} = 1.12$$

TOTAL ADJUSTM. FACTOR = (.8958)(1.12) = $\underline{1.0033}$

CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER L.D.			
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MAT'L IDENTIFICATION NO. 3, CONT'D.

BY SCALING AND ADJUSTING POINTS ON THE CURVE IN REF. 4, PG. 5-3, THE FOLLOWING POINTS ARE ARRIVED AT :

$\varepsilon = .002$ PERMANENT SET : $\sigma = \sigma_{yield} = (73\,000)(1.0033)$
$= \underline{73\,241}$ psi

$\varepsilon = .005$ PERMANENT SET : $\sigma = (82\,105)(1.0033)$
$= \underline{82\,376}$ psi

USING $E = 22.73 \times 10^6$ psi TOGETHER WITH THE TWO STRESS VALUES ABOVE AND COMPARING WITH THE CURVE IN REF. 4, PG. 5-3, THE STRESS-STRAIN CURVE DETAIL ON PG. 5-51 WAS DRAWN.

HONDO INPUT VALUES ARE SCALED FROM THIS GRAPH :

$t_o = \underline{64\,200}$ psi

$E_t = \underline{3.15 \times 10^6}$ psi

t_o FOR THE STRAIN RATE SENSITIVE CASE IS DETERMINED FROM EQUATION :

$$t_y = t_o \left[1 + \left(\frac{|\dot{\varepsilon}|}{D} \right)^{\frac{1}{P}} \right]$$

$$64\,200 = t_o \left[1 + \left(\frac{10^{-3}}{6.362 \times 10^{-5}} \right)^{\frac{1}{3.113}} \right]$$

$$= t_o \left[1 + 2.4228 \right]$$

$t_o = \underline{18\,756}$ psi

CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER LID.			
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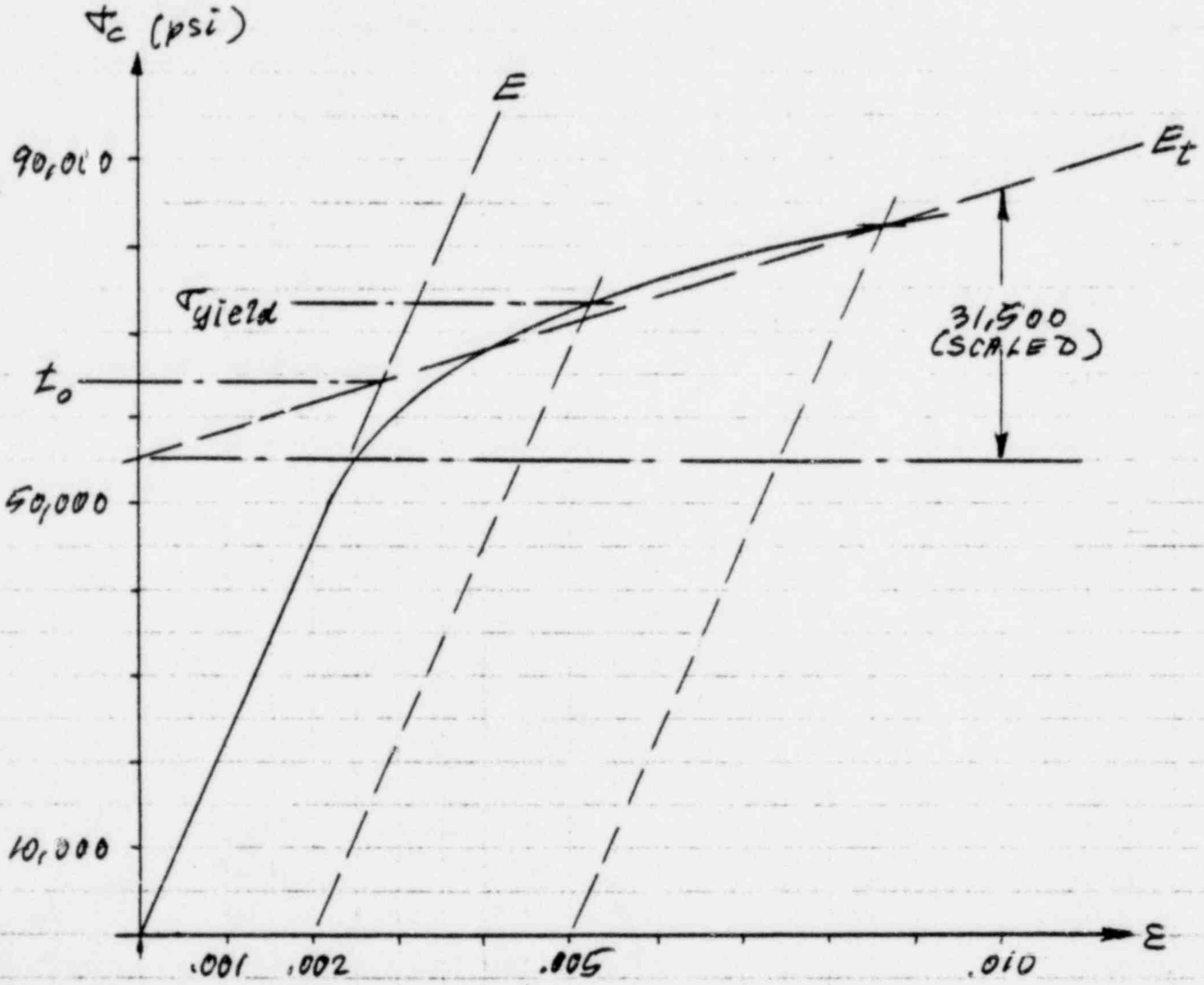
VERTICAL IMPACT ANALYSIS
MATERIALS DATA FOR HONDO INPUT



DETAIL OF STRESS-STRAIN CURVE FOR
.2% MO URANIUM ALLOY (CAST) @ 250 °F IN COMPR.

$E = 22.73 \times 10^6$ psi
$\sigma_{yield} = 73\ 241$ psi

BY SCALING GRAPH:
$t_o = \underline{64\ 200}$ psi
$E_t = \frac{\sigma}{\varepsilon} = \frac{31500}{.01} \doteq \underline{3.15 \times 10^6 \text{ psi}}$

CALCULATIONS FOR FSU FUEL SHIPPING CASK. CONTAINER LID.			
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<u>MAT'L IDENT. NO. 4</u> (PRIMARY CLOSURE. TOP MEMBRANE)

IS IDENTICAL TO MAT'L IDENTIFICATION NO. 5 EXCEPT FOR THE USE OF AN ARBITRARY SMALL E VALUE. THIS WAS DONE IN ORDER TO SIMULATE THE WEIGHT EFFECT OF THE LID MEMBRANE WITHOUT TAKING ADVANTAGE OF ANY STIFFNESS THAT IN THE SOLUTION COULD UNREALISTICALLY BENEFIT THE URANIUM SHIELD.

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER LID.			
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MAT'L IDENT. NO. 6 (TOP HEAD OF CASK)

4340 LOW ALLOY STEEL. HEAT TREATED TO MIN. 150 000 psi YIELD @ 300 °F TEMP.
COMPOSITION PER REF. 7 : .4C, 1.8 Ni, .8 Cr., .25 Mo

150 ksi yield @ 300 °F REQUIRES AN F_{tu} = APPROX. 175 ksi @ ROOM TEMP. BY COMPARISON WITH REF. 7, CODE 1206, FIG'S. 3.02111 AND 3.03111 (SEE PG. 5-59 & 5-60).

$\rho = .285\ \text{LB/IN}^3$

$$\text{MASS DENSITY} = \frac{\rho}{g} = \frac{.285}{386.088} = \underline{.0007382\ \frac{\text{LB sec}^2}{\text{IN}^4}}$$

E = <u>29.0×10⁶ psi</u> @ 300 °F PER REF. 2, TABLE I-6.0

STRESS - STRAIN DATA

SEE PG. 5-60.

REF. 7, CODE 1206, PG. 6 : FIG. 3.02111 SHOWS FLAT (HORIZONTAL) STRESS CURVES FOR 140 ksi - 180 ksi MAT'L @ ROOM TEMP.

.002 YIELD POINT FOR 175 ksi MAT'L WILL BE APPROX. 165 ksi PER REF. 7, CODE 1206, FIG. 3.0211.

REF. 2, TABLE I-2.1 : BY COMPARISON WITH LOW ALLOY STEEL SA-533 ($\frac{1}{2}$ Mo) : $\sigma_{yield} = \begin{cases} 82.5 \text{ ksi @ } 100\,°F \\ 76.0 \text{ ksi @ } 300\,°F \end{cases}$

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.

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REVIEWED BY John Stackson	DATE June 5-78		
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MAT'L IDENTIFICATION NO. 6, CONT'D.

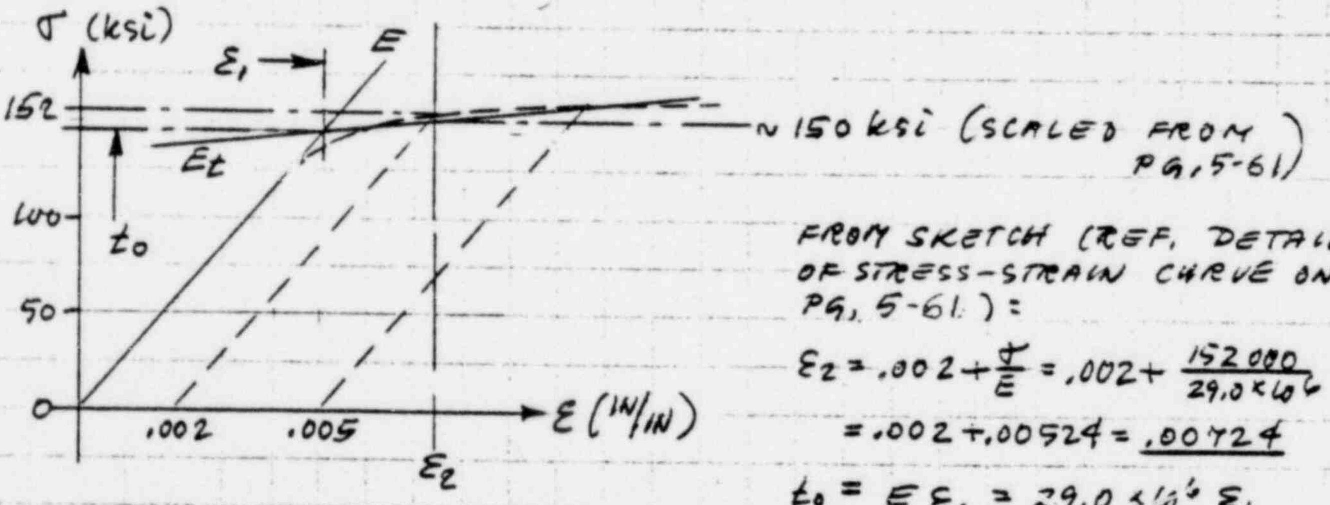
$$4340 \text{ YIELD POINT @ } 300\,°F = \left(\frac{76.0}{82.5}\right)(165)$$

$$= 152 \text{ ksi} \sim 150 \quad \text{O.K.}$$

REF. FIG. 3.03111 ON PG. 5-60 ALTHOUGH CURVE IS FLAT AT ROOM TEMP. THERE WILL BE SOME SLOPE AT 300 °F *). ASSUME APPROX. HALF OF THAT INDICATED FOR 200 H.T. MAT'L ON FIG. 3.0311.

$$E_t = \left(\frac{1}{2}\right)\left(\frac{54000}{.01221}\right) = \underline{2.22 \times 10^6 \text{ psi}}$$

THE STRESS-STRAIN CURVE ON PG. 5-61 WAS CONSTRUCTED BY COMPARISON WITH PG. 5-60 USING DATA DEVELOPED ABOVE.



FROM SKETCH (REF. DETAIL OF STRESS-STRAIN CURVE ON PG. 5-61.):

$$\varepsilon_2 = .002 + \frac{\sigma}{E} = .002 + \frac{152000}{29.0 \times 10^6}$$

$$= .002 + .00524 = \underline{.00724}$$

$$t_o = E\varepsilon_1 = \underline{29.0 \times 10^6\, \varepsilon_1}$$

$$150{,}000 = t_o + (\varepsilon_2 - \varepsilon_1)\,E_t = t_o + (.00724 - \varepsilon_1)(2.22 \times 10^6)$$

$$\text{OR: } 150\,000 = t_o + \left(.00724 - \frac{t_o}{29.0 \times 10^6}\right)(2.22 \times 10^6)$$

$$150\,000 = t_o + 16076 - .07655\, t_o$$

$$t_o = \underline{145\,000} \text{ psi}$$

*) FOOTNOTE 16 JAN. 1979 (REVISION A):
REF. FIG. 3.03111 ON PAGE 5-60 SHOWING SOME SLOPE AT ELEVATED TEMP.
IT TURNED OUT THAT STRESSES IN THE BULKHEAD NEVER REACHED t_o IN ANY OF THE HONDO RUNS. CONSEQUENTLY, THE E_t VALUE USED HAD NO EFFECT ON THE COMPUTER ANSWERS.

CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER LID.			
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MAT'L IDENTIFICATION NO. 6, CONT'D.

4340 LOW ALLOY STEEL

STRAIN RATE SENSITIVITY IS MINIMAL FOR 4340 MATERIAL @ 300 °F PER REF. 1, PG. 15.

MATERIALS DATA FROM REF. 7 (AEROSPACE STRUCTURAL METALS HANDBOOK, DEPT. OF DEFENSE):

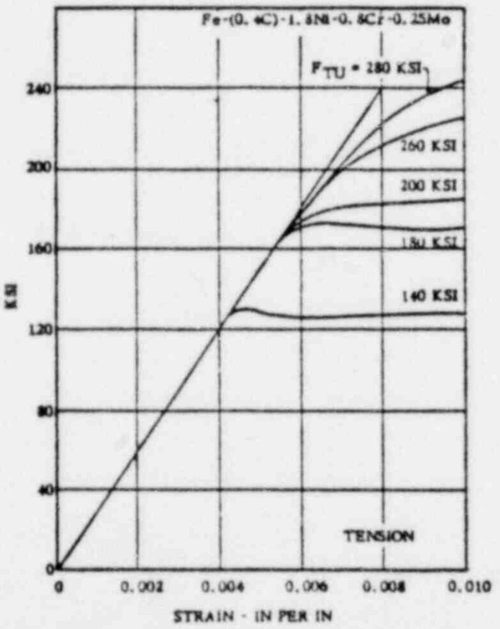

FIG. 3.03111 TYPICAL STRESS-STRAIN CURVES FOR VARIOUS STRENGTH LEVELS (31) (35)

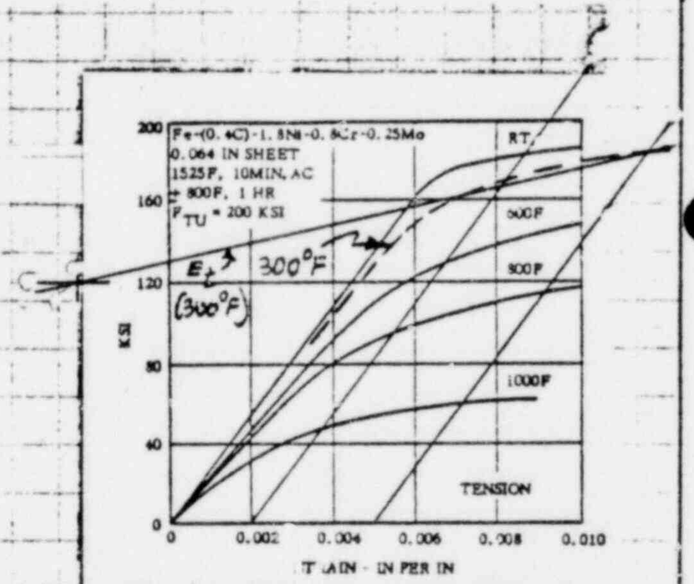

FIG. 3.03111 STRESS STRAIN CURVES AT ROOM AND ELEVATED TEMPERATURES FOR SHEET HEAT TREATED TO F_{TU} = 200 KSI (20, p. 15)

CODE	1206
PAGE	13

CODE	1206
PAGE	6

	Fe
0.4	C
1.8	Ni
0.8	Cr
0.25	Mo

4340, 4337

FIG. 3.03111: 300 °F DATA & .002 & .005 ELASTIC LINES ADDED.

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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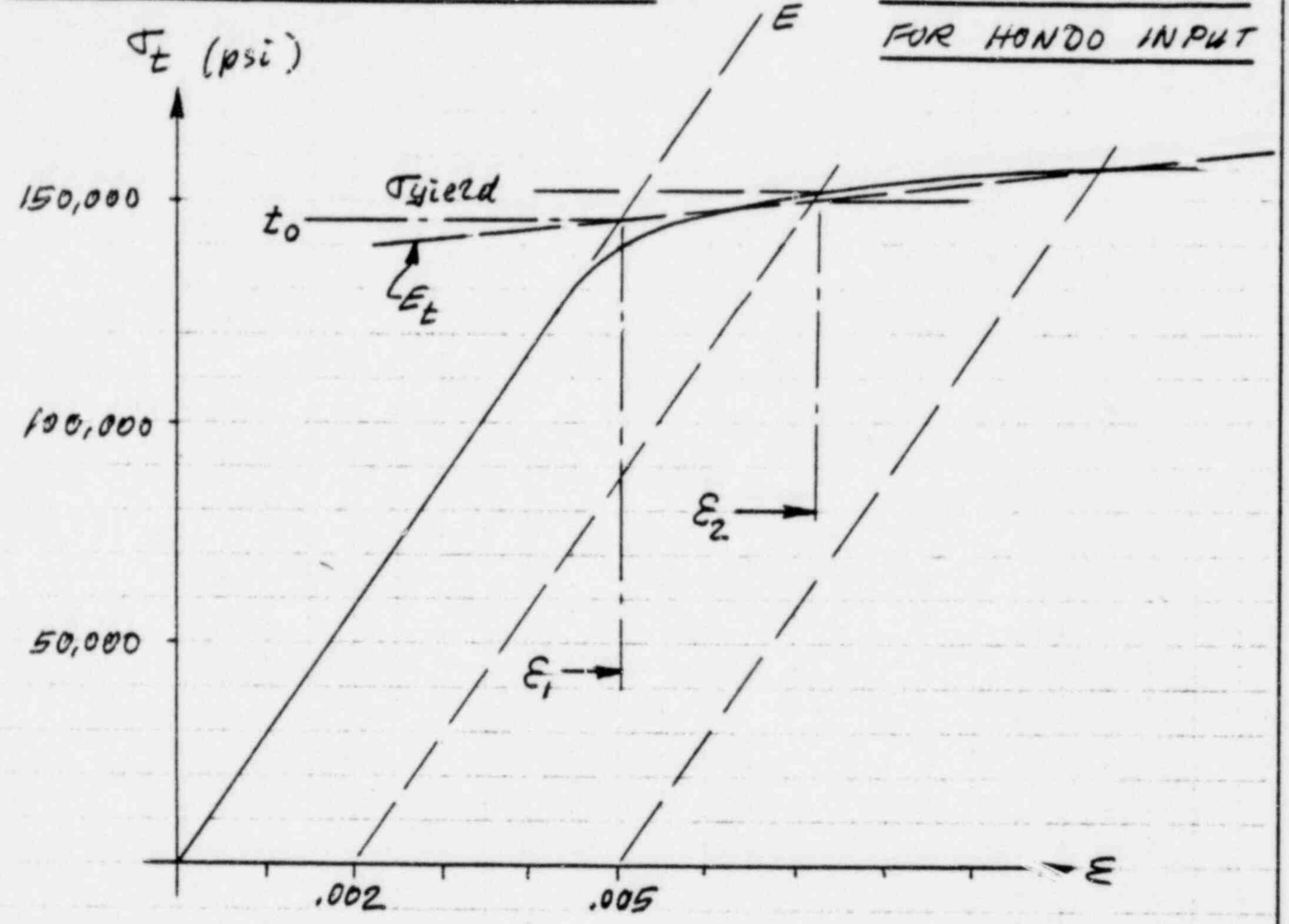
APPROVED BY	DATE		

VERTICAL IMPACT ANALYSIS

MATERIALS DATA FOR HONDO INPUT



DETAIL OF STRESS-STRAIN CURVE FOR 4340 LOW ALLOY STEEL (F_{tu} = 175 ksi) @ 300 °F

t_0 = 145 000 psi

E_t = 2.22×10^6 psi

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.
EQUIP. NO. PROJ. NO. CALC. NO. PAGE OF
PREPARED BY P. S. Brufford DATE 23 March 78 REF. DOCUMENTS:
REVIEWED BY John Glacko DATE June 9-78
APPROVED BY DATE

BOTTOM 30 FT. DROP

SUMMARY OF MATERIALS DATA FOR HONDO INPUT. REF. PG. 5-44 THROUGH 5-61

ITEM	MAT'L IDENT. NO	MAT'L	TEMP. (°F)	MASS DENSITY $\left(\frac{LB\ SEC^2}{IN^4}\right)$	E (10^6 psi)	ν	t_o (psi) STRAIN RATE SENSITIVE CASE ($\dot{\varepsilon} = 10^{-6}$)	STRAIN RATE INSENSITIVE CASE ($\dot{\varepsilon} = 10^{-3}$)	E_t (10^6 psi)	p	$D \times 10^5$	NOTES
CASK SHELLS CONTAINER SHELL	1	304 S.S. CAST	250	.0007511	27.4	.3	29 500	29 500	.4093	← NOTE	3 →	9
URANIUM SHIELD, LID	2	.2% MO-U. ALLOY CAST	300	.0017602	21.1	.21	8 180	28 000	1.35	3.113	6.362	4 5 6
URANIUM SHIELD, CYLINDER	3	.2% MO-U. ALLOY CAST	250	.0017640	22.73	.21	18 756	64 200	3.15	3.113	6.362	4 7
PRIMARY CLOSURE, TOP MEMBRANE	4	304 S.S. (LOW E)	300	.0007511	ARBITRARY	.3	28 400	28 400	.4093	← NOTE	3 →	5 9
PRIM. CLOSURE PLATE, TOP END OF CASK SHELLS	5	304 S.S.	300	.0007511	27.1	.3	28 400	28 400	.4093	← NOTE	3 →	5 9
TOP HEAD OF CASK	6	4340 LOW ALLOY STEEL F_{tu} = 175 ksi	300	.0007382	29.0	.3	NOTE 8	145000	2.22	← NOTE	8 →	5 6 9

NOTES:

1. SYMBOLS PER REF. 6, PG. 41.
2. $\beta = 1.0$ FOR ALL MATERIALS.
3. 304 S.S. : $t_y = t_o + [3571][\log_{10}(10^3 \dot{\varepsilon})]$ FOR $\dot{\varepsilon} \geq 10^{-5}$ IN STRAIN RATE SENSITIVE CASE.
4. STRAIN RATE SENSITIVITY GOVERNED BY POWER LAW (REF. 6, PG. 18) FOR MAT'LS NO. 2 & 3.
5. TOP END OF CASK IS INSULATED BY PLYWOOD. DESIGN TEMP. = 300 °F.
6. STRESS-STRAIN CONSTANTS BASED ON TENSILE DATA.
7. STRESS-STRAIN CONSTANTS BASED ON COMPRESSION DATA.
8. STRAIN RATE SENSITIVITY IS NEGLIGIBLE FOR MAT'L NO. 6 @ 300 °F (REF. 1, PG. 15)
9. STRESS-STRAIN FUNCTIONS FOR THIS MAT'L ARE SIMILAR FOR TENSION AND COMPRESSION WITHIN RANGE CONSIDERED (PERMANENT SET ≤ .5%).

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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PREPARED BY	DATE 28 March, -78	REF. DOCUMENTS:	
REVIEWED BY	DATE June 9-78		
APPROVED BY	DATE		

VERTICAL IMPACT ANAL.

LIST OF REFERENCES

1. H. J. RACK: "THE INFLUENCE OF STRAIN RATE AND TEMPERATURE --- STEELS -- SHIPPING CASK" SAND-75-0579. UC-79c. DTD. FEBRUARY 1976.
2. ASME CODE SECT. III, 1974 EDITION INCLUDING ALL ISSUED ADDENDA THROUGH WINTER 1974 ADDENDA.
3. DELETED FOR REVISION A. INFORMATION INCLUDED IN REF. 4.
4. GADR-55 SUPPLEMENT B "FINAL DESIGN REPORT FOR FORT ST. VRAIN FUEL SHIPPING CASK--" MAY 22 1970
5. BURKE, COLLING, GORUM, & GREENSPAN: "PHYSICAL METALLURGY OF URANIUM ALLOYS" FIRST ED. 1976.
6. SLA-74-0039 "HONDO - A FINITE ELEMENT COMPUTER PROGRAM ---" BY S.W. KEY APRIL 1974.
7. AEROSPACE STRUCTURAL METALS HANDBOOK. DEPARTMENT OF DEFENSE.
8. BLASCH, STUKENBROEKER, LUSKY, BONILLA, BERGER: "THE USE OF URANIUM AS A SHIELDING MATERIAL". NUCLEAR ENGINEERING AND DESIGN, VOL. 13 (1970), PG. 146 & ON.
9. Y-DA-3616 "COMPILATION OF THE MECHANICAL PROPERTIES OF DILUTE (5 PERCENT MAXIMUM) ALLOYS OF URANIUM." UNION CARBIDE CORP.
10. J. M. STEICHEN: "HIGH STRAIN RATE MECHANICAL PROPERTIES OF TYPE 304 STAINLESS ---" HEDL-TME 71-145. HANFORD ENG. DEVELOPM. LAB. DTD. SEPTEMBER 1971.

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L.	DATE 16 Feb., 1979	REF. DOCUMENTS:	
REVIEWED BY J S	DATE 2-16-79		
APPROVED BY	DATE		

VERTICAL IMPACT ANAL.

LIST OF REFERENCES, CONT'D.

11. 209:254:75 "IMPACT TESTS OF DEPLETED URANIUM". G.A. MEMO FROM A. B. SMITH TO M. K. NICHOLS, DATED 5 MAY 1978.

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK, BOTTOM 30 FT. DROP.			
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PREPARED BY P. G. Stanford	DATE 27 April, '78	REF. DOCUMENTS:	
REVIEWED BY C. M. Charman	DATE 13 June, 78		
APPROVED BY	DATE		

HONDO MODEL

A DESCRIPTION (GEOMETRY, NODE & ELEMENT NUMBERS, ELEMENT MATERIAL DESIGNATIONS) OF THE HONDO MODEL (REF. 6) IS PRESENTED ON PAGES 5-66 THROUGH 5-71.

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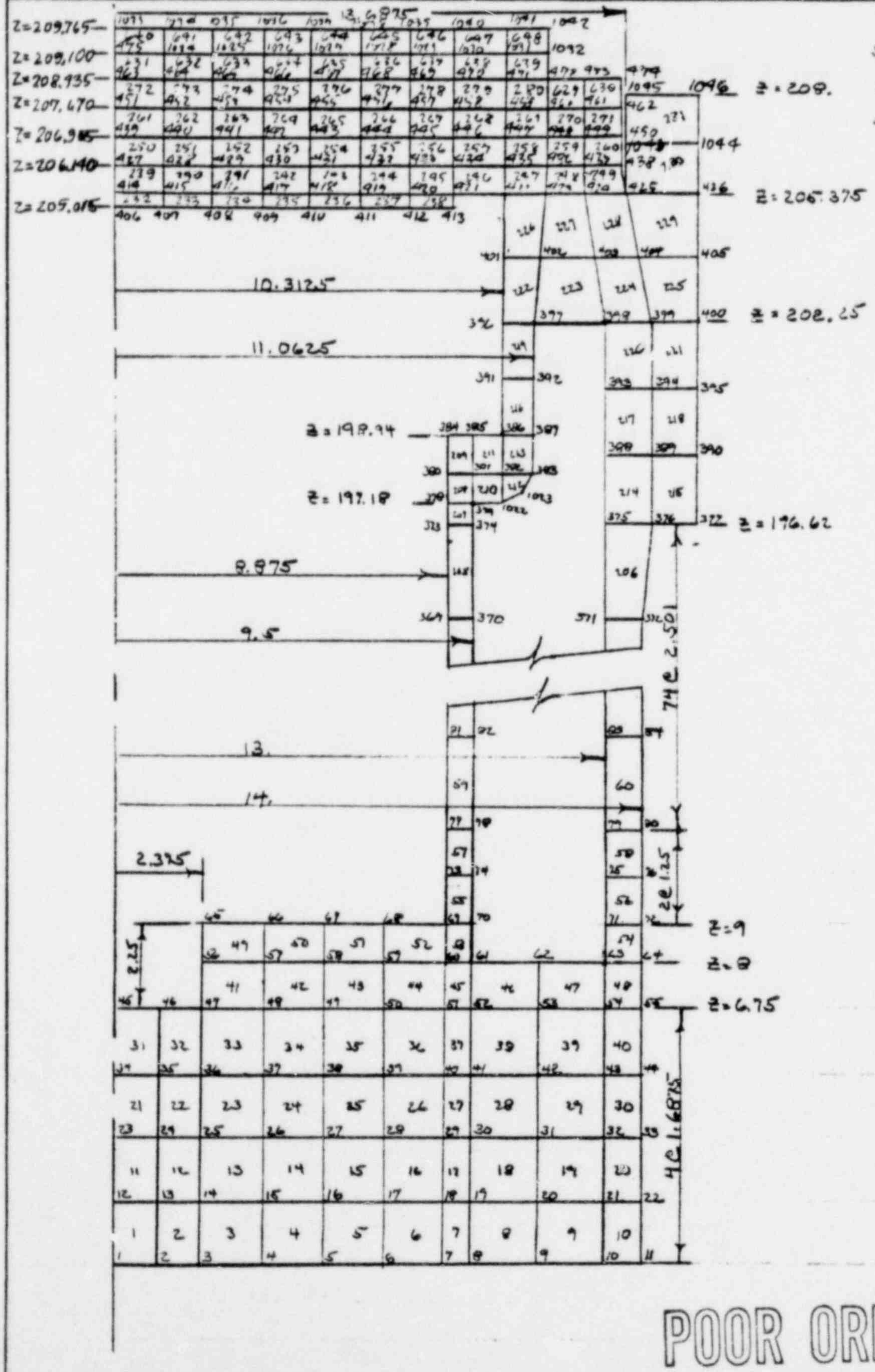

STAINLESS STEEL
SHELLS
4340 STL. TOP BULKH'D.

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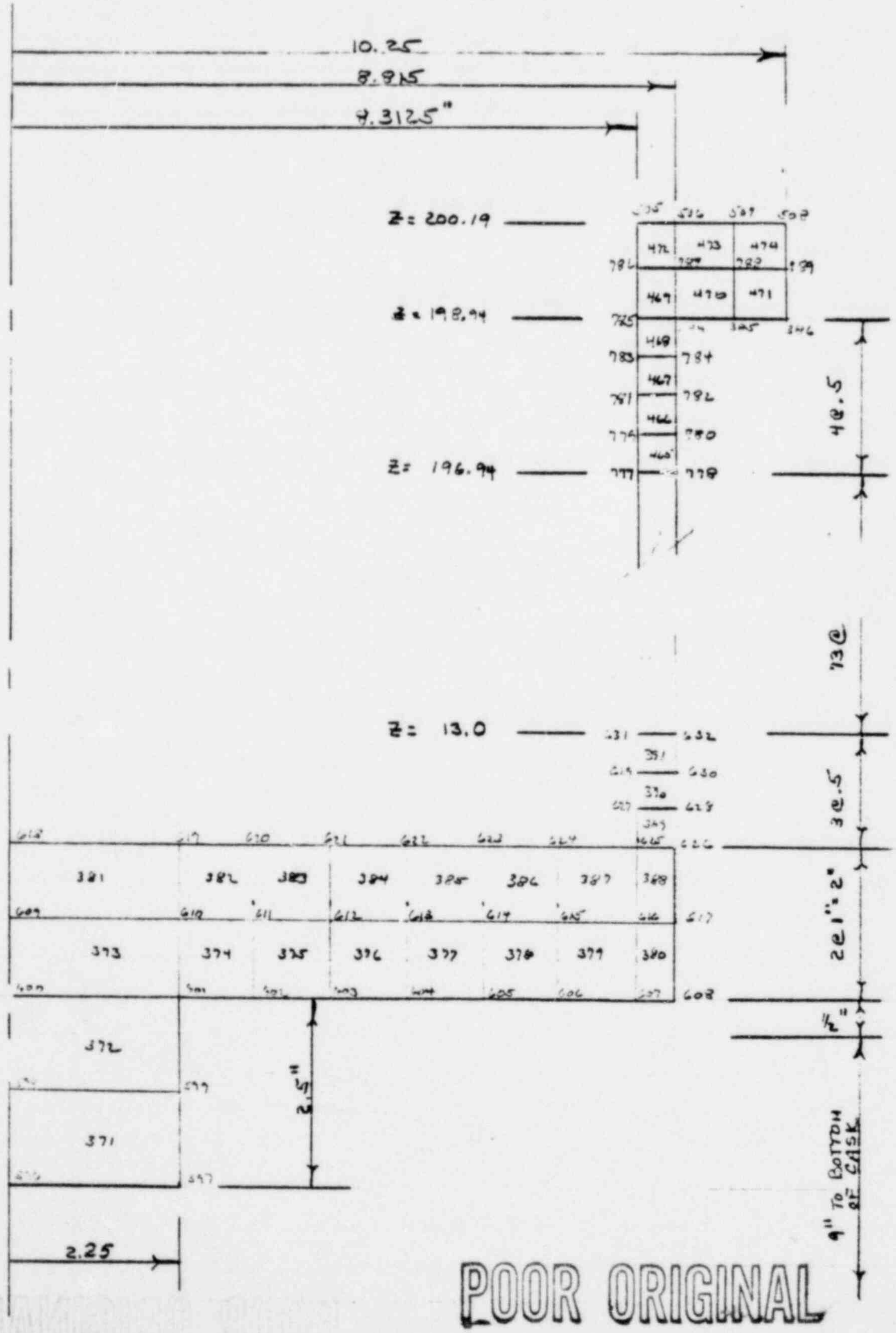
REVIEWED BY D. L. Tinsford	DATE 28 April, -78		
APPROVED BY	DATE		



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CALCULATIONS FOR			
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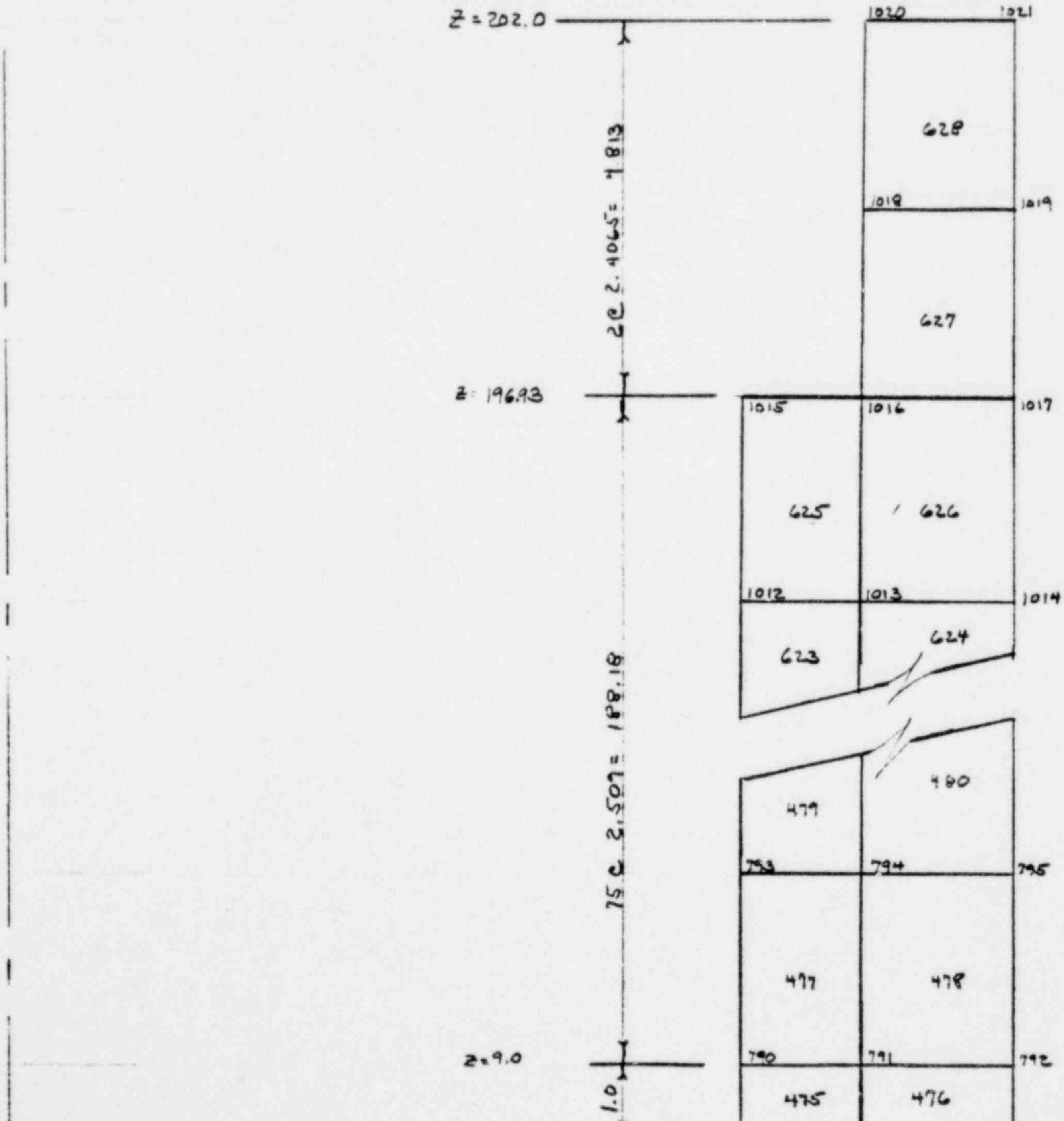
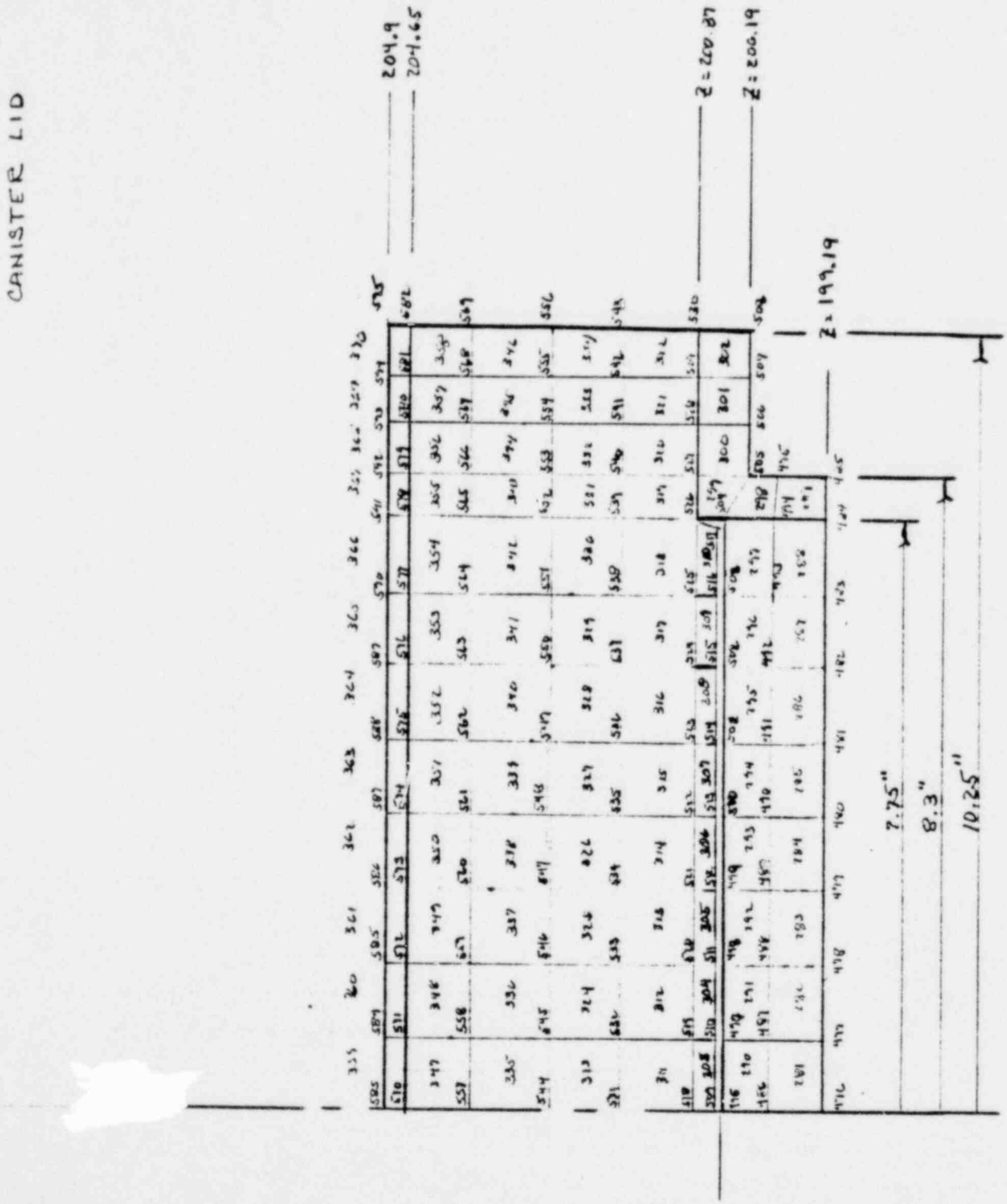
PREPARED BY	DATE	REF. DOCUMENTS:	
REVIEWED BY P. L. [illegible]	DATE 28 April -78		
APPROVED BY	DATE		



POOR ORIGINAL

CALCULATIONS FOR			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE	REF. DOCUMENTS:	
REVIEWED BY D. L. Winford	DATE 28 April '78		
APPROVED BY	DATE		



POOR ORIGINAL

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
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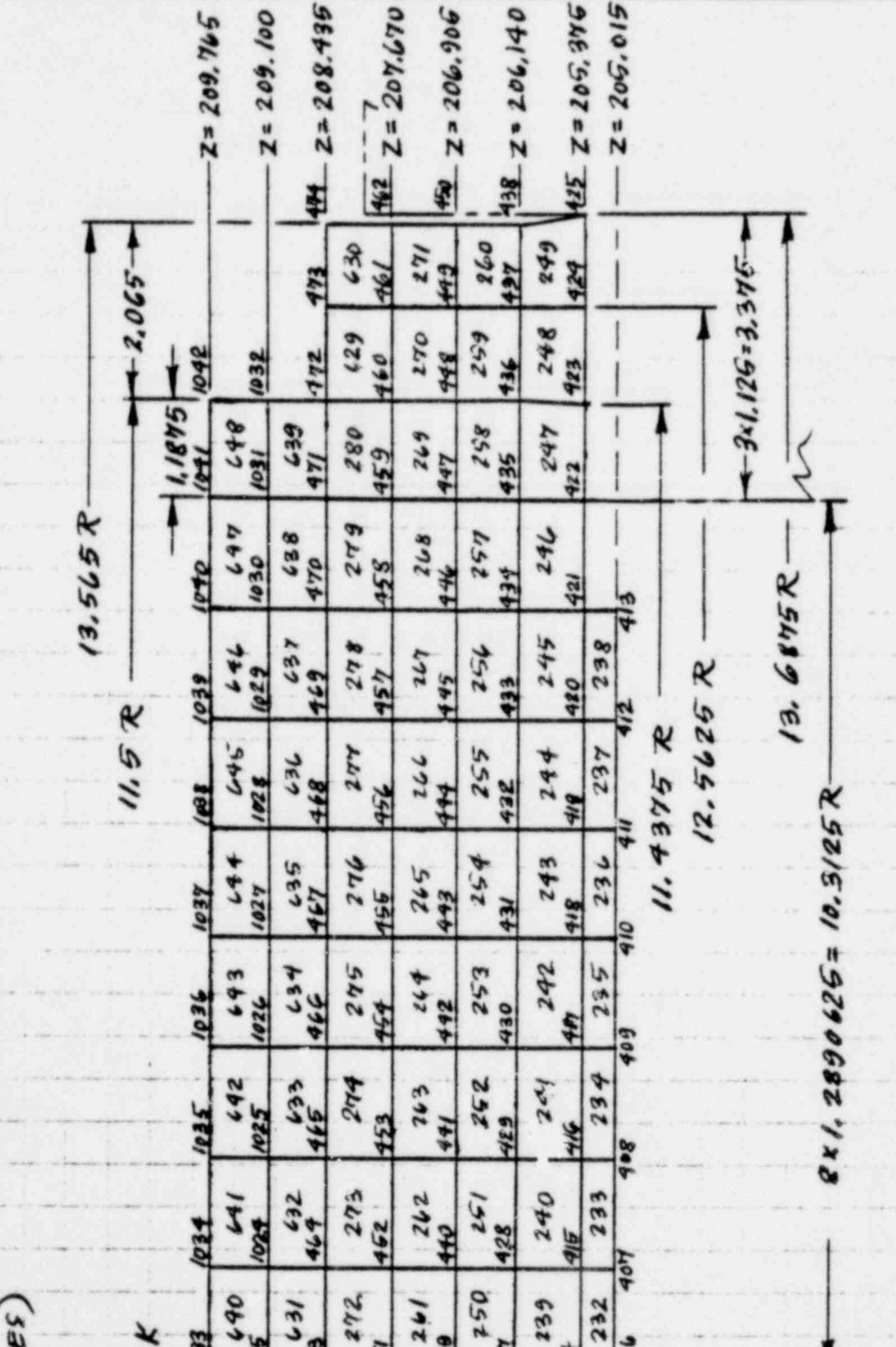
PREPARED BY D. S. Stanford	DATE 5 April, 78	REF. DOCUMENTS:	
REVIEWED BY C. M. Charman	DATE 13 June, 78		
APPROVED BY	DATE		

HONDO MODEL. TOP BULKHEAD

4340 LOW ALLOY STEEL (F_{tu} = 175 ksi)

SCALE : 1/2

DIMENSIONS IN INCHES



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CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. L. Stanford	DATE 6 April, 1978	REF. DOCUMENTS:	
REVIEWED BY C.M. Chairman	DATE 13-June, 1975		
APPROVED BY	DATE		

BOTTOM 30 FT DROP

HONDO MODEL. ELEMENT MATERIALS SUMMARY

ELEMENT		ITEM	MATERIAL	TYPE (IDENTIFICAT. NO.)
FROM	TO			
1	206	CASK SHELLS	304 S.S. @ 250 °F	1
207	231	TOP END OF CASK SHELLS	304 S.S. @ 300 °F	5
232	280	BULKHEAD TOP END	4340 LOW ALLOY STEEL	6
281	302	PRIMARY CLOSURE PLATE	304 S.S. @ 300 °F	5
303	358	URANIUM SHIELD, LID	.2 % Mo URANIUM ALLOY	2
359	370	PRIMARY CLOSURE, TOP MEMBRANE	304 S.S. (LOW E)	4
371	464	CONTAINER SHELL	304 S.S. @ 250 °F	1
465	474	CONTAINER SHELL, TOP END	304 S.S. @ 300 °F	5
475	628	URANIUM SHIELD, CYLINDER	.2 % Mo URANIUM ALLOY	3
629	648	BULKHEAD TOP END	4340 LOW ALLOY STEEL	6

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID & BULKHEAD.			
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BOTTOM 30 FT. DROP

CONCLUSIONS OF HONDO ANALYSIS

DISCUSSION AND SUMMARY

THE TWO HONDO RUNS MADE (FOR STRAIN RATE SENSITIVE AND STRAIN RATE INSENSITIVE MATERIAL BEHAVIOR) WERE BASED ON AN ASSUMED PERFECTLY VERTICAL BOTTOM IMPACT AFTER A 30 FT. DROP.

ANY IMPACT AT AN ANGLE WITH THE VERTICAL SUFFICIENTLY SMALL TO PREVENT THE CASK FROM FALLING ON ITS SIDE AFTER THE INITIAL CONTACT (THAT IS WITH THE PROJECTED C.G. BEING WITHIN THE BOTTOM SUPPORT CIRCLE) WILL BE VERY SIMILAR TO THE PERFECTLY VERTICAL CASE. IN FACT, AN IMPACT AT A SLIGHT ANGLE WILL PROBABLY RESULT IN MORE ENERGY ABSORPTION THROUGH PLASTIC FLOW [IN COMPRESSION WITH NO TENDENCY TO CRACKING] OF THE IMPACTED CORNER AND CONSEQUENTLY A LOWER G-LOADING OF THE CONTAINER LID STRUCTURE. THE PERFECT CASE ANALYZED SHOULD THEREFORE CONSERVATIVELY COVER ALL IMPACTS WITH THE PROJECTED C.G. WITHIN THE BOTTOM SUPPORT CIRCLE.

A DROP AT A LARGER ANGLE WITH THE VERTICAL WILL BE LESS SEVERE ON THE INITIAL IMPACT BECAUSE PART OF THE FALL ENERGY IS BEING CONVERTED INTO ROTATION OF THE CASK. THE EVENTUAL SIDE IMPACT OF THE CASK WOULD BE

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID & BULKHEAD.			
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CONT'D:

LESS SEVERE THAN A PERFECT SIDE IMPACT AFTER A 30 FT. DROP. IN CONCLUSION THE PERFECT VERTICAL IMPACT AND THE PERFECT HORIZONTAL IMPACT CASES WILL CONSERVATIVELY COVER ANY CASE IN BETWEEN.

THE FOLLOWING COMPUTER GENERATED PLOTS ARE PRESENTED ON THE FOLLOWING PAGES:

1) COMPUTER MODEL WITH NODE & ELEMENT NUMBERS (RESULT OF A MESH GENERATION PROGRAM).
2) PLOTS FROM TIME OF IMPACT OF SELECTED STRESSES, DISPLACEMENTS, AND DISPLACEMENT GRADIENTS ($\frac{L+\Delta L}{L}$) VS. TIME FOR THE STRAIN RATE SENSITIVE AND STRAIN RATE INSENSITIVE CASE (HONDOPLOT).

IT IS EVIDENT FROM THE PLOTS THAT ABSOLUTE VALUES OF ALL CRITICAL STRESSES ARE MAXIMUM FOR THE STRAIN RATE SENSITIVE CASE. ABSOLUTE VALUES OF ALL CRITICAL DISPLACEMENTS ARE MAXIMUM FOR THE STRAIN RATE INSENSITIVE CASE.

VERTICAL DISPLACEMENTS OF TOP BULKHEAD LOWER SURFACE AND CONTAINER LID UPPER SURFACE VS. TIME ARE VIRTUALLY IDENTICAL. SIMILARLY, THE BOTTOM SURFACE OF THE URANIUM SHIELD IN THE CONTAINER LID AND THE TOP SURFACE OF THE LID ITSELF ARE MOVING AT THE SAME RATE. THUS, THERE APPEARS TO BE NO PROBLEM OF INTERFERENCE AMONG THESE PARTS BY CLOSING OF THE INITIAL GAPS BETWEEN THEM.

THE MAXIMUM ABSOLUTE PRINCIPAL STRESSES IN THE TOP END OF THE CASK HAVE BEEN EXTRACTED

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID & BULKHEAD.			
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REVIEWED BY C. M. Charmonge	DATE 13 June, 78		
APPROVED BY	DATE 2-16-79		

CONT'D.:

FROM THE HONDO OUTPUT AND LISTED BELOW. AS EXPECTED SOME YIELDING WILL TAKE PLACE IN THE CYLINDRICAL STAINLESS STEEL PORTION OF THE CASK AND CONTAINER SHELLS. HOWEVER, STRESSES IN THE CONTAINER LID AND BULKHEAD ARE BELOW THE YIELD STRENGTHS OF THE MATERIALS AT 300 °F. DISTORTION OF THE STRUCTURE SUPPORTING THE SEALS SHOULD THEREFORE BE NEGLIGIBLE, ASSURING THAT NO LEAKAGE PAST THE SEALS DEVELOPS AS A RESULT OF THE DROP.

MAX. ABSOLUTE STRESS SUMMARY PER C.P.O. (STRAIN RATE SENSITIVE CASE). RUN NO. BOT-12

COMPONENT	ELEMENT NO.	TIME (10^{-4} secs)	PREDOMINANT STRESS TYPE(S)	MAX. OR MIN. PRINCIPAL STRESS (psi)	YIELD STRENGTH AT TEMP. (psi)	
						REF. PG.
4340 STL BULKHEAD	232 (BOTTOM ℄)	12.0	RADIAL & HOOP	38 970	150 000 (300 °F)	5-48
.2% MO-URAN. ALLOY SHIELD, LID	347 (TOP ℄) 303 (BOTT. ℄)	13.5 13.5	RAD. & HOOP RAD. & HOOP	-29 030 28 850	36300 (300 °F)	5-47
TOP END OF CASK	205 (INNER CYL.)	12.0	AXIAL COMPR.	-53 140	* 30 300 (250 °F)	5-45
TOP END OF CONTAINER	468 {CYLINDER BELOW FLANGE	19.0	AXIAL TENS.	** 50 990	* 29 200 (300 °F)	5-45
CONTAINER LID HOUSING	281 (BOTT. ℄)	13.0	RAD. & HOOP	27 860	* 29 200 (300 °F)	5-45

$$* \quad \sigma_y \sim t_o + E_t (.002) = 29500 + (409300)(.002) = \underline{30300 \text{ psi}} \text{ @ } 250°F$$

$$\sigma_y \sim t_o + E_t (.002) = 28400 + (409300)(.002) = \underline{29200 \text{ psi}} \text{ @ } 300°F$$

** ULTIMATE TENSILE STRENGTH = <u>64 300 psi</u> AT 300 °F (SEE PG. 5-97 E)

$(.90)(\text{U.T.S.}) = (.90)(64300) = \underline{57870 \text{ psi}}$

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CALCULATIONS FOR FSV FUEL SHIPPING CASK, CONTAINER LID & BULKHEAD.			
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CONCLUSIONS OF HONDO ANALYSIS, CONT'D.

BOLTS

THE $\frac{1}{2}$" BOLTS FOR THE CONTAINER LID AND THE $1\frac{1}{4}$" BOLTS FOR THE CASK COVER HEAD ARE DESIGNED FOR SIDE AND DROP CASES, AND ARE NOT CRITICAL FOR THE BOTTOM DROP CONDITIONS, WHERE THE LIDS ARE BEING FORCED BY INERTIA DOWNWARD TOWARD THE SEALS.

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID & BULKHEAD.			
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PREPARED BY P. L. Thorford	DATE 31 Jan., 1979	REF. DOCUMENTS:	
REVIEWED BY cmc	DATE 2-8-79		
APPROVED BY JG	DATE 2-16-79		

BOTTOM 1 FT. DROP

THE INTEGRITY OF THE ALTERNATE CLOSURE SYSTEM FOR A ONE FOOT BOTTOM DROP WAS VERIFIED THROUGH HONDO RUN NO. BOT-11. THIS RUN IS SIMILAR TO THE STRAIN RATE SENSITIVE CASE SUMMARIZED ON PG. 5-68 EXCEPT FOR THE INITIAL Z-VELOCITY V.

BY COMPARISON WITH PG. 5-34A:

$S = 1$ FT. $= 12$ IN. FOR $\frac{1}{2} a t^2 = 12$

OR $t = \sqrt{\frac{2 \times 12}{384}} = \underline{.25 \text{ sec.}}$

$V = 0 + (384)(.25) = \underline{96.0 \text{ in./sec.}}$

INITIAL Z-VELOCITY $= \underline{-96.0 \text{ in/sec.}}$ FOR ALL NODES EXCEPT NODES 1 THROUGH 11.

* $1.2\, S_m = (1.2)(19\,800) = 23\,040$ psi < 29 200 psi
ALLOWABLE = <u>29 200</u> psi PER REF. 2, NB-3224.1

STRESS SUMMARY PER HONDO OUTPUT FOR 1 FT. BOTTOM DROP. (STRAIN RATE SENSITIVE CASE. RUN NO. BOT-11. COMPARE W. PG. 5-68)						
COMPONENT	ELEMENT NO.	TIME (10^{-4} sec's)	PREDOMINANT STRESS TYPE (S)	MAX. OR MIN. PRINCIPAL STRESS (psi)	YIELD STRENGTH AT TEMP. (psi)	REF. PG.
4340 STL BULKHEAD	232 (BOTTOM ℄)	17.0	RADIAL & HOOP	-11 420	150 000 (300°F)	5-48
.2% MO-URAN ALLOY SHIELD, LID	347 (TOP ℄) 303 (BOT. ℄)	14.0 13.5	RAD. & HOOP RAD. & HOOP	-12 970 12 270	36 300 (300°F)	5-47
TOP END OF CASK	205 (INNER CYL.)	12.5	AXIAL COMPR.	-28 520	30 300 (250°F)	5-74
TOP END OF CONTAINER	468 {CYLINDER BELOW FLANGE	17.5	AXIAL TENS.	21 580	*29 200 (300°F)	5-74
CONTAINER LID HOUSING	281 (BOT. ℄)	13.0	RADIAL & HOOP	11 650	* 29 200 (300°F)	5-74

CALCULATIONS FOR FSV FUEL SHIPPING CASK. CONTAINER LID & BULKHEAD.			
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DROP CONDITIONS AT LOW TEMPERATURE (-40 °F)

PROTECTION AGAINST BRITTLE FRACTURE AT TEMPERATURES DOWN TO -40 °F IS PROVIDED THROUGH THE SELECTION OF PROPER MATERIALS FOR THE STRUCTURAL PARTS OF THE ALTERNATE CLOSURE SYSTEM.

THE CONTAINER LID HOUSING (304 STAINLESS STEEL SA-240) WITH ITS BOLTS (HIGH ALLOY STEEL PER AMS 5735), AND THE OUTER LID BOLTS (SA-453, GRADE 660) ARE ALL OF AUSTENITIC STAINLESS STEEL MATERIAL FOR WHICH NO IMPACT TESTING IS REQUIRED (SEE REF. 2, ART. NB-2310).

FOR THE OUTER LID HY-140(T) MATERIAL TYPICAL DATA FROM REF. 7 (AEROSPACE STRUCTURAL METALS HANDBOOK. DEPARTMENT OF DEFENSE) INDICATE AN ENERGY ABSORPTION OF AT LEAST 15 FT LB AT -40 °F.

THE .2 % MO-URANIUM ALLOY LID SHIELD MATERIAL HAS BEEN IMPACT TESTED AND FOUND TO EXHIBIT ACCEPTABLE TOUGHNESS AT -40 °F. DOCUMENTATION OF THE CHARPY V-NOTCH TESTING OF THIS AND OTHER ALLOYS OF DEPLETED URANIUM IS PROVIDED IN MEMO. NO. 209:254:75 FROM A. B. SMITH TO M. K. NICHOLS, DATED 5 MAY 1978 ("IMPACT TESTS OF DEPLETED URANIUM"), REF. 11.

DOCUMENT/ PAGE PULLED

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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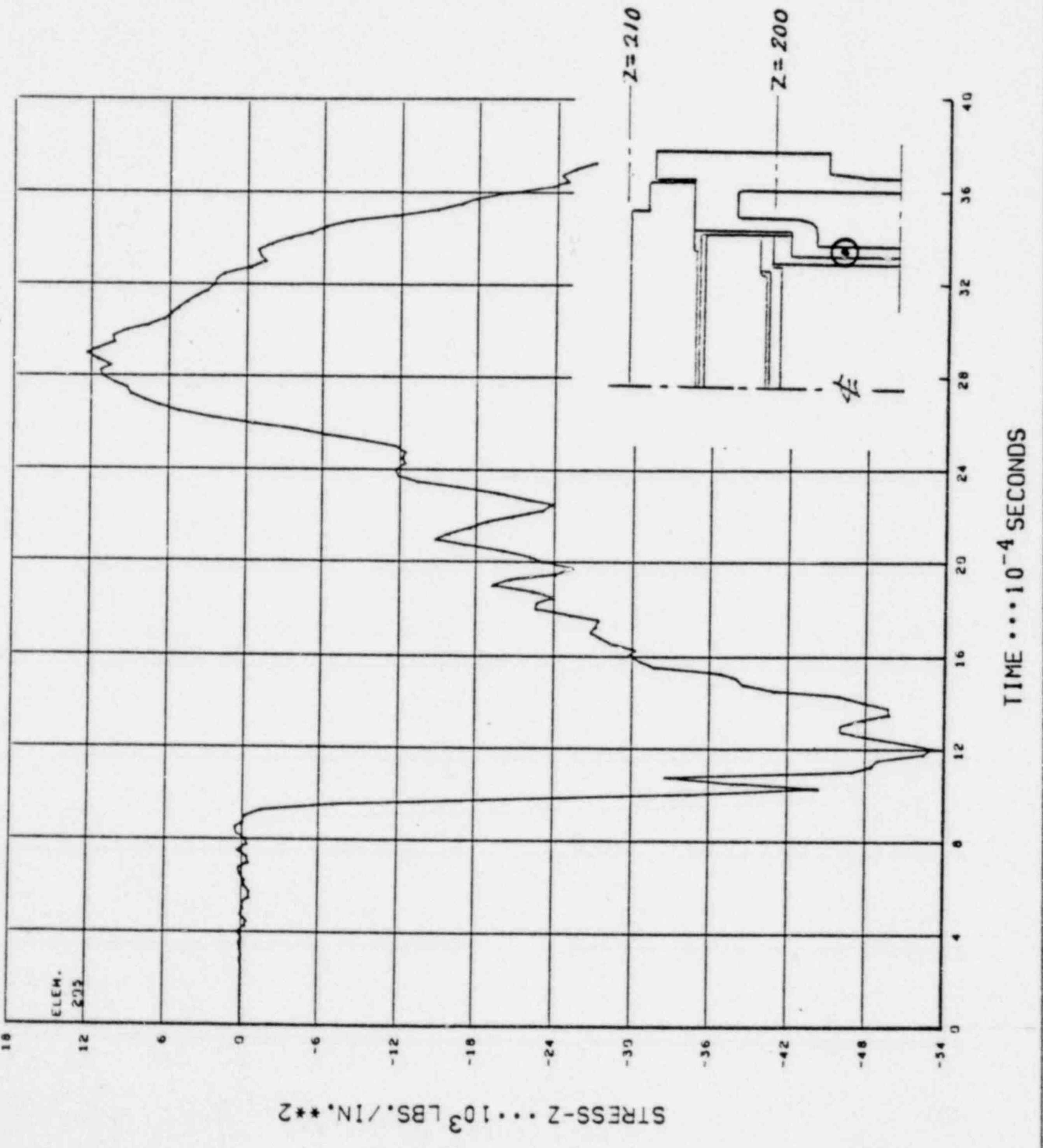
REF. HONDO RUN NO. BOT-12.

AXIAL STRESS IN ELEMENT 205. STRAIN RATE SENSITIVE CASE



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CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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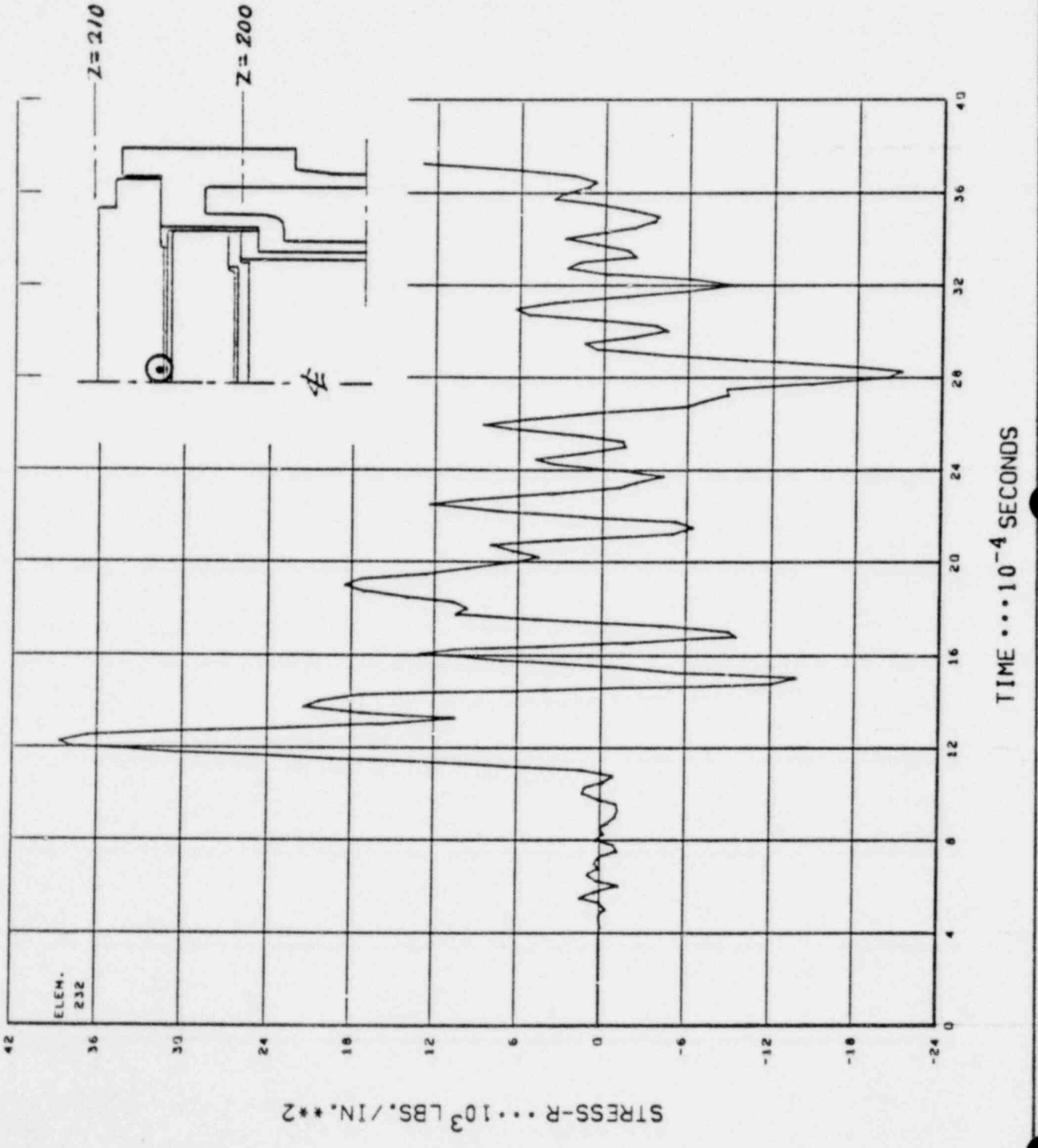
APPROVED BY	DATE		

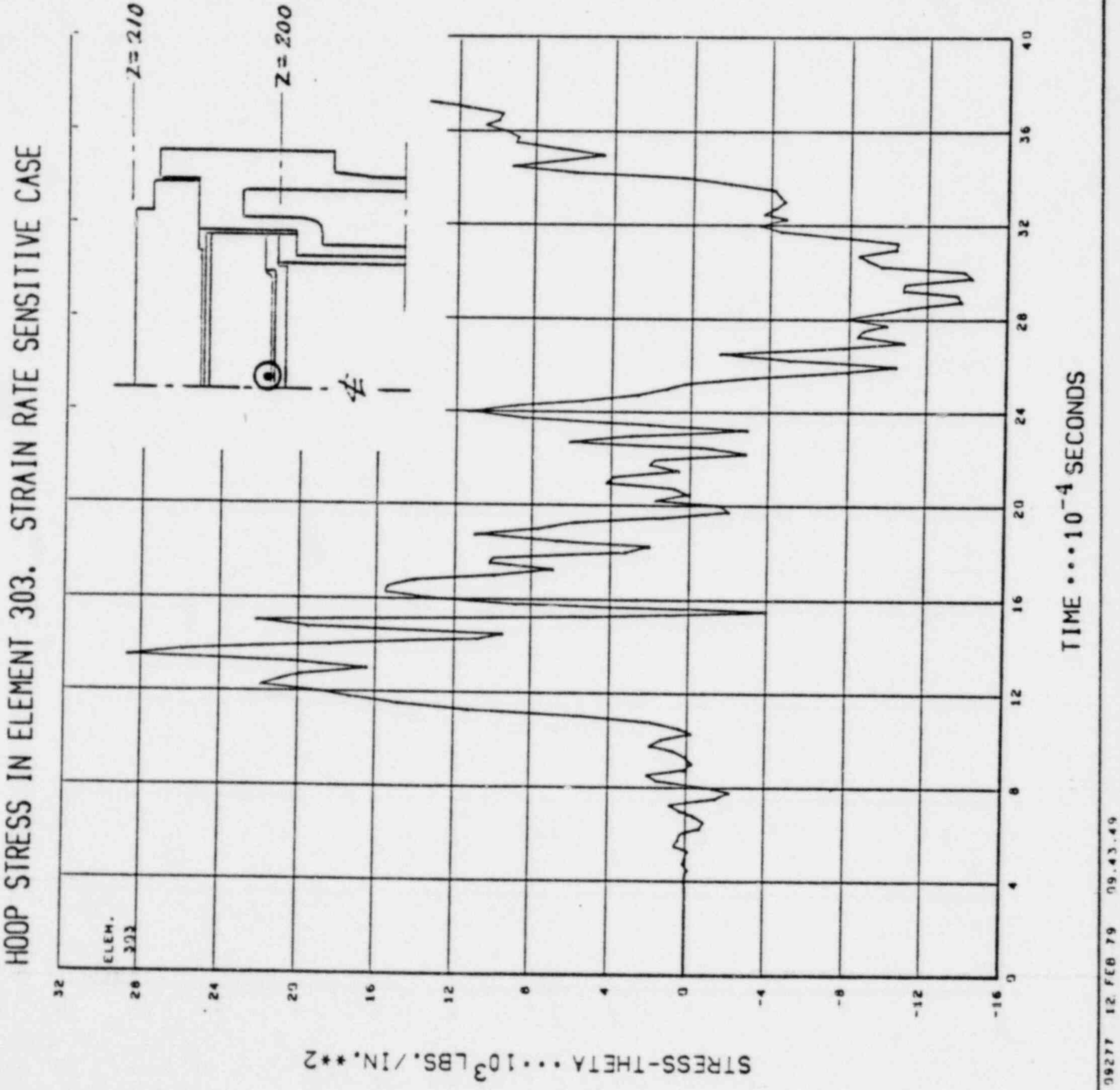
REF. HONDO RUN NO. BOT-12.

RADIAL STRESS IN ELEMENT 232. STRAIN RATE SENSITIVE CASE



CALCULATIONS FOR *FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.*			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY *P. L.*	DATE *14 Feb., 1979*	REF. DOCUMENTS:	
REVIEWED BY *J. S.*	DATE *2-16-79*		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



HOOP STRESS IN ELEMENT 303. STRAIN RATE SENSITIVE CASE

5 82

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CALCULATIONS FOR *FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.*			
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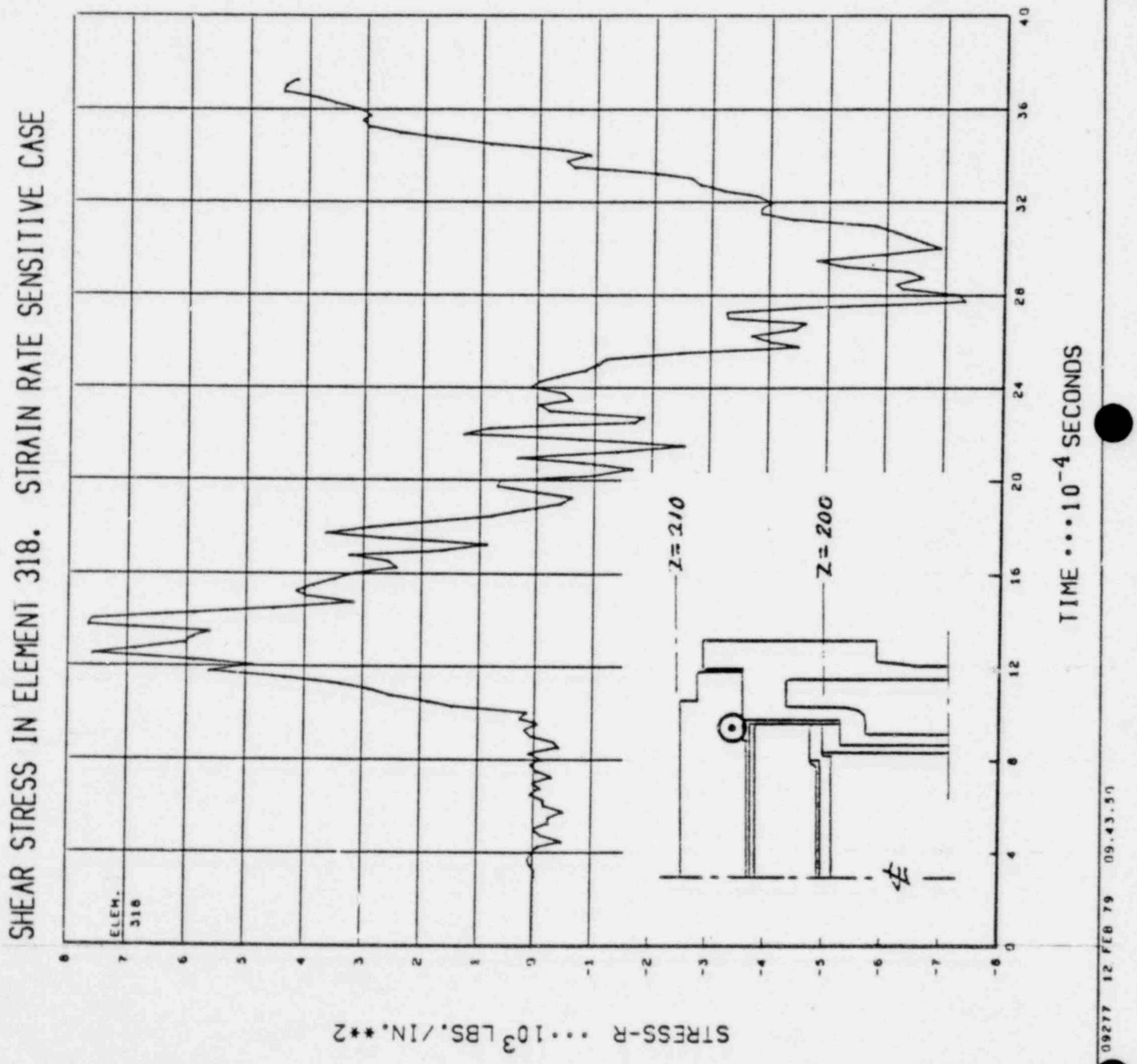
PREPARED BY *D. L. Threlford*	DATE *14 Feb., 1979*	REF. DOCUMENTS:	
REVIEWED BY *John S. Gecko*	DATE *2-16-79*		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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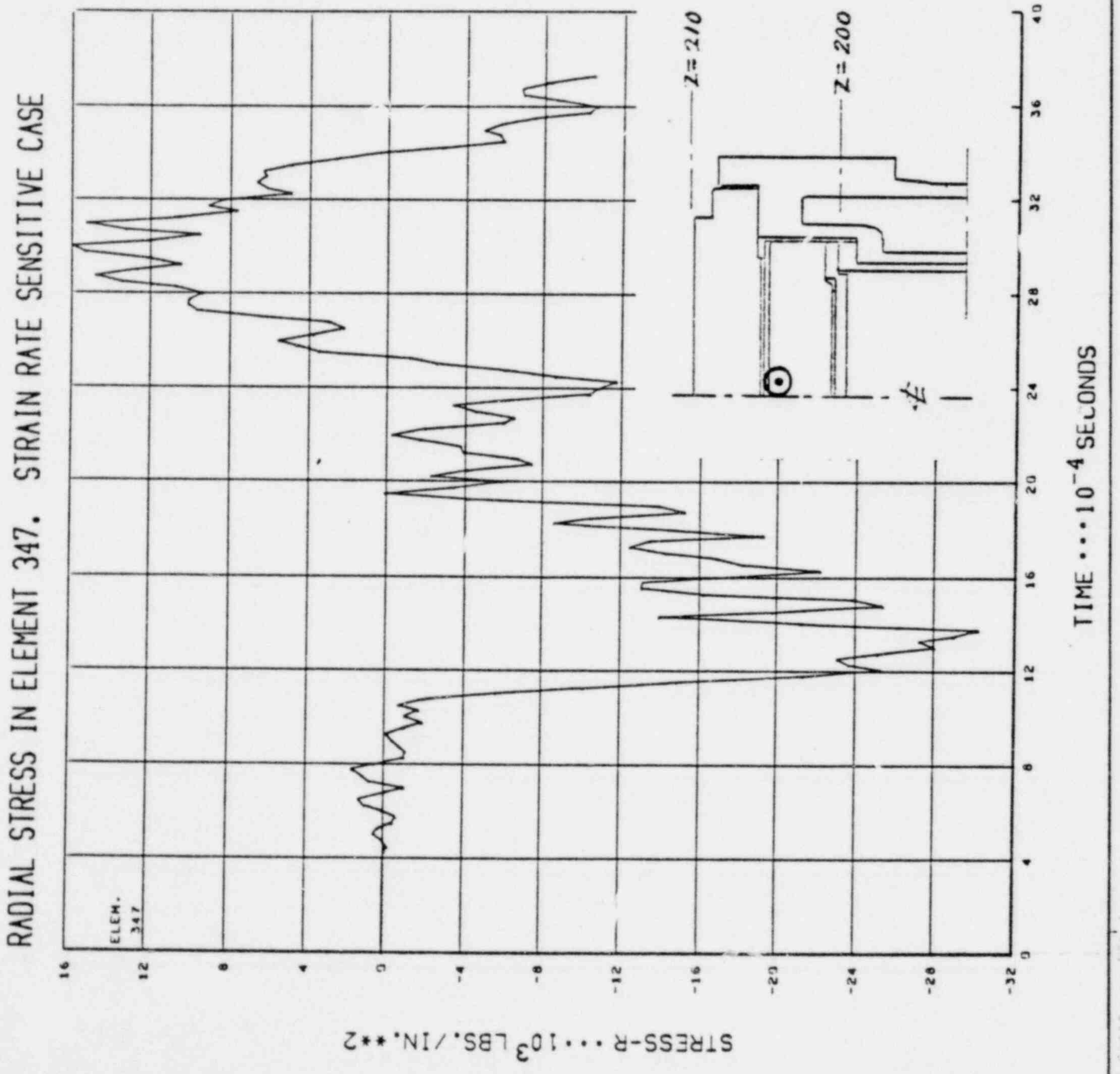
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



RADIAL STRESS IN ELEMENT 347. STRAIN RATE SENSITIVE CASE

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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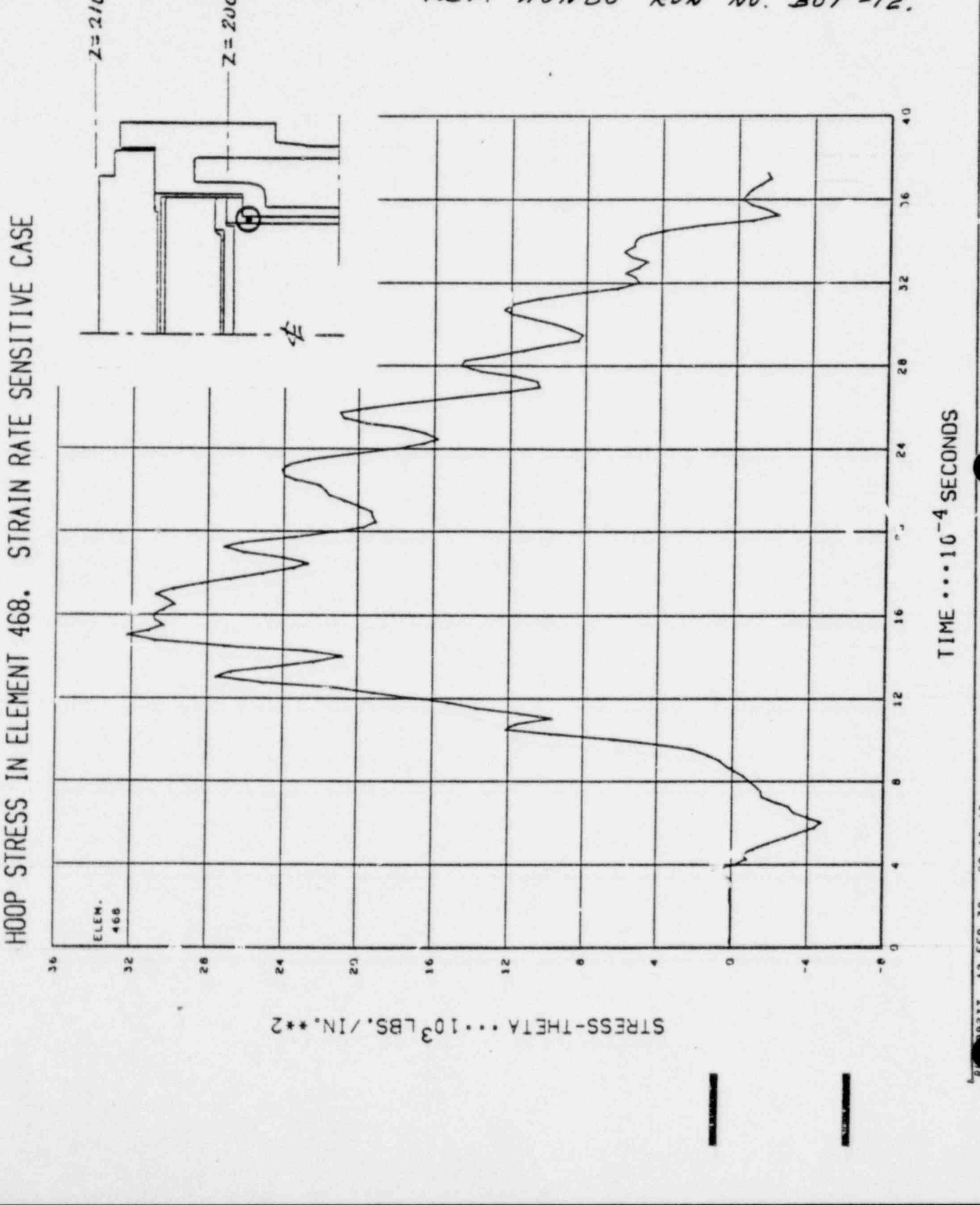
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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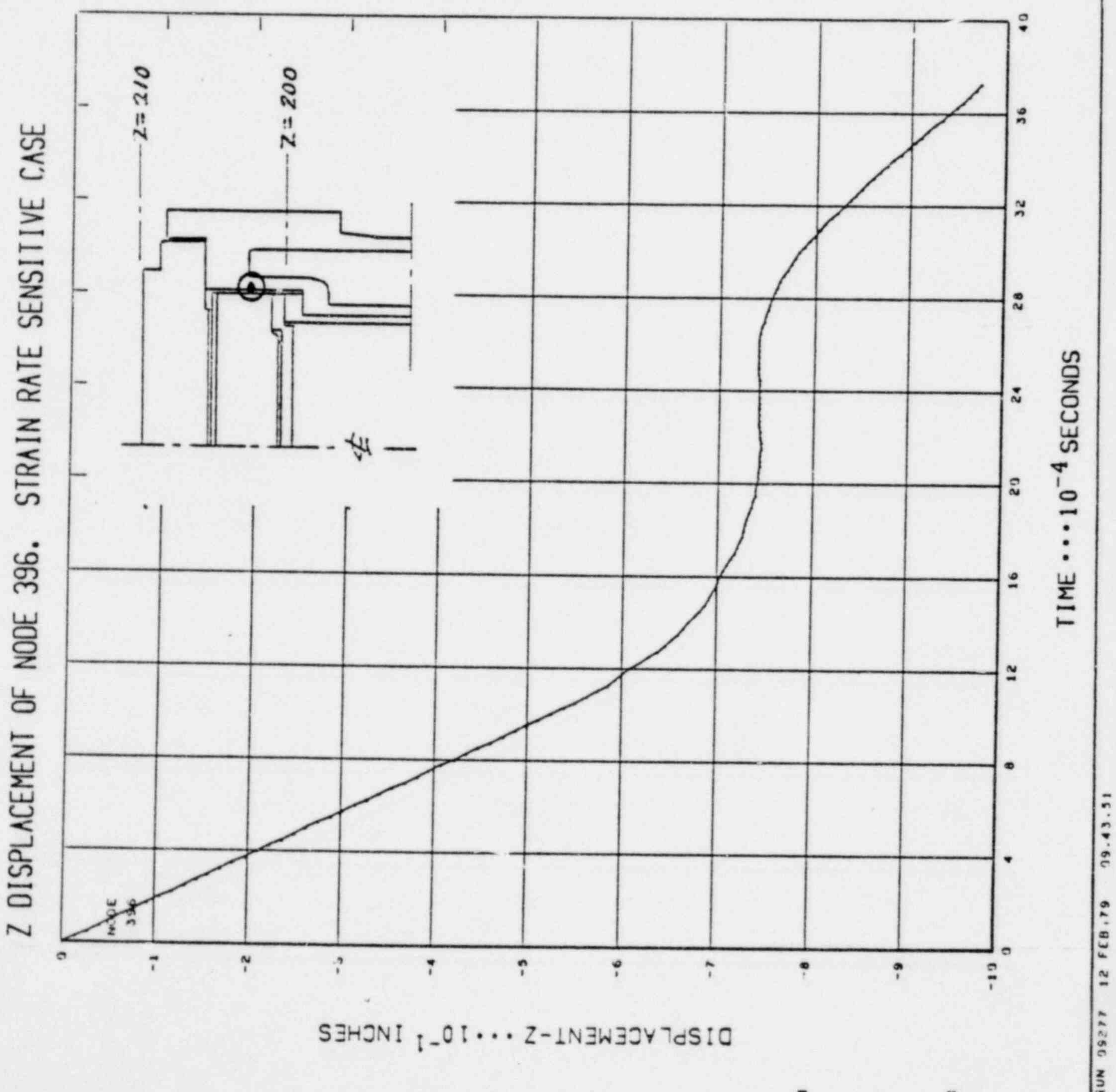
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



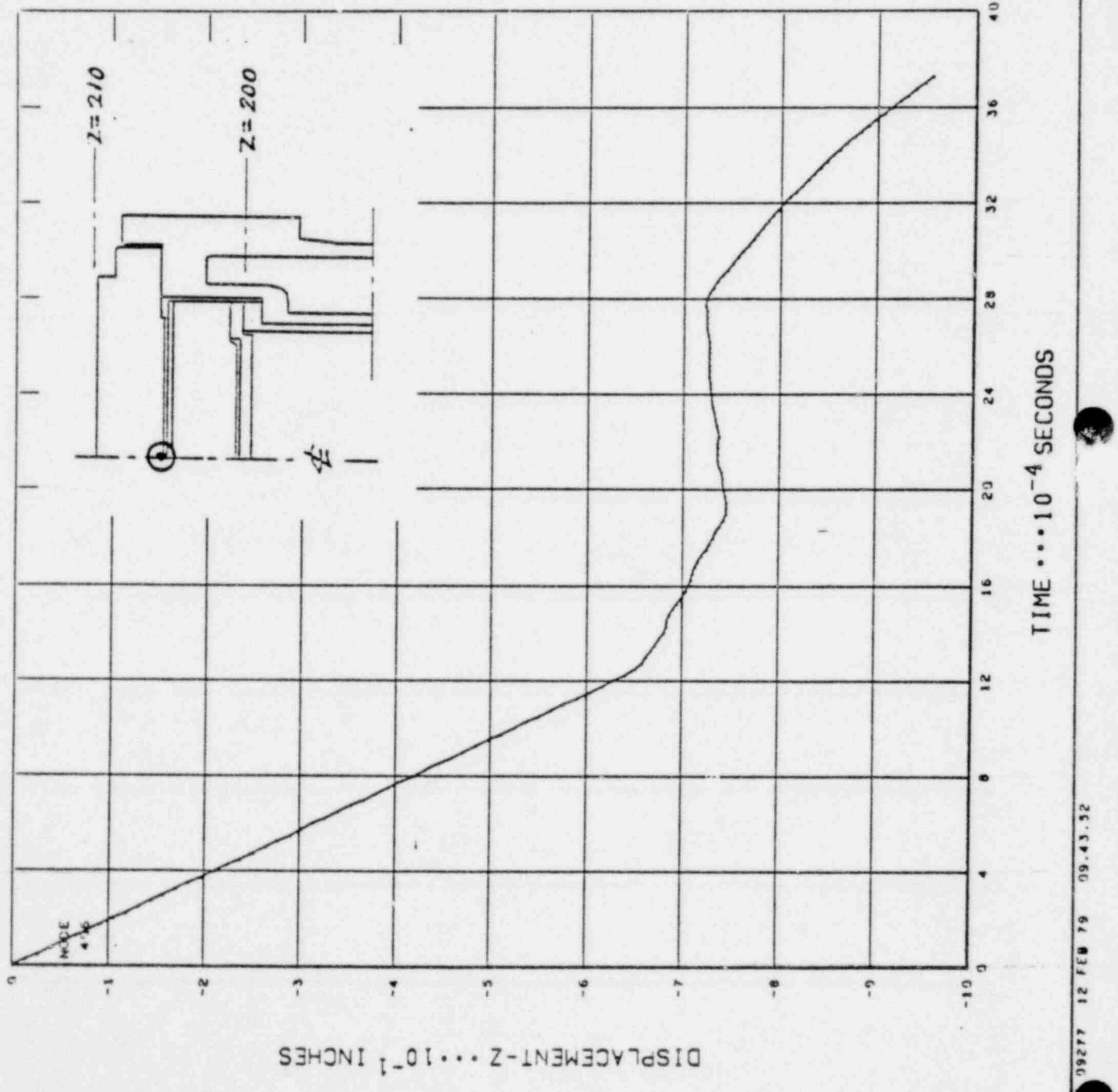
GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Hanford	DATE 14 Feb., 1979	REF. DOCUMENTS:	
REVIEWED BY J S	DATE 2-16-79		
APPROVED BY	DATE		

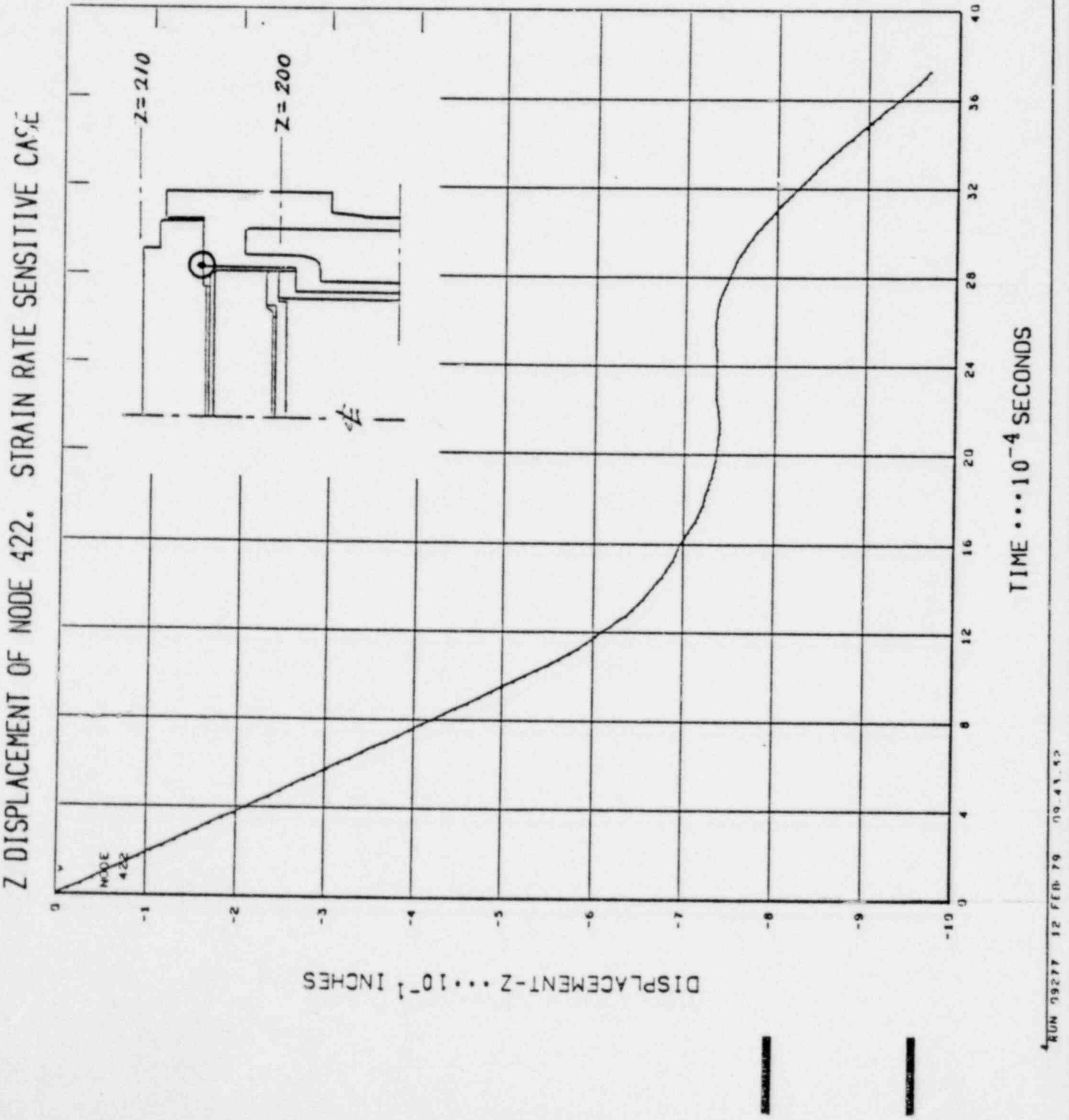
REF. HONDO RUN NO. BOT-12.

Z DISPLACEMENT OF NODE 406 (Z=205.015). STRAIN RATE SENSITIVE CASE



CALCULATIONS FOR *FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.*			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY *P. L. Thurford*	DATE *14 Feb., 1949*	REF. DOCUMENTS:	
REVIEWED BY *J S Glacko*	DATE *2-16-79*		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



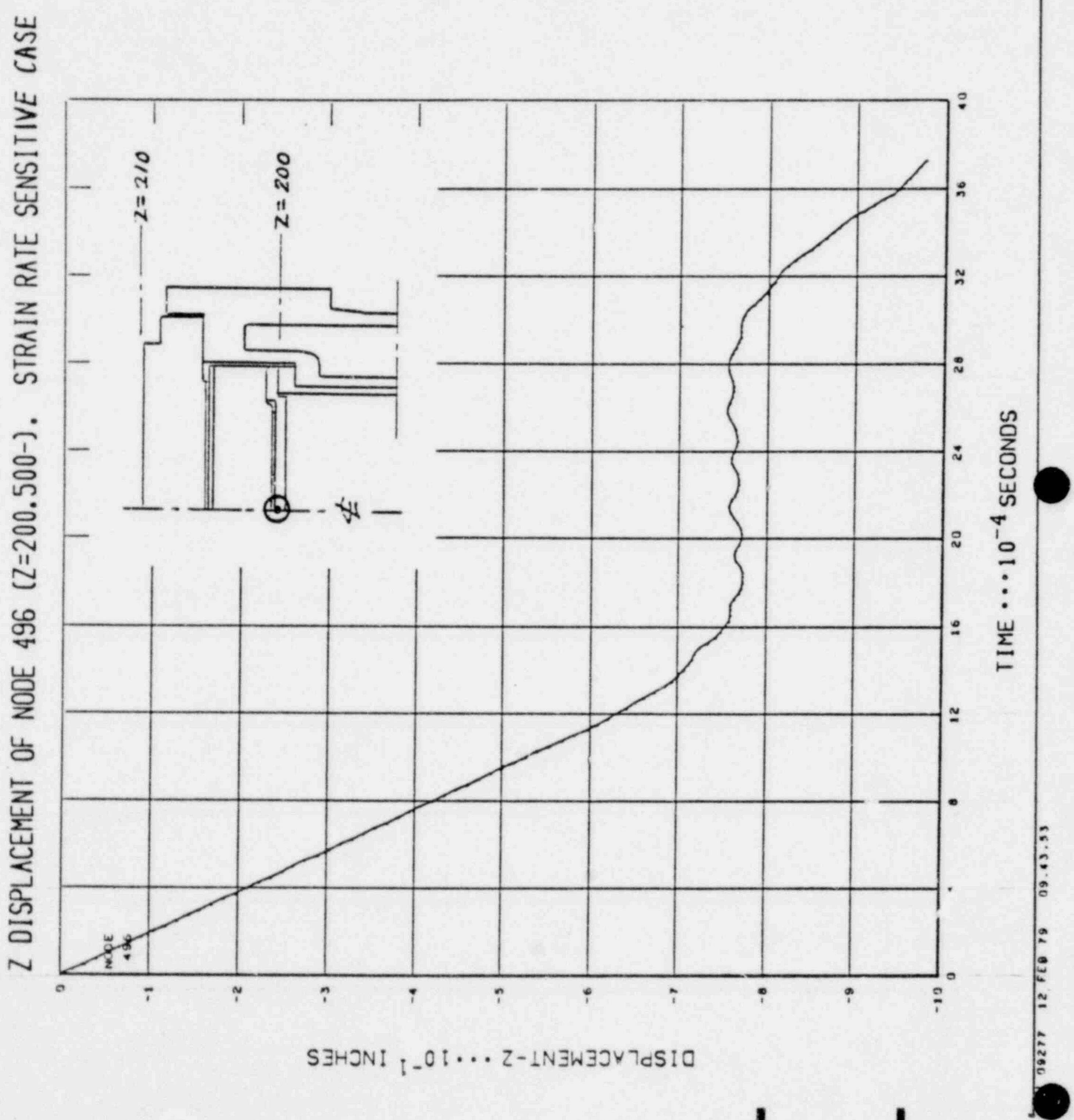
GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.

EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY R. L. Morford	DATE 14 Feb., 1979	REF. DOCUMENTS:	
REVIEWED BY J. S. Glacho	DATE 2-16-79		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.



GA 268 Rev. 1/74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.

EQUIP. NO.	PROJ. NO.	CALC. NO.
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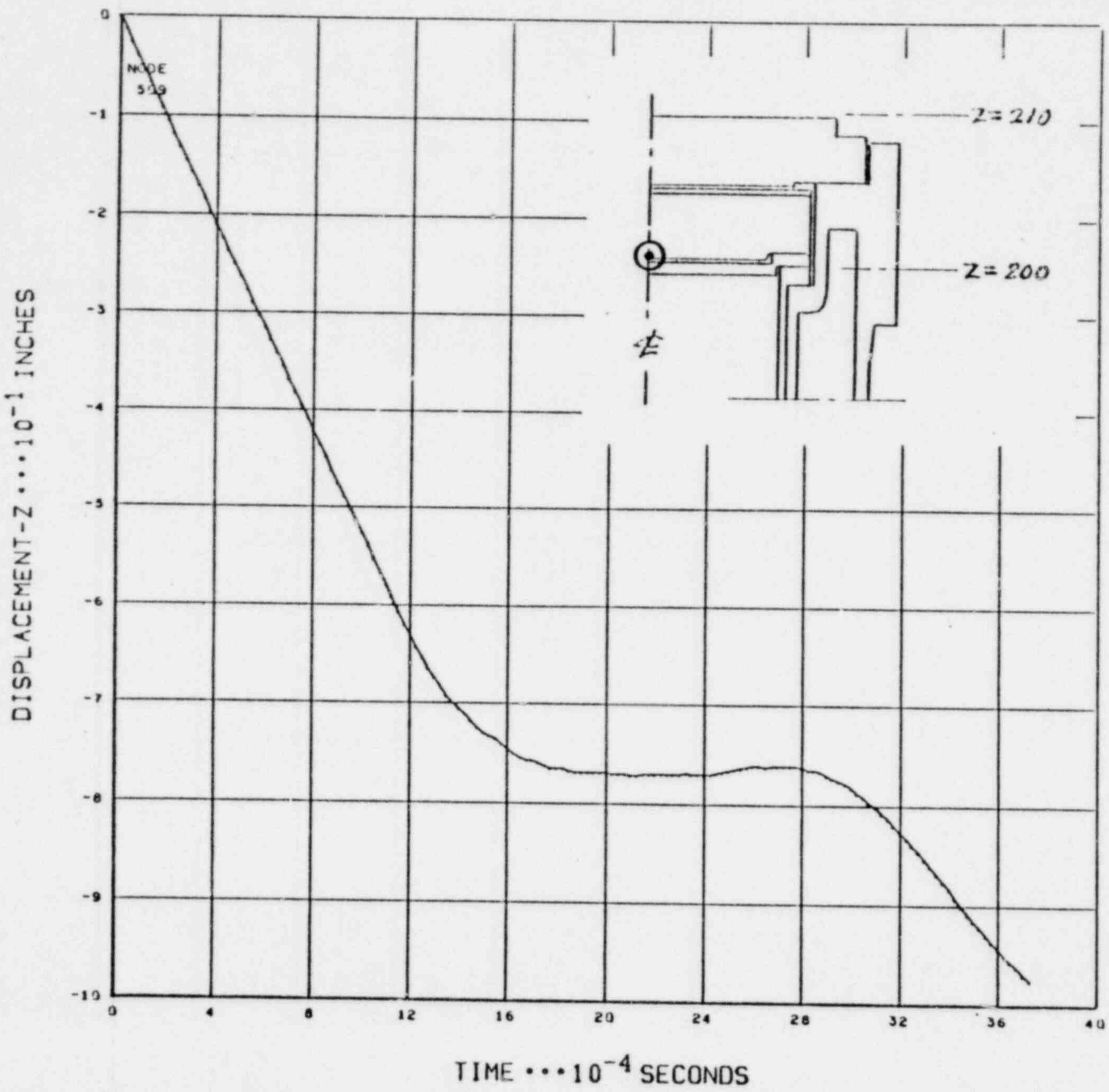
		PAGE OF

REF. HONDO RUN NO. BOT-12.

Z DISPLACEMENT OF NODE 509 (Z=200.500+). STRAIN RATE SENSITIVE CASE



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5-90

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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PREPARED BY J. L. Thurford	DATE 14 Feb. 1979	REF. DOCUMENTS:	
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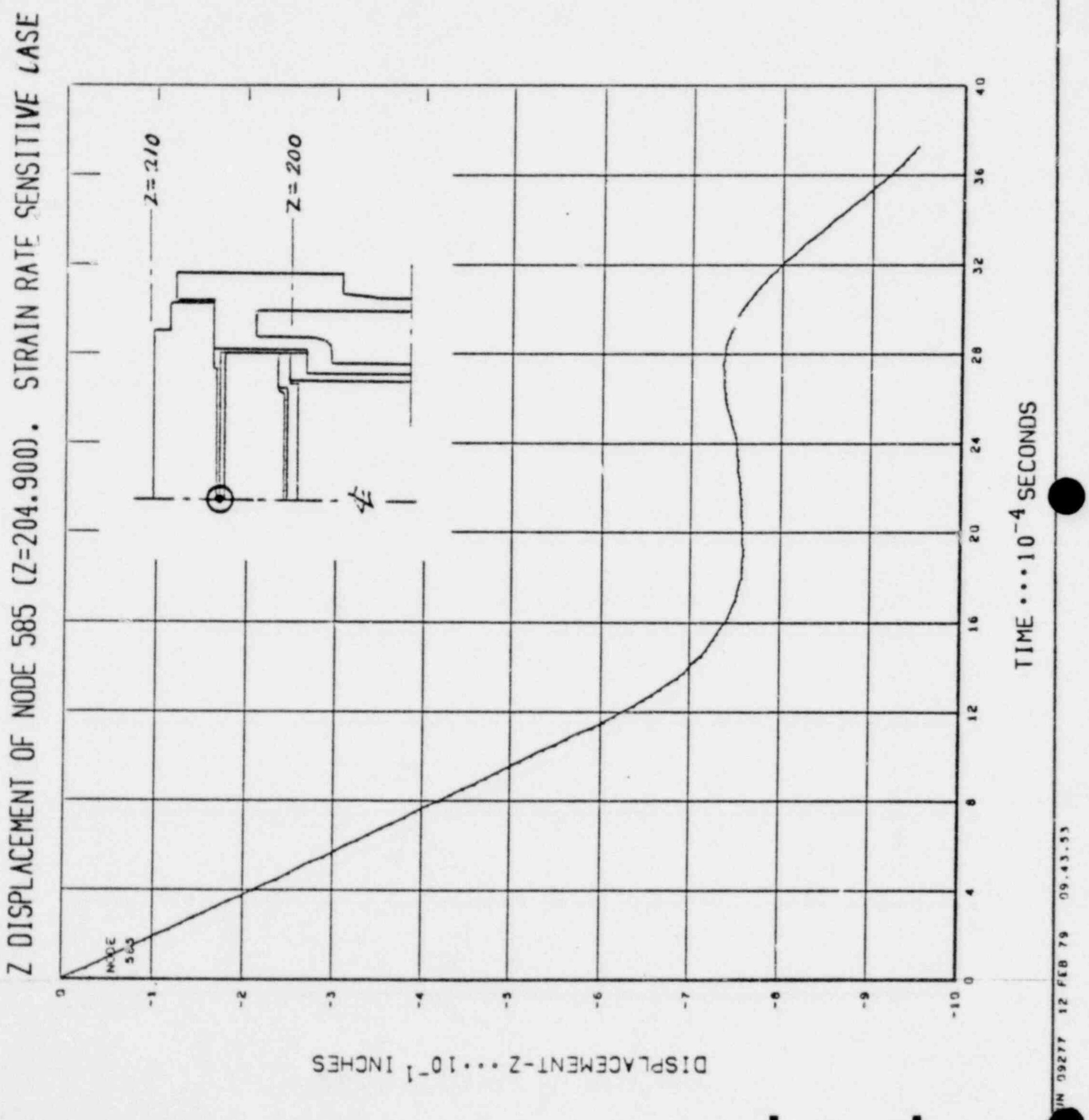
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.

Z DISPLACEMENT OF NODE 585 (Z=204.900). STRAIN RATE SENSITIVE CASE



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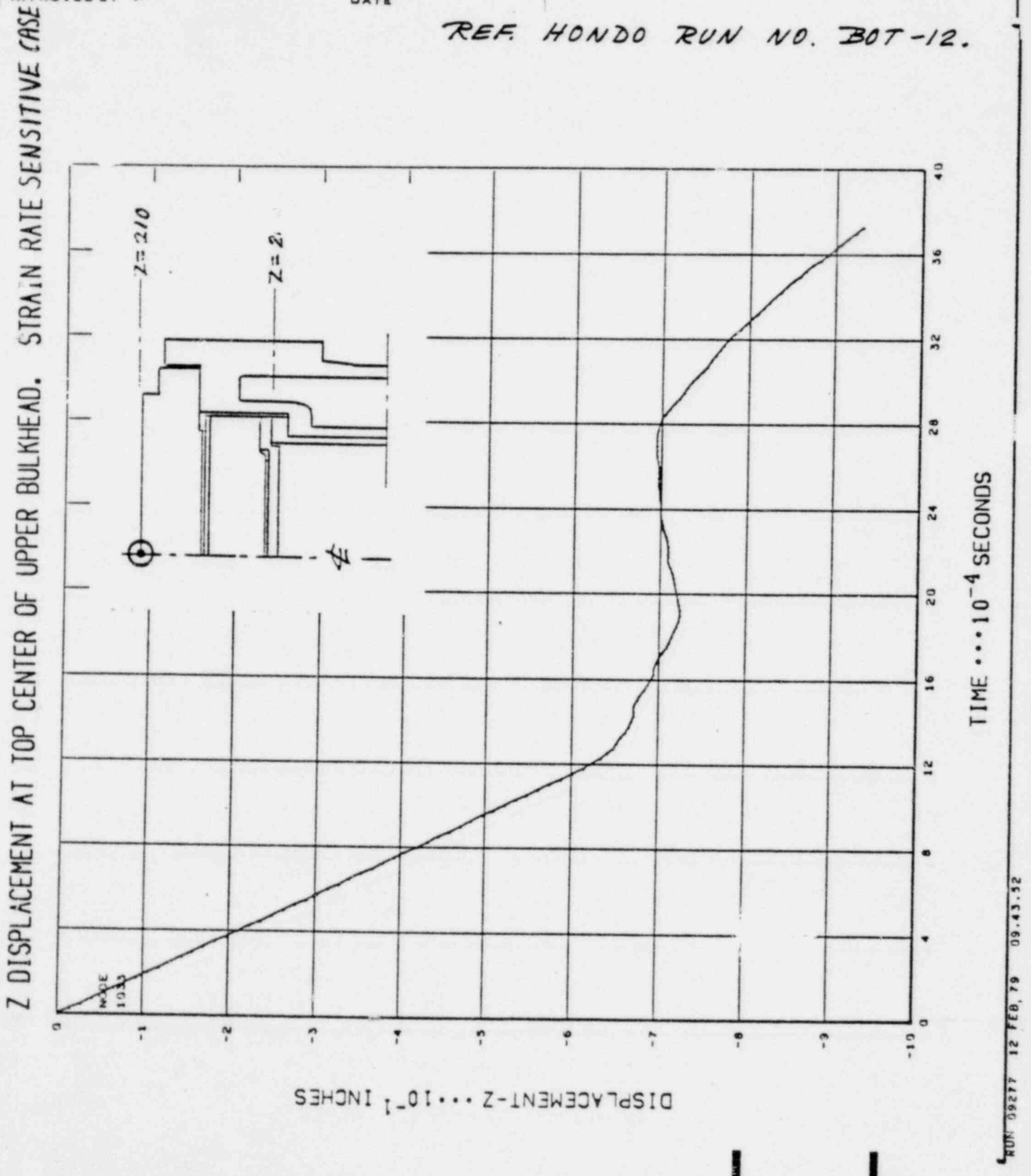
GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.
EQUIP. NO. PROJ. NO. CALC. NO. PAGE OF
PREPARED BY V. L. Hinford DATE 14 Feb. 1979 REF. DOCUMENTS:
REVIEWED BY J. S. Glacla DATE 2-16-79
APPROVED BY DATE

REF. HONDO RUN NO. BOT-12.


Z DISPLACEMENT AT TOP CENTER OF UPPER BULKHEAD. STRAIN RATE SENSITIVE CASE

5-32

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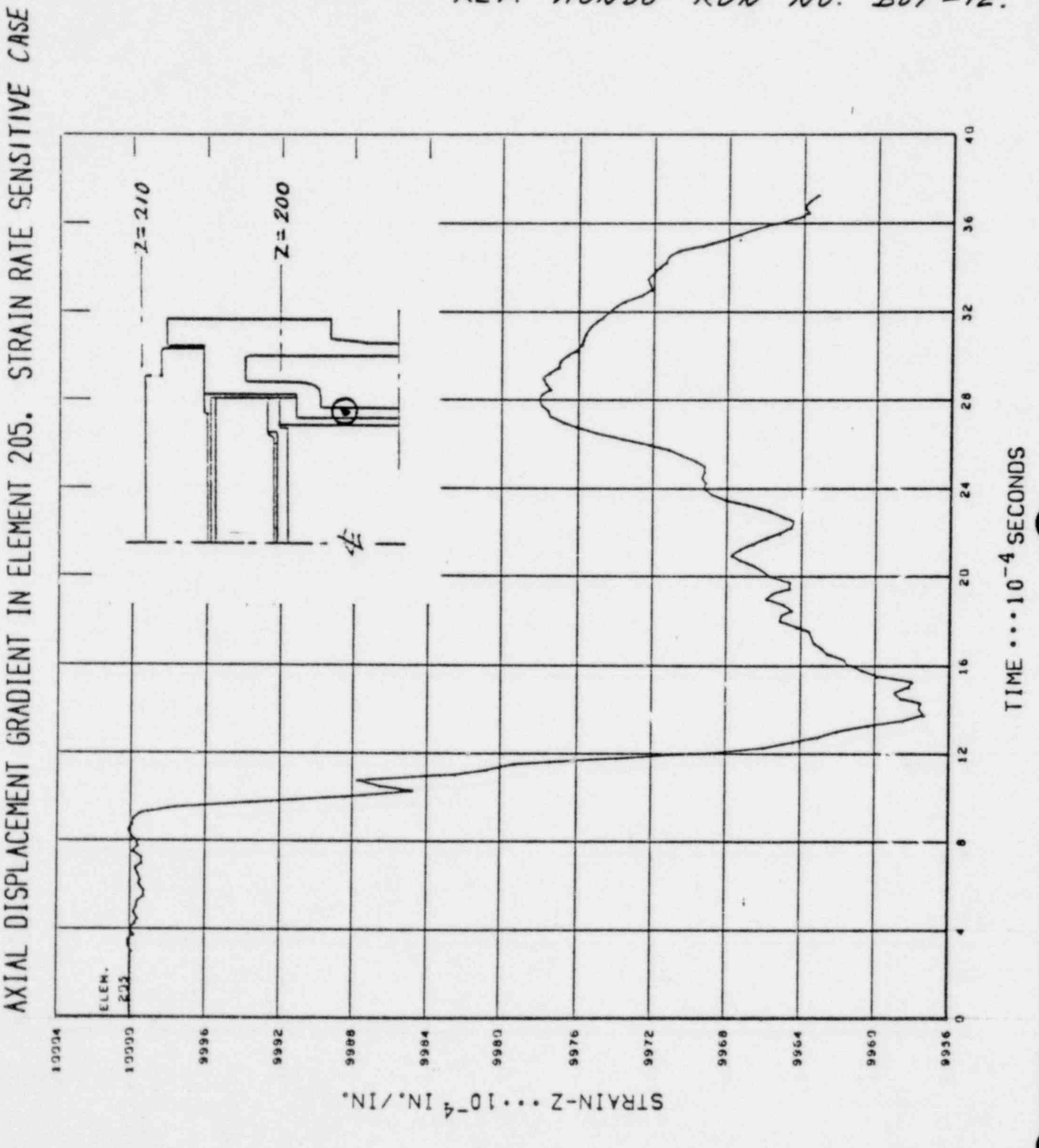
GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Hanford	DATE 14 Feb., 1979	REF. DOCUMENTS:	
REVIEWED BY J. S. Lacko	DATE 2-16-79		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-12.


AXIAL DISPLACEMENT GRADIENT IN ELEMENT 205. STRAIN RATE SENSITIVE CASE

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

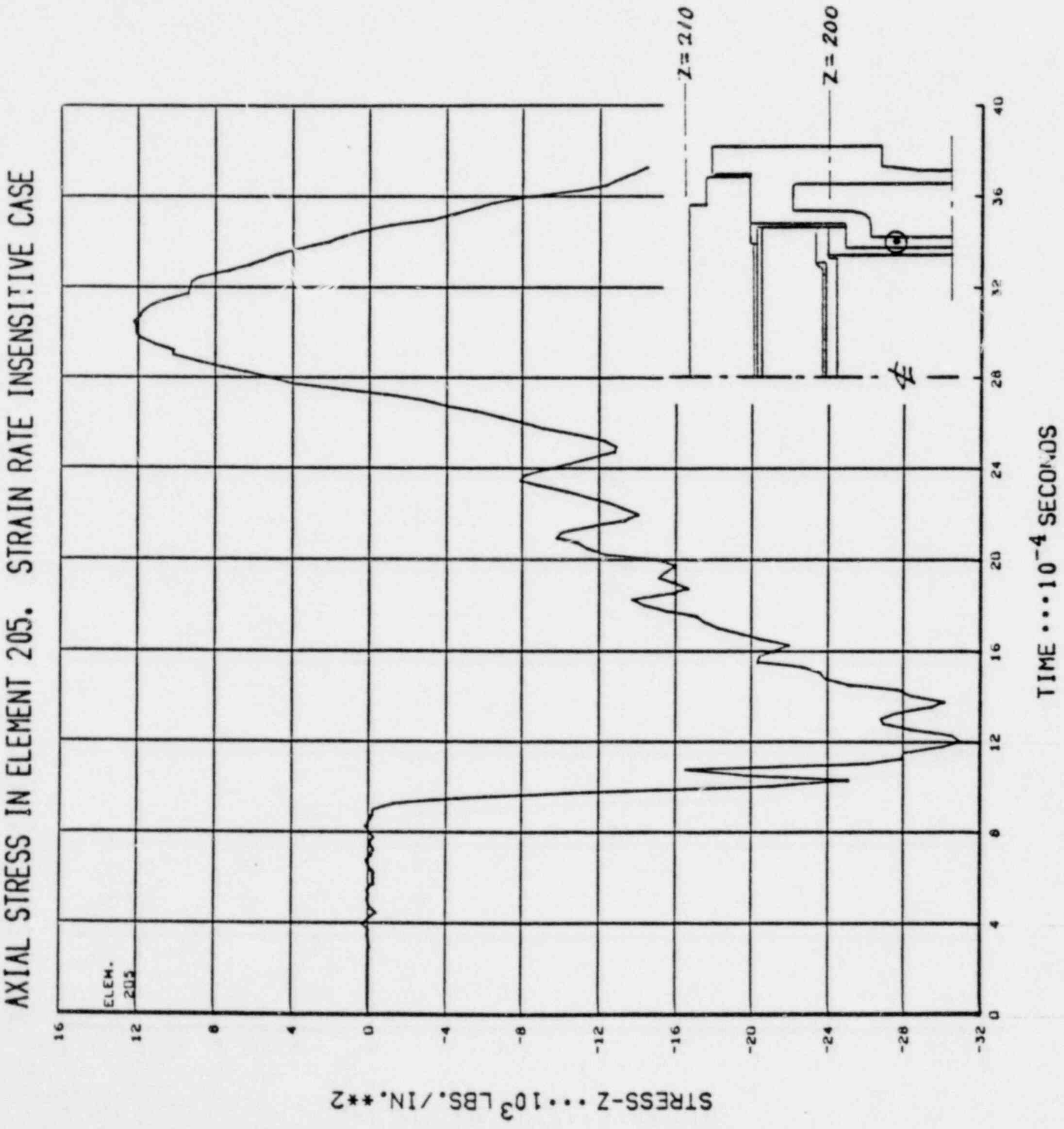
CALCULATIONS FOR *FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.*

EQUIP. NO.
PROJ. NO.
CALC. NO.
PAGE OF

PREPARED BY *D. L. Thurfford* DATE *26 April, -78*
REF. DOCUMENTS:

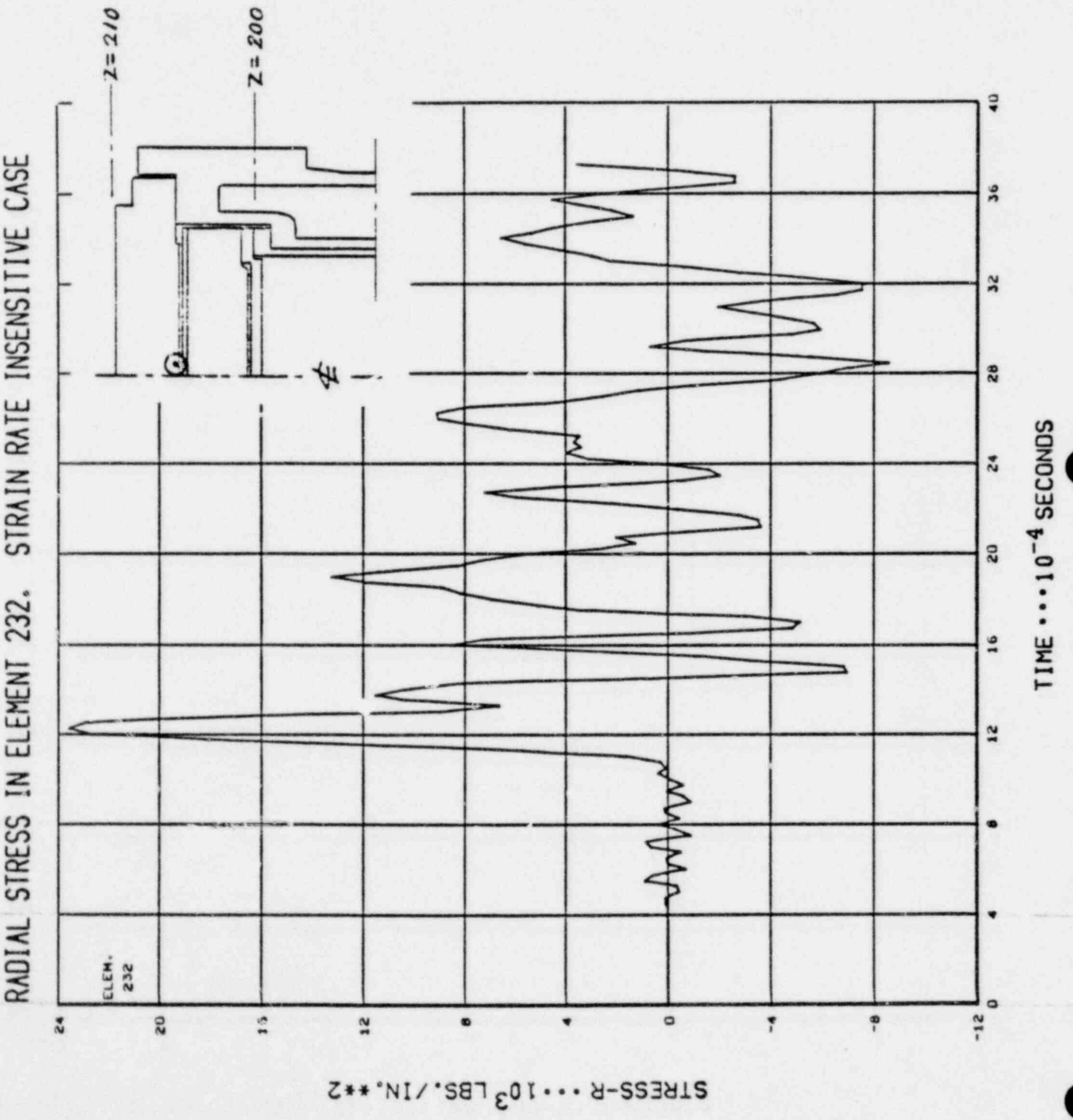
REVIEWED BY
DATE

APPROVED BY
DATE



GENERAL ATOMIC COMPANY

CALCULATIONS FOR *FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.*			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY *D. L. Hornford*	DATE *26 April, -78*	REF. DOCUMENTS	
REVIEWED BY	DATE		
APPROVED BY	DATE		



RADIAL STRESS IN ELEMENT 232. STRAIN RATE INSENSITIVE CASE

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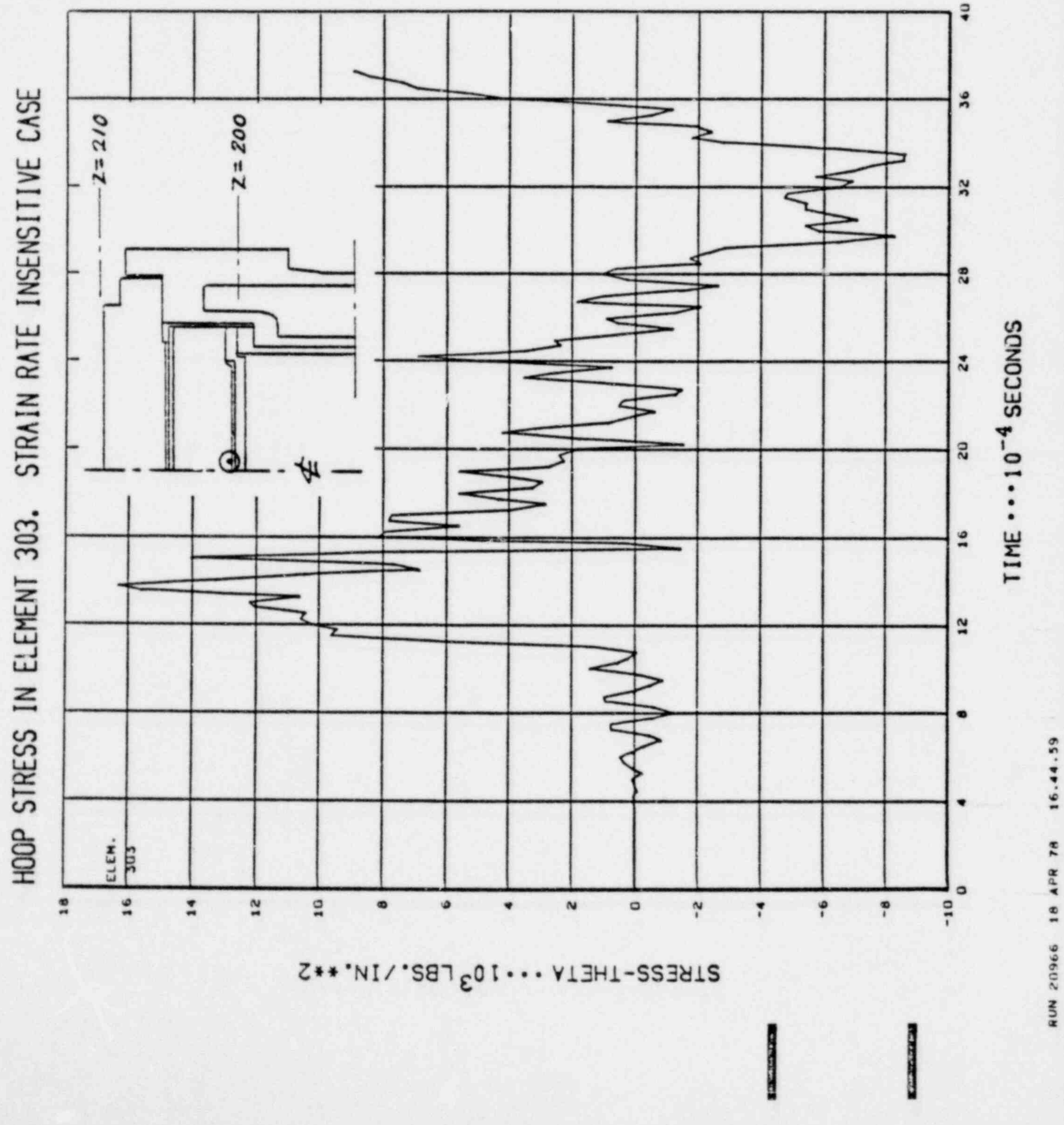
CALCULATIONS FOR FSV FUEL SHIPPING CASK, BOTTOM 30 FT. DROP.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 26 April, -78	REF. DOCUMENTS:	
REVIEWED BY	DATE		
APPROVED BY	DATE		



HOOP STRESS IN ELEMENT 303. STRAIN RATE INSENSITIVE CASE

GADR-55 ADDENDUM 1
REVISION 1

5-96

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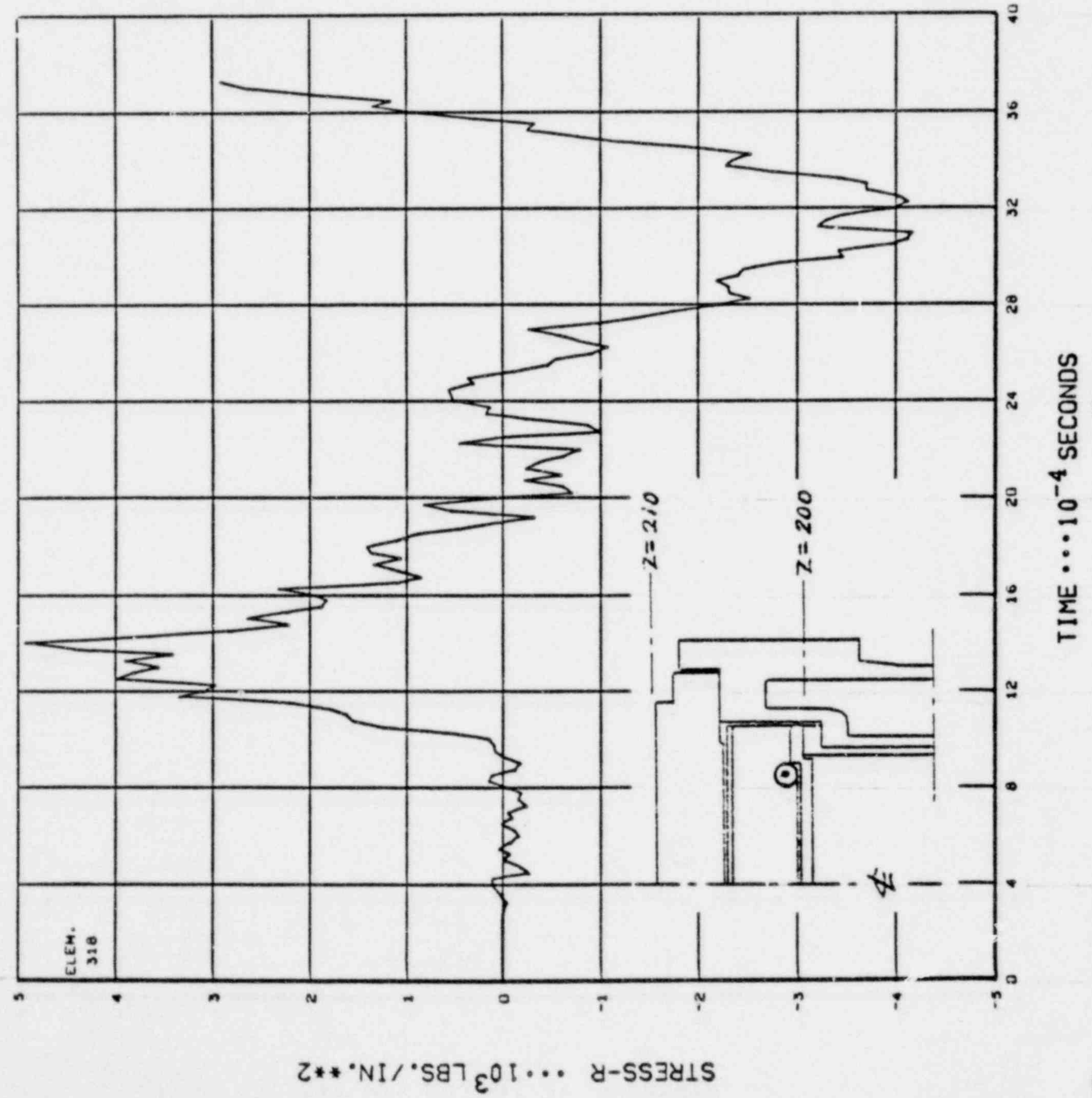
GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. I[illegible]M 30 FT. DROP			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY R. H. Stanford	DATE 26 April, 78	REF. DOCUMENTS	
REVIEWED BY	DATE		
APPROVED BY	DATE		


SHEAR STRESS IN ELEMENT 318. STRAIN RATE INSENSITIVE CASE

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GENERAL ATOMIC COMPANY

GADR-55 ADDENDUM 1
REVISION 1

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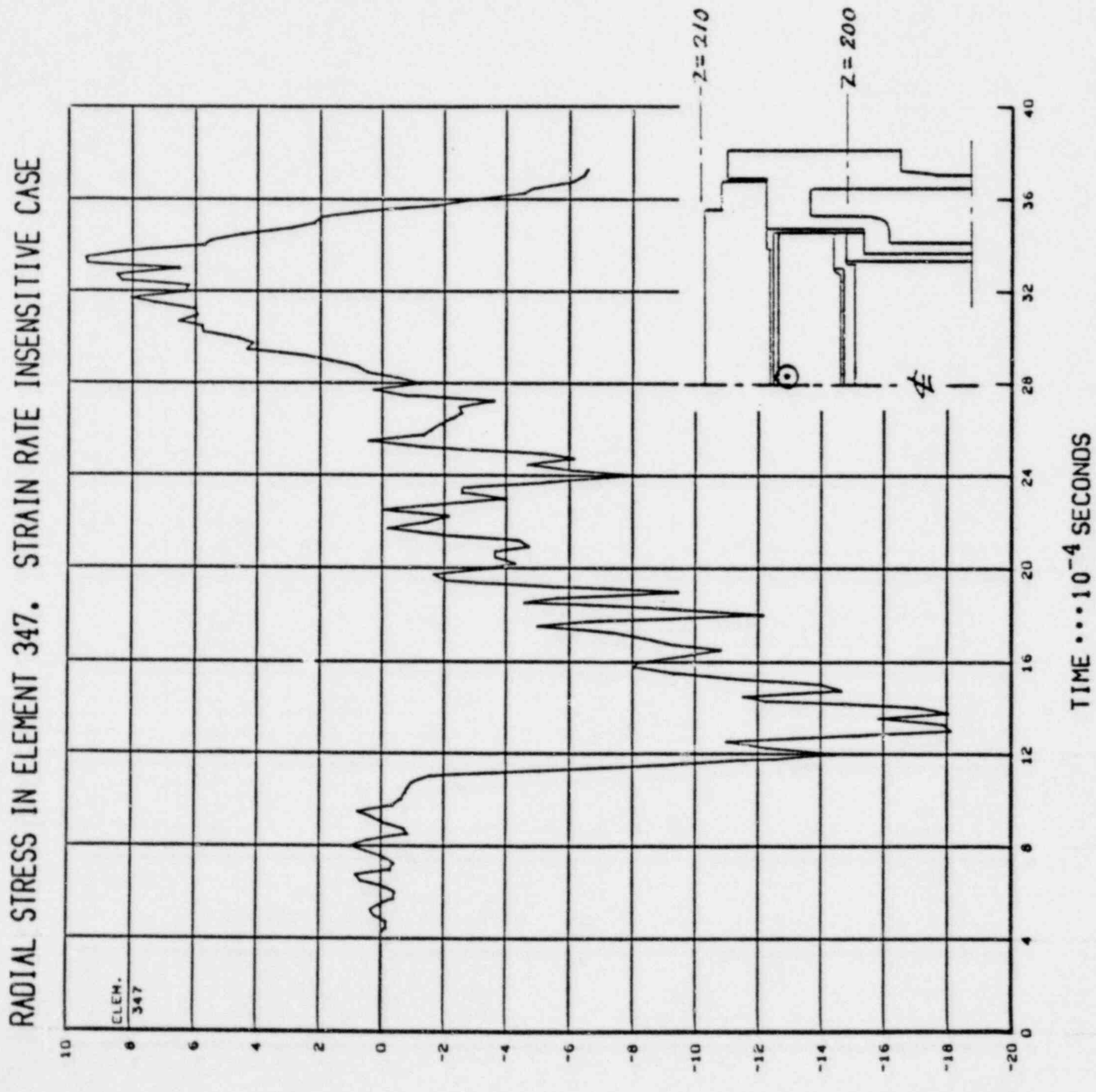
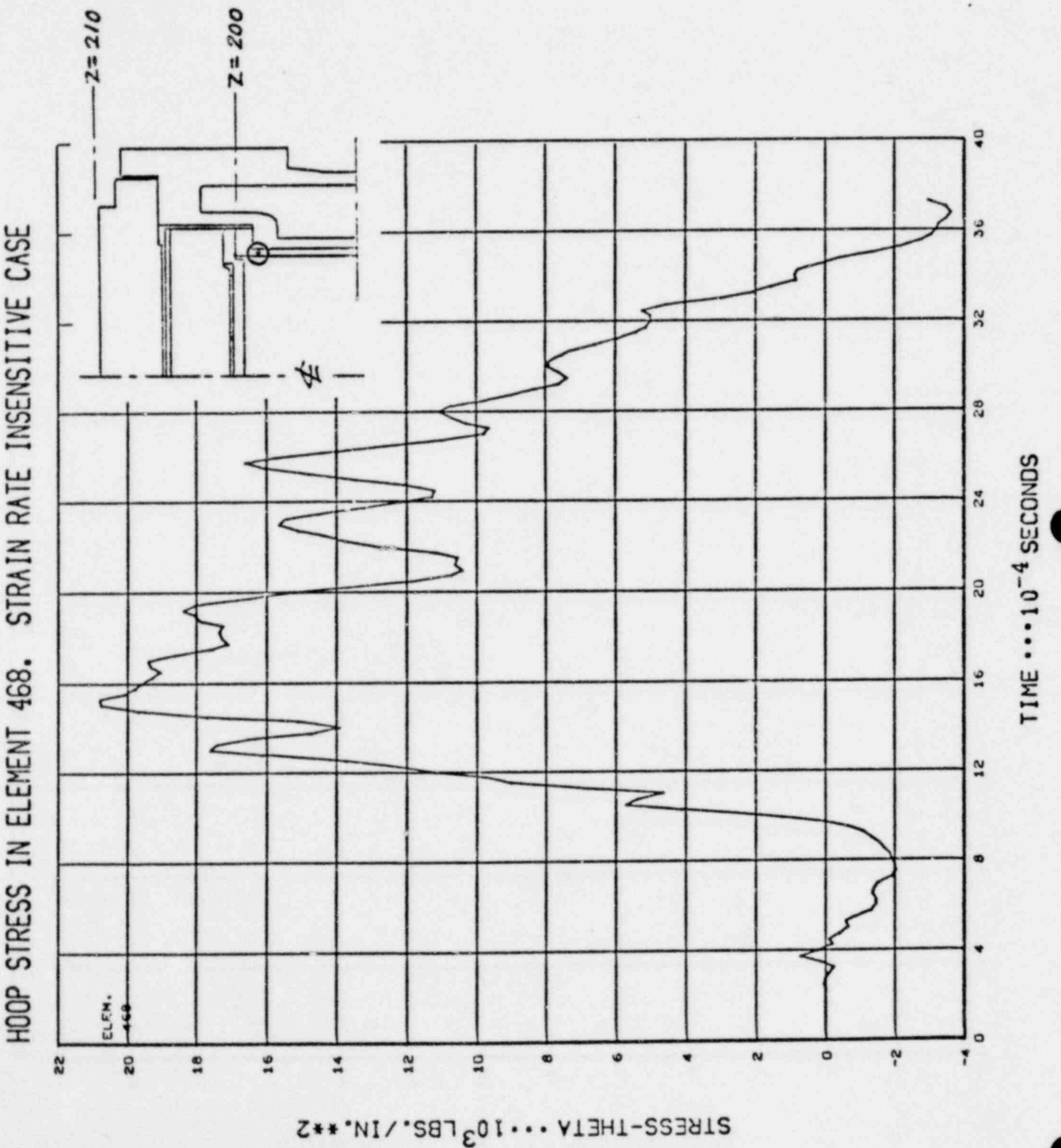
CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY R. D. Mulford	DATE 26 April, -78	REF. DOCUMENTS	
REVIEWED BY	DATE		
APPROVED BY	DATE		


RADIAL STRESS IN ELEMENT 347. STRAIN RATE INSENSITIVE CASE

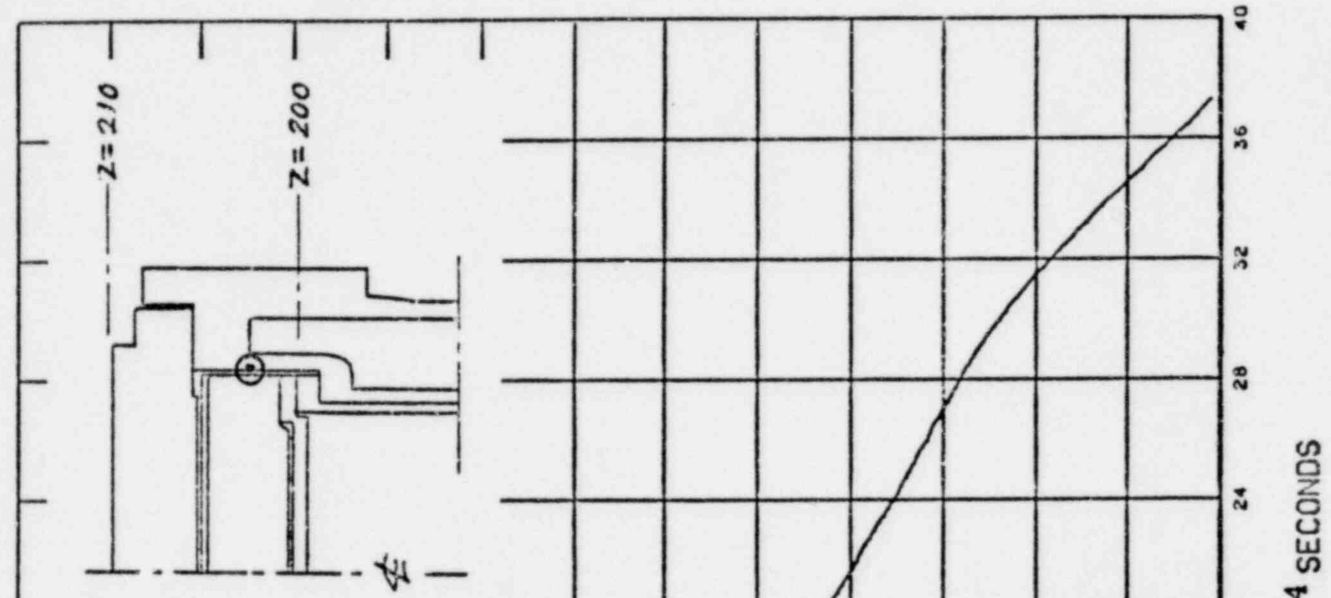
RUN 20966 18 APR 78 16.45.00

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. L. Hornford	DATE 26 April, -78	REF. DOCUMENTS:	
REVIEWED BY C.M. Unterman	DATE 13 June, 78		
APPROVED BY	DATE		


HOOP STRESS IN ELEMENT 468. STRAIN RATE INSENSITIVE CASE

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 26 April -78	REF. DOCUMENTS:	
REVIEWED BY	DATE 13 Dec, 78		
APPROVED BY	DATE		

Z DISPLACEMENT OF NODE 396. STRAIN RATE INSENSITIVE CASE



GENERAL ATOMIC COMPANY

CALCULATIONS FOR *FSV FUEL SHIPPING CASK, BOTTOM 30 FT. DROP*		
EQUIP. NO.	PROJ. NO.	CALC. NO.
PREPARED BY	DATE *26 April, '78*	PAGE OF
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APPROVED BY	DATE	

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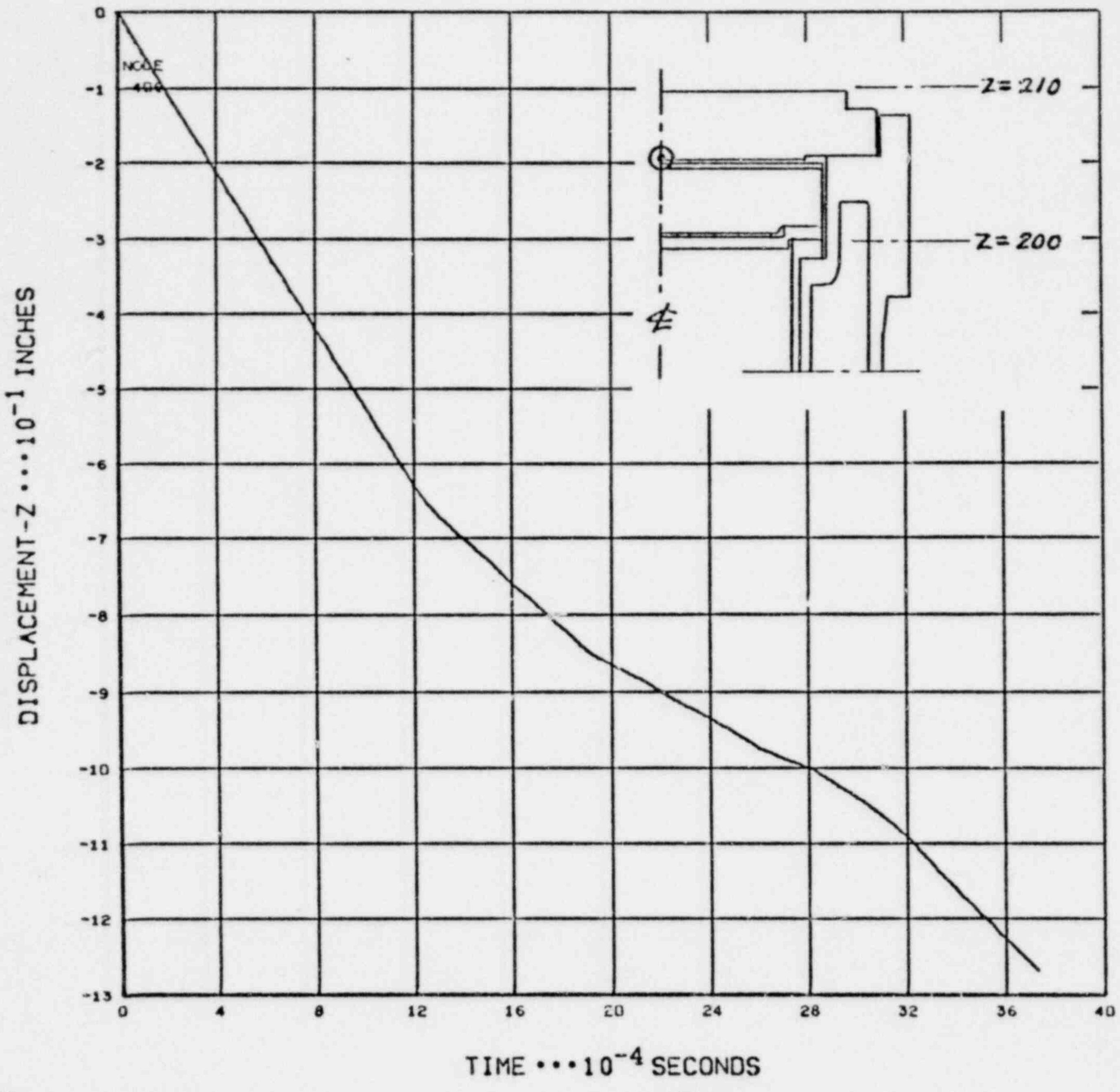
Z DISPLACEMENT OF NODE 406 (Z=205.015). STRAIN RATE INSENSITIVE CASE



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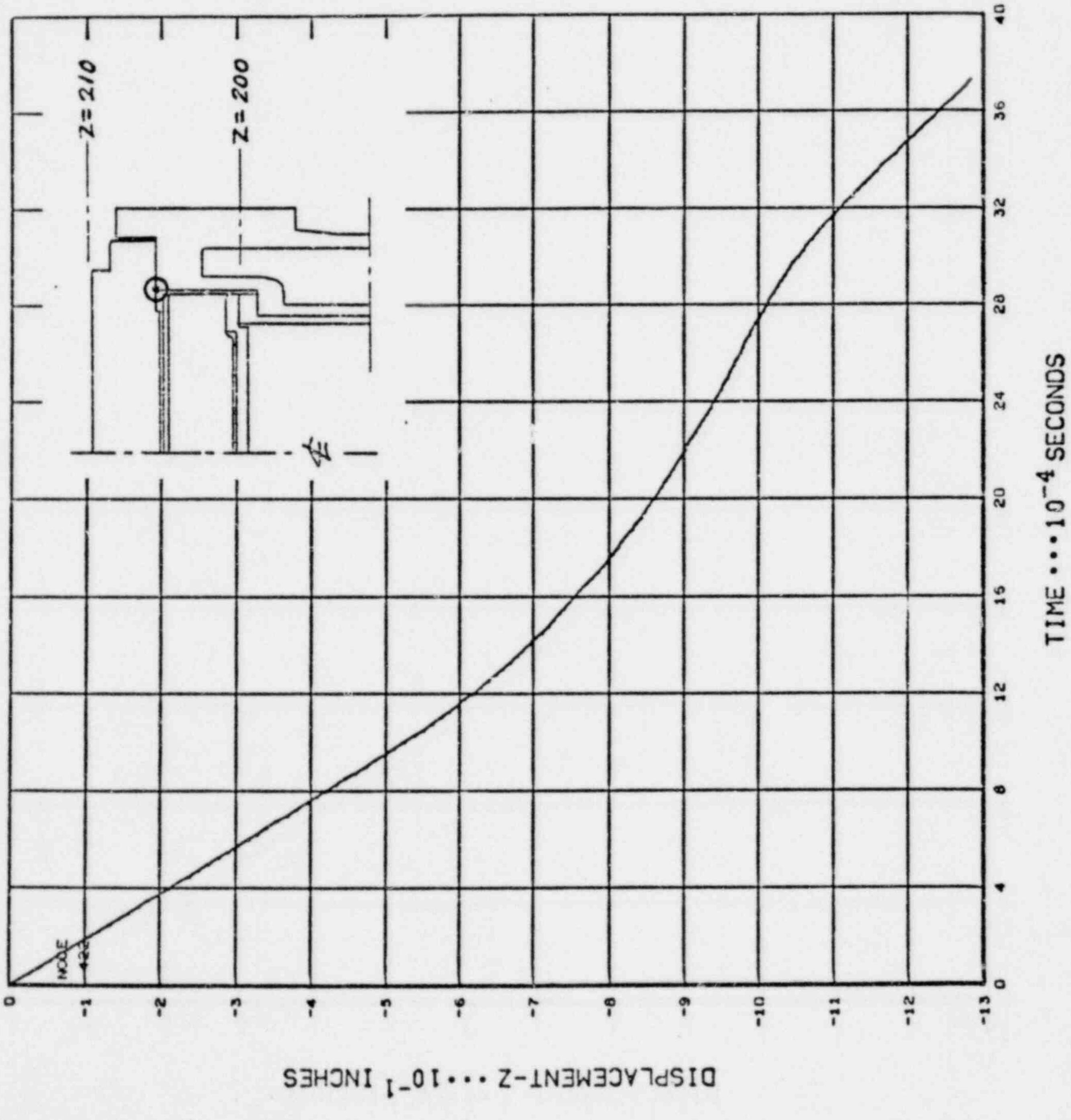
CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. L. Wilford	DATE 26 April-78	REF. DOCUMENTS:	
REVIEWED BY C.M. [illegible]	DATE 3 June 78		
APPROVED BY	DATE		

Z DISPLACEMENT OF NODE 422. STRAIN RATE INSENSITIVE CASE



RUN 20966 20 APR 78 14.00.33

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.
EQUIP. NO. PROJ. NO. CALC. NO. PAGE OF
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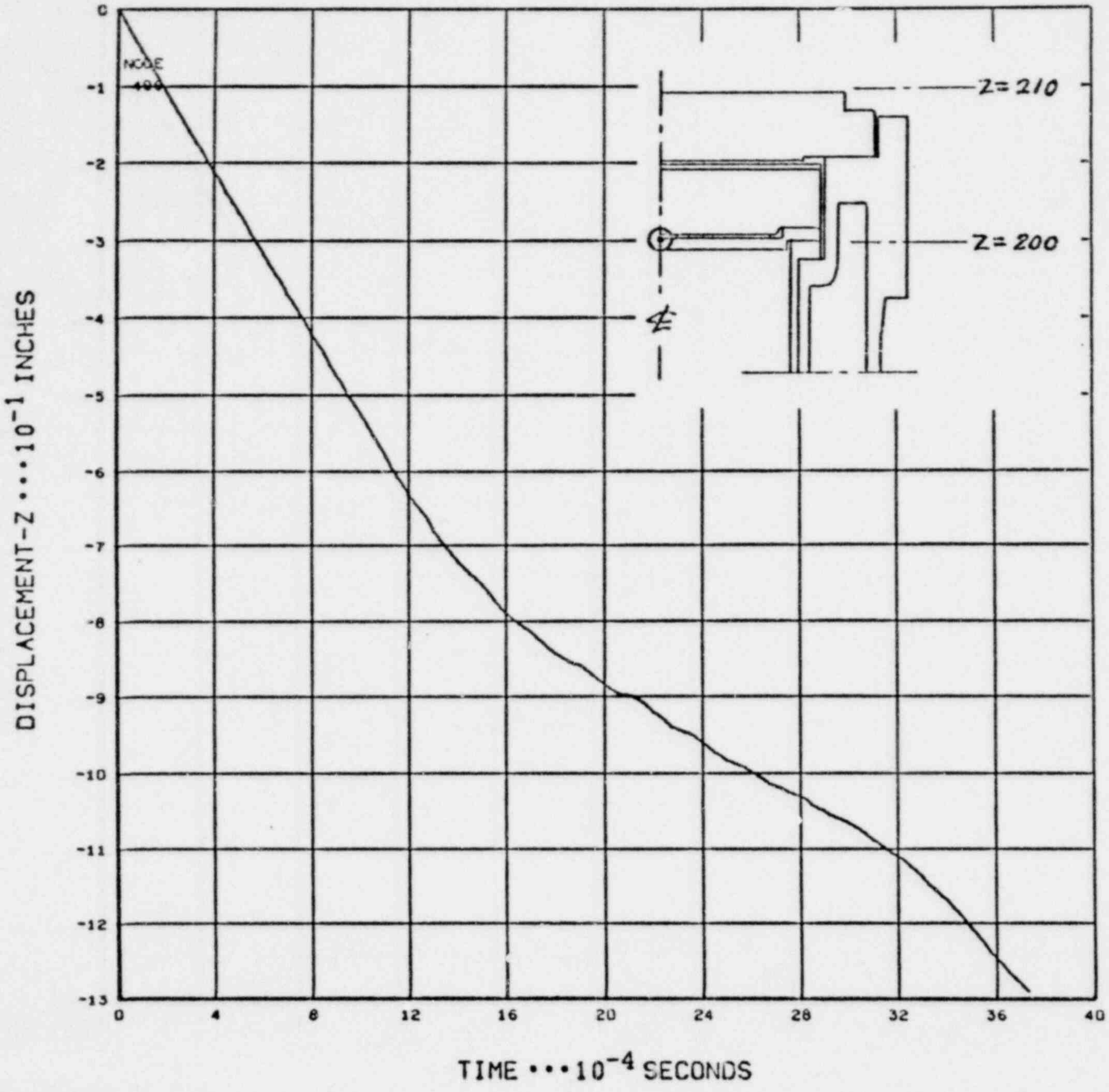
REVIEWED BY DATE 13 ... 78
APPROVED BY DATE

Z DISPLACEMENT OF NODE 496 (Z=200.500-). STRAIN RATE INSENSITIVE CASE



R 0965 18 APR 78 16.45.03

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
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REVIEWED BY	DATE 13 Jan. 78		
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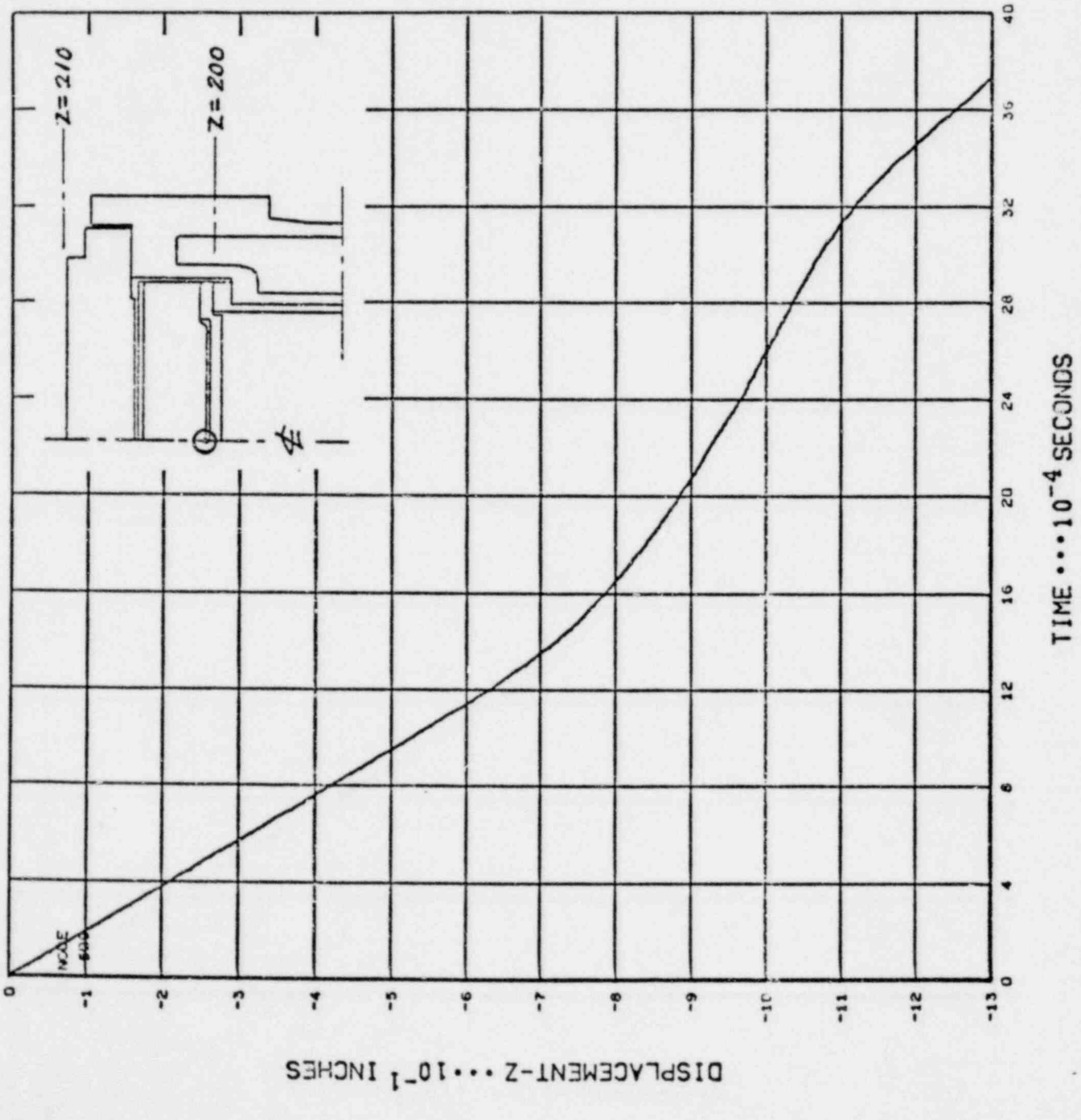
Z DISPLACEMENT OF NODE 509 (Z=200.500+). STRAIN RATE INSENSITIVE CASE



RUN 20565 18 APR 78 16.45.02

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK, BOTTOM 30 FT. DROP.

EQUIP. NO.	PROJ. NO.	CALC. NO.
PREPARED BY P. K. Shrikant	DATE 26 April, -78	REF. DOCUMENTS:
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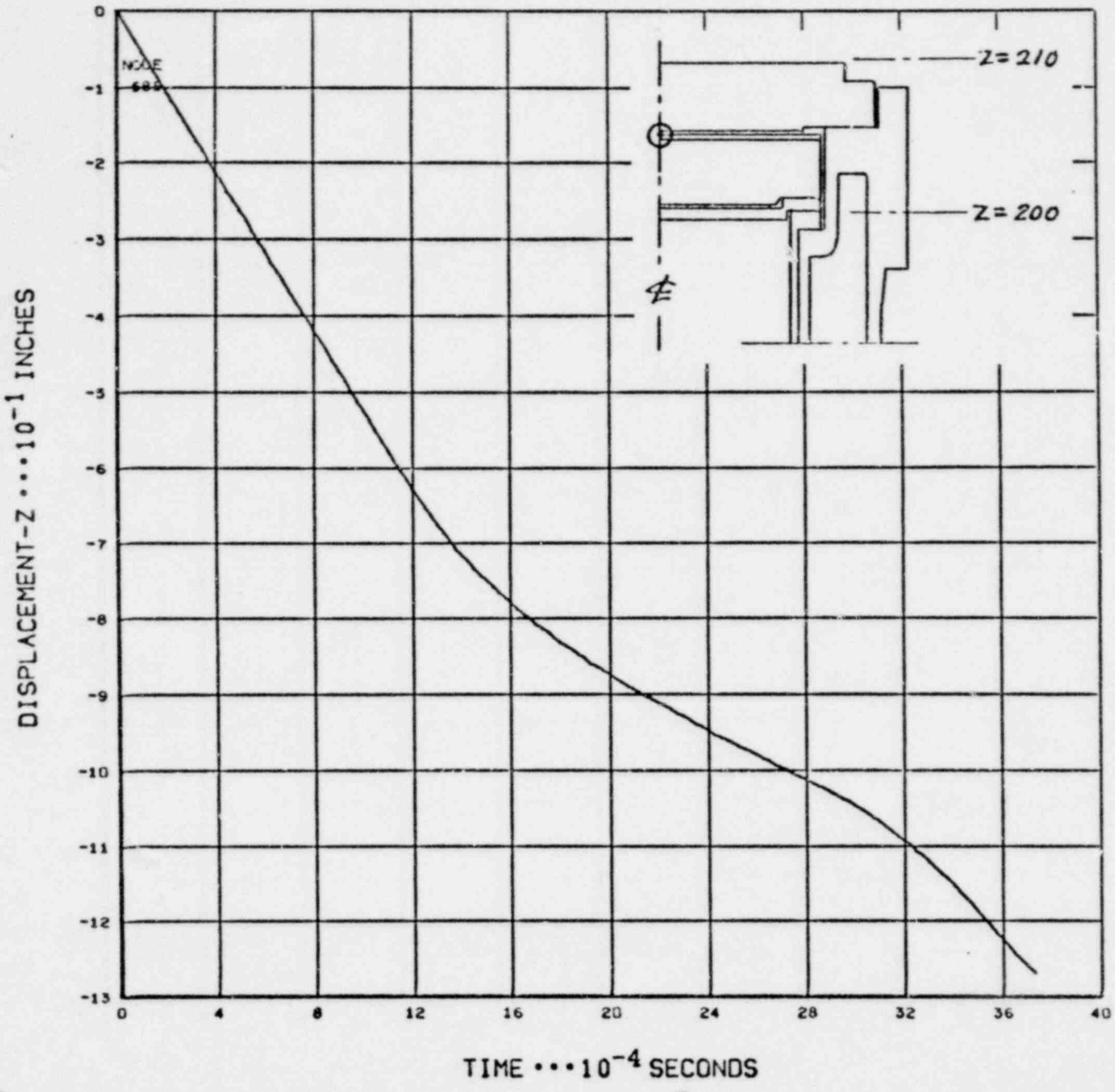
Z DISPLACEMENT OF NODE 585 (Z=204.900). STRAIN RATE INSENSITIVE CASE



[illegible]0966 18 APR 78 16.45.02

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. J.	DATE 26 April -78	REF. DOCUMENTS:	
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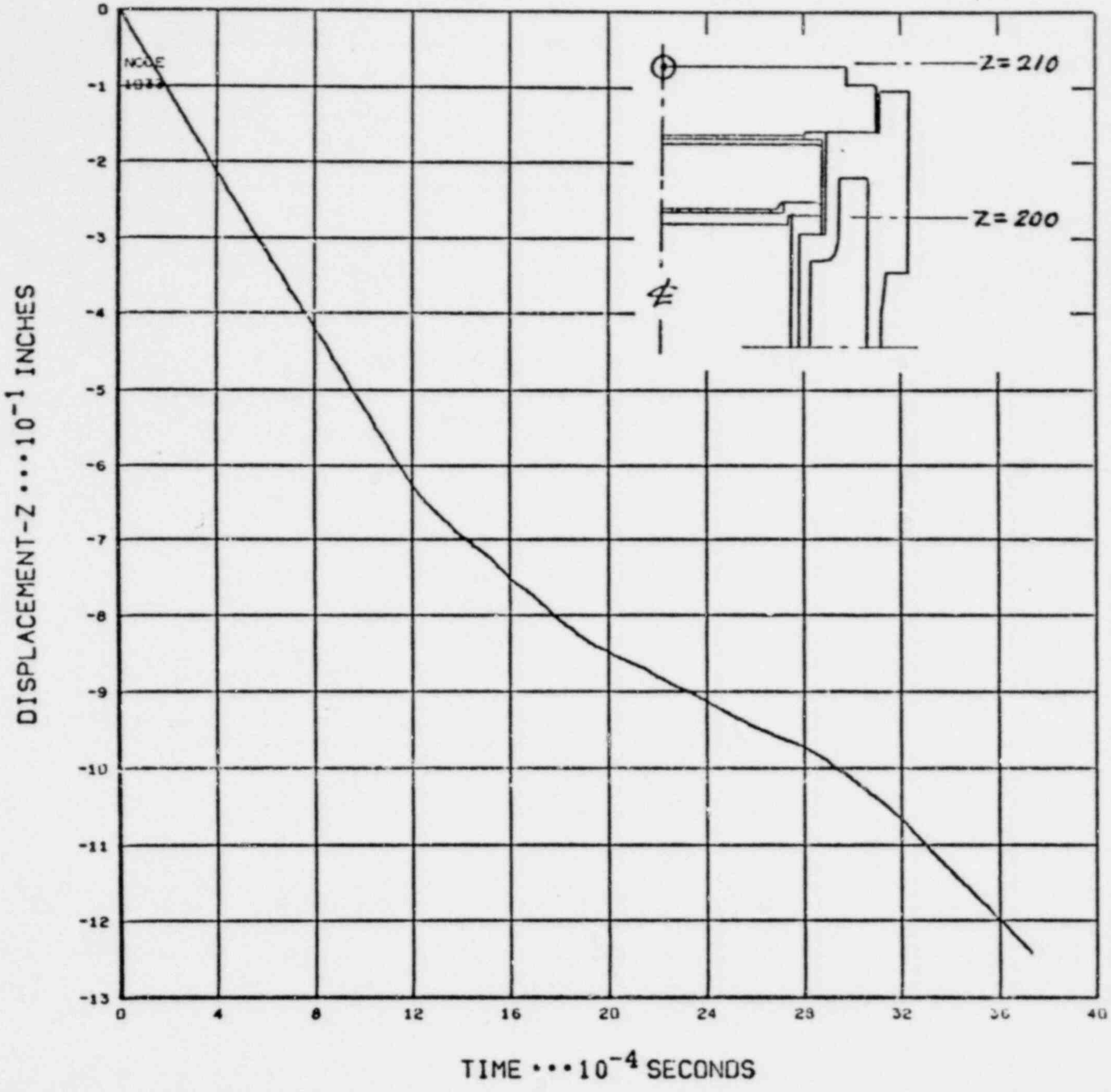
APPROVED BY	DATE		

GADR-55 ADDENDUM 1
REVISION 1

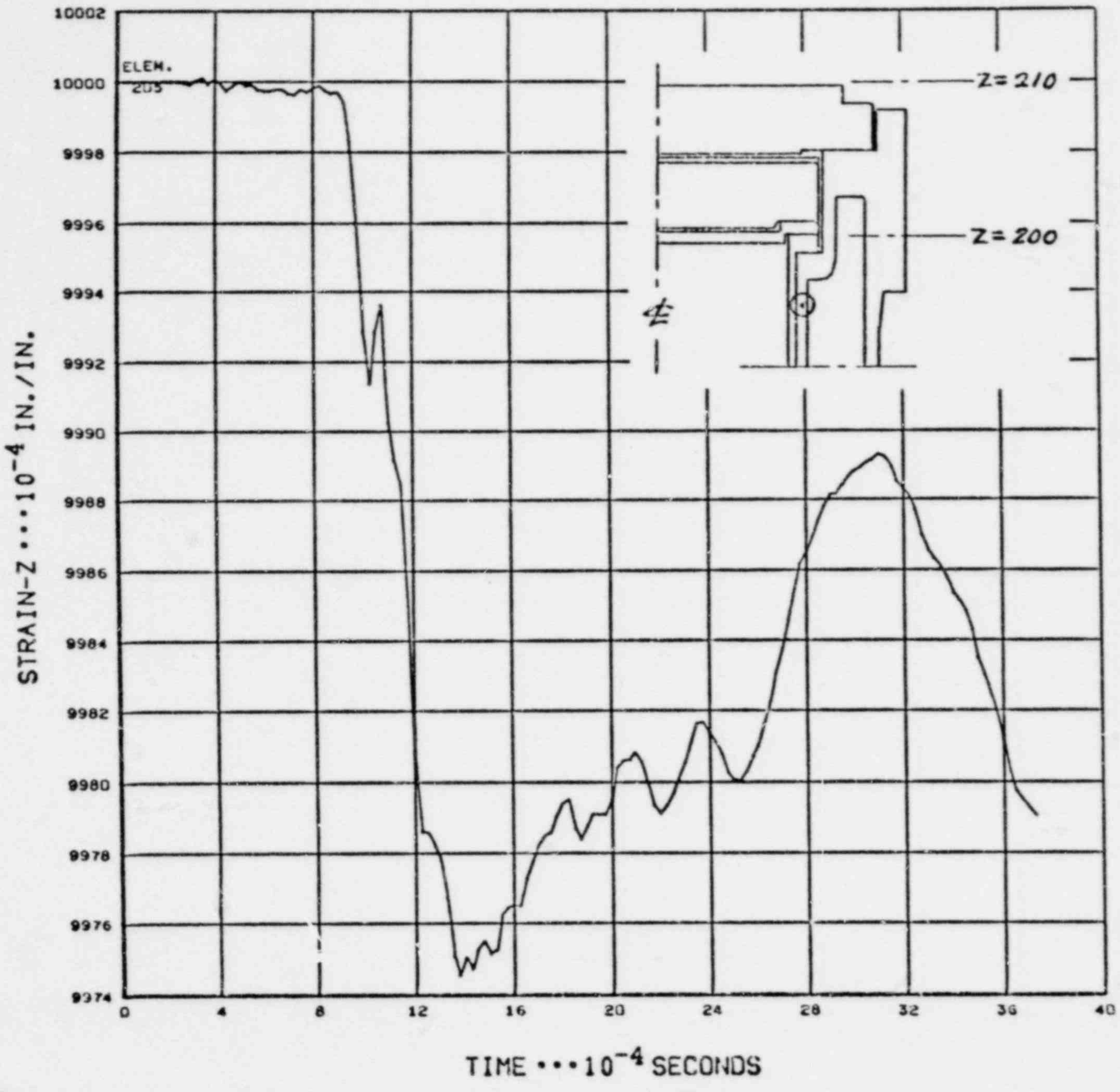
Z DISPLACEMENT AT TOP CENTER OF UPPER BULKHEAD. STRAIN RATE INSENSITIVE CASE



RUN 20966 18 APR 78 16.45.01

CALCULATIONS FOR *FSV FUEL SHIPPING CASK, BOTTOM 30 FT. DROP.*			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY *D. G. Thornford*	DATE *26 April, -78*	REF. DOCUMENTS:	
REVIEWED BY *C.M. Clusemann*	DATE *13 June 78*		
APPROVED BY	DATE		

AXIAL DISPLACEMENT GRADIENT IN ELEMENT 205. STRAIN RATE INSENSITIVE CASE



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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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APPROVED BY	DATE 2-16-79		

DISCUSSION OF HONDO ANALYSIS

AS STATED ON PG. 5-73 CRITICAL STRESSES ARE MAXIMUM FOR THE STRAIN RATE SENSITIVE CASE. FOR COMPARISON WITH THE STRESS SUMMARY ON PAGE 5-74 THE TABLE BELOW IS PROVIDED FOR THE STRAIN RATE INSENSITIVE CASE HONDO RUN.

MAX. ABSOLUTE STRESS SUMMARY PER C.P.O.
(STRAIN RATE INSENSITIVE CASE. RUN NO. BOT-03)

COMPONENT	ELEMENT NO.	TIME (10^{-4} sec's)	PREDOMINANT STRESS TYPE(s)	MAX. OR MIN. PRINCIPAL STRESS (psi)	YIELD STRENGTH AT TEMP. (psi)	
						REF. PG.
4340 STL. BULKHEAD	232 (BOTTOM ℄)	12.5	RADIAL & HOOP	23 520	150 000 (300°F)	5-48
.2% MO-URAN. ALLOY SHIELD, LID	347 (TOP ℄) 303 (BOTT. ℄)	13.0 13.5	RAD. & HOOP RAD. & HOOP	-18 110 15 650	36300 (300°F)	5-47
TOP END OF CASK	205 (INNER CYL.)	12.0	AXIAL COMPR.	-30 980	30 300 (250°F)	5-74
TOP END OF CONTAINER	468 {CYLINDER BELOW FLANGE	23.0	AXIAL TENS.	30 820	29 200 (300°F)	5-74
CONTAINER LID HOUSING	281 (BOTT. ℄)	13.0	RAD. & HOOP	18 260	29 200 (300 °F)	5-74

Z-DISPLACEMENTS DEPICTED ON PAGES 5-85 THROUGH 5-91 AND 5-99 THROUGH 5-105 VARY BETWEEN APPROXIMATELY .7 INCHES AND 1.3 INCHES FOR THE TIME SPAN CONSIDERED.

CORRESPONDING RANGE OF ELONGATION BASED ON A CASK LENGTH OF APPROX. 200 INCHES:

$$\frac{.7}{200} < \varepsilon < \frac{1.3}{200}$$

OR: $$.35\% < \varepsilon < .65\%$$

WHICH CORRESPONDS WELL TO THE .5% RANGE USED FOR CONSTRUCTION OF STRESS-STRAIN DIAGRAMS IN THE MATERIALS DATA SECTION PG. 5-41 & ON.

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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PREPARED BY P. S. Harford	DATE 14 Jan., 1979	REF. DOCUMENTS:	
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APPROVED BY	DATE		

DISCUSSION OF HONDO ANALYSIS, CONT'D.

MATERIALS

IN ORDER TO CLARIFY THE VALIDITY OF THE MATERIALS DATA USED, AN ADDITIONAL HONDO RUN WAS MADE IN DECEMBER 1978 (RUN NO. BOT-08). THE MODEL FOR THIS RUN IS IDENTICAL TO THE ORIGINAL STRAIN RATE SENSITIVE CASE MODEL (RUN NO. BOT-02) WITH THE EXCEPTION OF THE LID URANIUM SHIELD, FOR WHICH STRAIN RATE INSENSITIVE BEHAVIOR WAS INPUT.

AS EXPECTED THE STRESS AND STRAIN HISTORIES OF ALL POINTS OUTSIDE OF THE LID ARE VIRTUALLY IDENTICAL FOR THE TWO MODELS. FOR THE CRITICAL POINTS (TOP AND BOTTOM ℄) OF THE LID SHIELD RESULTS FROM RUN NO. BOT-08 ARE SUMMARIZED BELOW (COMPARE WITH PG. 5-74):

MAX. ABSOLUTE STRESS SUMMARY PER C.P.O. (RUN NO. BOT-08) (STRAIN RATE SENSITIVE CASE, EXCEPT FOR LID SHIELD)						
COMPONENT	ELEMENT NO.	TIME (10^{-4} sec's)	PREDOMINANT STRESS TYPE (s)	MAX. OR MIN. PRINCIPAL STRESS (psi)	YIELD STRENGTH AT TEMP. (psi)	
						REF. PG.
.2% MO-URAN. ALLOY SHIELD, LID	347 (TOP ℄)	13.0	RAD. & HOOP	-28 930	36 300 (300°F)	5-47
	303 (BOT ℄)	13.5	RAD. & HOOP	29 660		

PLOTS OF THE HOOP STRESS IN ELEM. 303 AND THE RADIAL STRESS IN ELEM. 347 VS. TIME FOR RUN NO. BOT-08 ARE SHOWN ON PAGES 5-112 & 5-113, (COMPARE WITH PAGES 5-81 & 5-83).

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSU FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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PREPARED BY P. L. Thurford	DATE 17 Jan., 1979	REF. DOCUMENTS:	
REVIEWED BY amc	DATE 2-8-79		
APPROVED BY	DATE		

DISCUSSION OF HONDO ANALYSIS, CONT'D.

IT IS SEEN THAT FOR ALL THREE ENVELOPING MODELS (STRAIN RATE INSENSITIVE CASE, STRAIN RATE SENSITIVE CASE, AND STRAIN RATE SENSITIVE WITH INSENSITIVE SHIELD CASE) THE MAXIMUM ABSOLUTE STRESS IN THE URANIUM ALLOY LID SHIELD WILL BE BELOW STATIC ($\dot{\varepsilon} = 10^{3}$) YIELD STRENGTH AT 300 °F.

RUN BOT-08 VERTICAL DISPLACEMENTS OF BULKHEAD & LID ARE VIRTUALLY IDENTICAL TO THOSE DEPICTED ON PAGES 5-86 & 5-90. THE COMMENTS ON PG. 5-73 REGARDING POSSIBLE INTERFERENCE ARE THEREFORE STILL APPLICABLE.

FOR THE STRAIN RATE SENSITIVE CASE DEPICTED ON PG. 5-81 FOR ELEM. 303 THERE MAY THEORETICALLY BE SOME PLASTIC STRAIN IN THE SHIELD SINCE A YIELD STRENGTH OF 8180 psi IS ASSUMED AT AN EXTREME LOW STRAIN RATE OF 10^{-6}. HOWEVER, AS SHOWN BELOW BY A CONSERVATIVE CALCULATION, THE AMOUNT OF PLASTIC STRAIN WILL BE NEGLIGIBLE.

FOR $\sigma \leqq 8180$ psi : ELASTIC STRAIN REGARDLESS OF STRAIN RATE.

TIME SPAN DURING WHICH $8180 \text{ psi} < \sigma < 26\,190 \text{ psi}$:
$T = 6 \times 10^{-4}$ sec's (REF. PG. 5-81 & 5-62).

PLASTIC STRAIN MAY OCCUR DURING THIS TIME SPAN, PROVIDED THE STRAIN RATE $\dot{\varepsilon} < 10^{-3}$.

IF $\dot{\varepsilon}$ EXCEEDS 10^{-3} THE MATERIAL WILL NOT YIELD AT STRESSES BELOW 28 000 psi (REF. PG. 5-62).

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
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PREPARED BY P. L. Thurlford	DATE 17 Jan., 1979	REF. DOCUMENTS:	
REVIEWED BY Cme	DATE 2-8-79		
APPROVED BY	DATE		

DISCUSSION OF HONDO ANALYSIS, CONT'D.

TOTAL PLASTIC STRAIN $\varepsilon = \int_{T_1}^{T_2} (\dot{\varepsilon})\, dT$

WHERE T_1 = TIME WHEN σ FIRST EXCEEDS 8180 psi.
T_2 = TIME WHEN σ DROPS BELOW 8180 psi.
$\dot{\varepsilon}$ = STRAIN RATE

CONSEQUENTLY FOR $\dot{\varepsilon} < 10^{-3}$:

$$\varepsilon < (10^{-3}) \int_{T_1}^{T_2} dT = (10^{-3})(T)$$

$$= (10^{-3})(6 \times 10^{-4}) = \underline{6 \times 10^{-7} \tfrac{IN}{IN}}$$

$$\sim 6 \times 10^{-5}\,\% = \underline{\underline{.00006\,\%}}$$

THIS AMOUNT OF PLASTIC STRAIN IS MINUTE COMPARED WITH THE TESTED FAILURE STRAIN OF THE MATERIAL AND WILL NOT AFFECT THE INTEGRITY OF THE SHIELD.

PROPERTIES INPUT FOR THE URANIUM SHIELD, CYLINDER, MATERIAL (MAT'L IDENTIFICATION NO. 3) ARE IRRELEVANT FOR THE ANALYSIS OF THE TOP HEAD AND LID OF THE CASK. THIS IS BECAUSE THE URANIUM CYLINDER IS SLIP-FITTED BETWEEN THE INNER AND OUTER CONTAINER SHELLS, AND THERE IS A .25 INCH GAP BETWEEN THE TOP OF THE SHIELD AND THE STAINLESS STEEL CAVITY CONTAINING IT (REF. PG. 5-65 AND 5-68). THE PRESSURE WAVE FROM THE GROUND IMPACT WILL THEREFORE TRAVEL THROUGH THE STAINLESS STEEL SHELLS (MAT'L NO. 1) UNAFFECTED BY THE

(CONT'D.)

CULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			
UIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY D. L. Shurford	DATE 17 Jan., 1979	REF. DOCUMENTS:	
REVIEWED BY CMC	DATE 2-8-79		
APPROVED BY	DATE 2-26-79		

DISCUSSION OF HONDO ANALYSIS, CONT'D.

URANIUM SHIELD. IN OTHER WORDS: THE HONDO STRESS-STRAIN HISTORY OF THE ALTERNATE CASK CLOSURE SYSTEM WOULD HAVE BEEN THE SAME REGARDLESS OF WHAT PROPERTIES HAD BEEN INPUT FOR MATERIAL NO. 3.

THE PRINCIPAL TENSION STRESS OF 50 990 psi SHOWN FOR ELEM. 468 ON PG. 5-74 IS ACCORDING TO THE COMPUTER OUTPUT DERIVED FROM THE FOLLOWING STRESS COMPONENTS:

$\sigma_r = -4530$ psi (RADIAL STRESS)
$\sigma_z = 50\,850$ psi (AXIAL TENSION STRESS)
$\sigma_T = 26\,120$ psi (HOOP TENSION STRESS)
$\tau = 2\,741$ psi (SHEAR STRESS)

CLEARLY THE MAX. PRINCIPAL STRESS IN ELEM. 468 IS ORIENTED VERY CLOSE TO THE AXIAL DIRECTION OF THE CASK.

ULTIMATE TENSILE STRENGTH OF MAT'L NO. 1 : 70 000 psi MIN. @ ROOM TEMP. (REF. PG. 3-2).
ACCORDING TO THE "INTERNATIONAL NICKEL COMPANY STAINLESS STEEL DATA BOOK, SECT. 2, BULLETIN A (1963 EDITION)", PG. 9, THE NOMINAL U.T.S. VARIES FROM 78000 psi @ 70 °F TO 55 000 psi @ 1000 °F. CONSERVATIVELY ASSUMING A LINEAR VARIATION EVEN AT THE LOWER END OF THE RANGE FROM 70°F TO 1000°F THIS CORRESPONDS TO $\frac{78000 - 55000}{1000 - 70} = 24.73$ psi/°F

$$U.T.S. @ 300\,°F = 70\,000 - (300-70)(24.73) = 70\,000 - 5700$$
$$= \underline{64\,300}\ psi$$

GENERAL ATOMIC COMPANY

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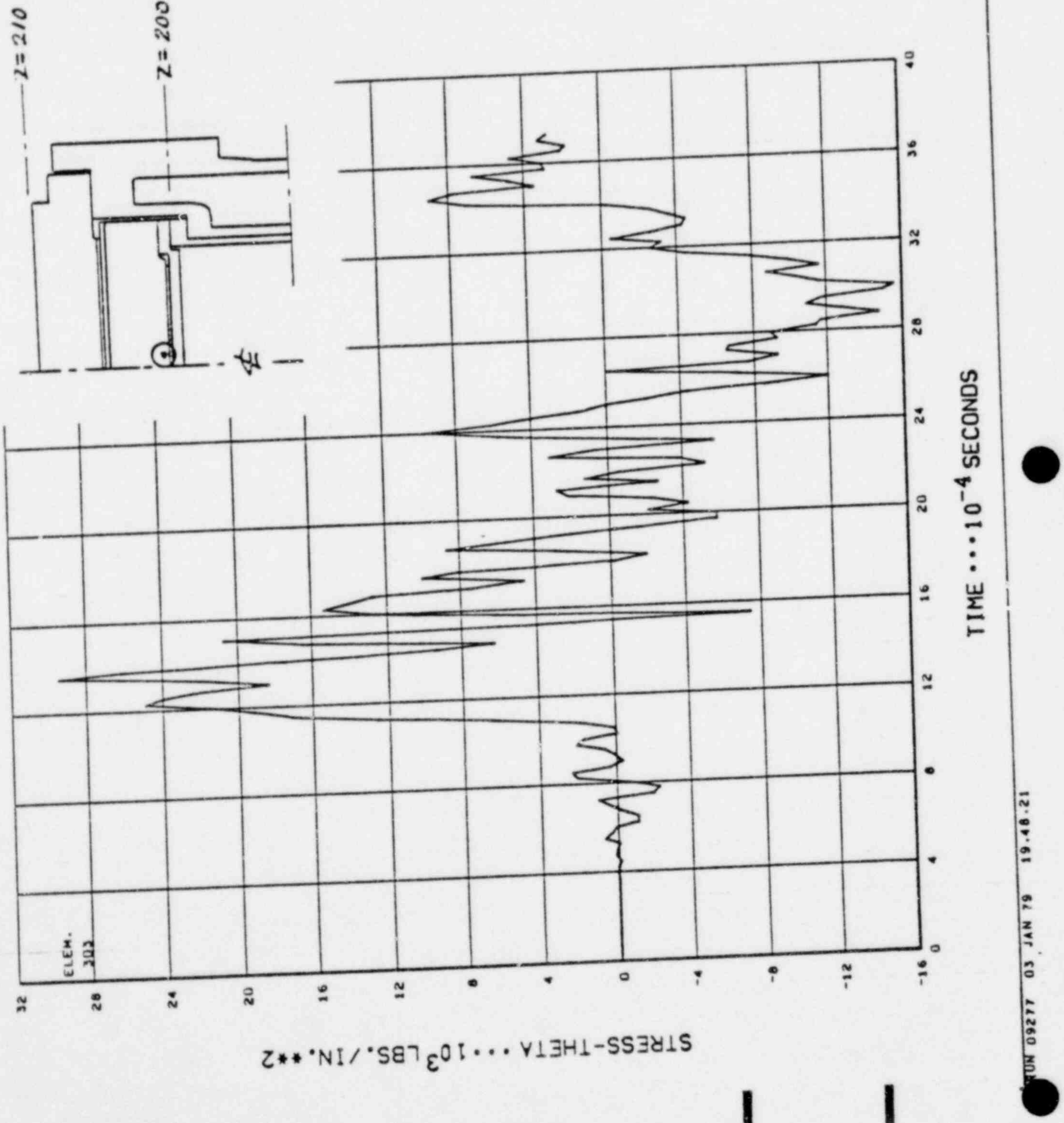
CALCULATIONS FOR FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.			PAGE OF
EQUIP. NO.	PROJ. NO.	CALC. NO.	
PREPARED BY D. L. Hinford	DATE 12 JAN., 1979	REF. DOCUMENTS:	
REVIEWED BY CMC	DATE 2-8-79		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-08.

HOOP STRESS IN ELEMENT 303. STRAIN RATE SENSITIVE CASE (EXCEPT LID SHIELD)

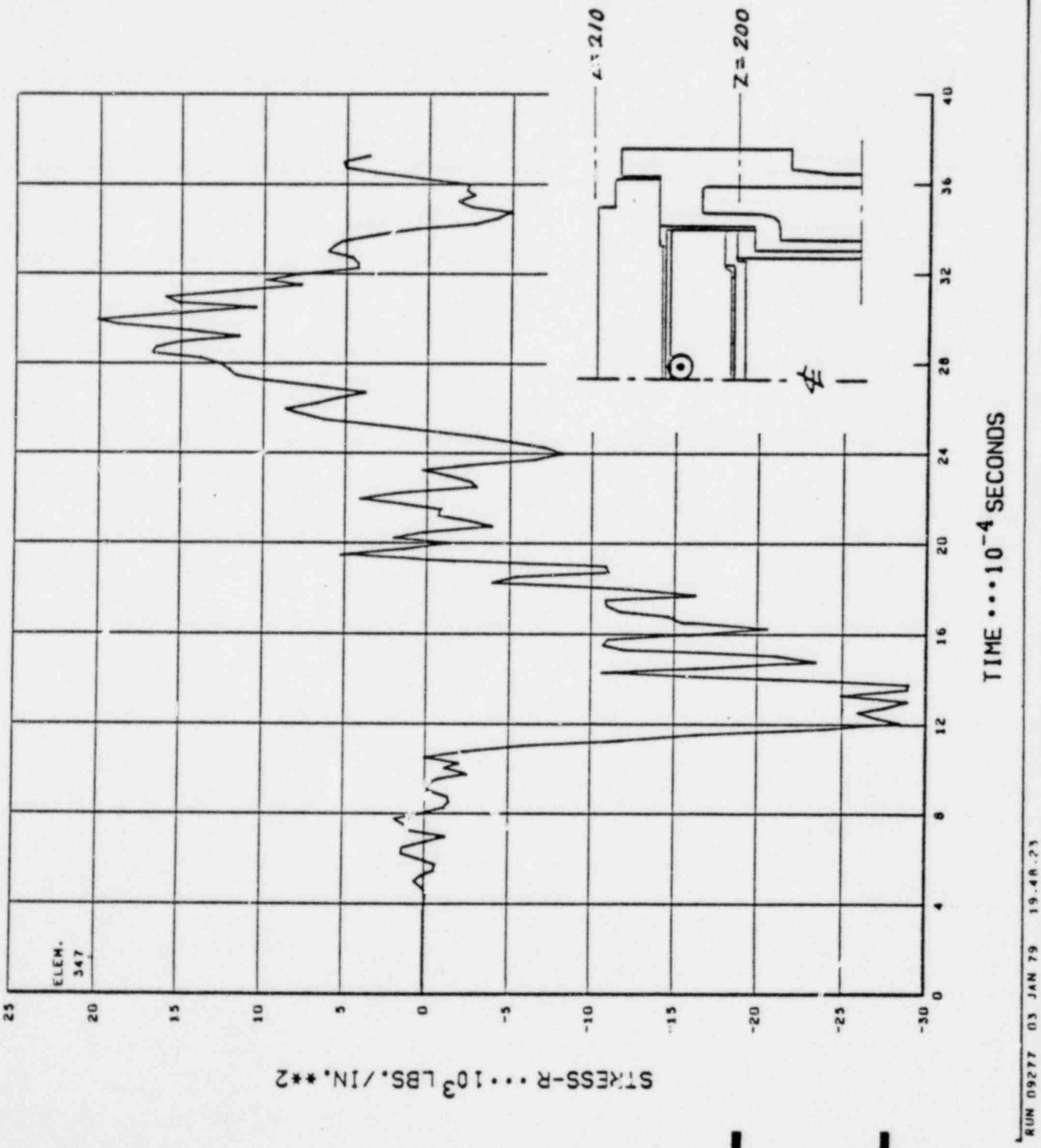


GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR *FSV FUEL SHIPPING CASK. BOTTOM 30 FT. DROP.*			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY *P. L. Shoreford*	DATE *12 Jan., 1979*	R DOCUMENTS:	
REVIEWED BY *Cme*	DATE *2-8-79*		
APPROVED BY	DATE		

REF. HONDO RUN NO. BOT-08.



RADIAL STRESS IN ELEMENT 347. STRAIN RATE SENSITIVE CASE *(EXCEPT LID SHIELD)*

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 8 June, 1978	REF. DOCUMENTS:	
REVIEWED BY	DATE 16 June 78		
APPROVED BY	DATE		

E. PUNCTURE STRESS DUE TO 40" DROP

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GOCHO	DATE 3-8-78	REF. DOCUMENTS:	
REVIEWED BY C. L. Stanford	DATE 5 May, 1978		
APPROVED BY	DATE		

<u>PIN LOADS</u> (FOR IMPACT PLATE SIZING)

ASSUME ALL ENERGY ($1.88 \cdot 10^6$ IN LB) IS
ABSORBED BY PIN (40" DROP)

$$PE = A L \int_0^{\epsilon_f} \sigma \, d\epsilon \qquad \overset{*}{\sigma} = 2.56 \cdot 10^5 \epsilon + 60{,}000$$

$$1.88 \cdot 10^6 = 28.27(8)\left\{\tfrac{1}{2}\, 2.56 \cdot 10^5 \epsilon_f^2 + 60{,}000\, \epsilon_f\right\}$$

$$\epsilon_f^2 + .468758\, \epsilon_f - .064944 = 0$$

$$\epsilon_f = \tfrac{1}{2}\left[-.468758 \pm \{.468758^2 + 4(.064944)\}^{1/2}\right]$$

$$\underline{\epsilon_f = .11185 \text{ in/in}}$$

$$\sigma_{pin} = 2.56 \cdot 10^5 \; .11185 + 60{,}000 = \underline{88{,}635 \text{ PSI}}$$

$$F_p = \sigma_p A_p = 88{,}635 \frac{\pi 6^2}{4} = \underline{\underline{2.50 \cdot 10^6 \text{ LBS}}}$$

MAX PIN FORCE

* REFERENCE:

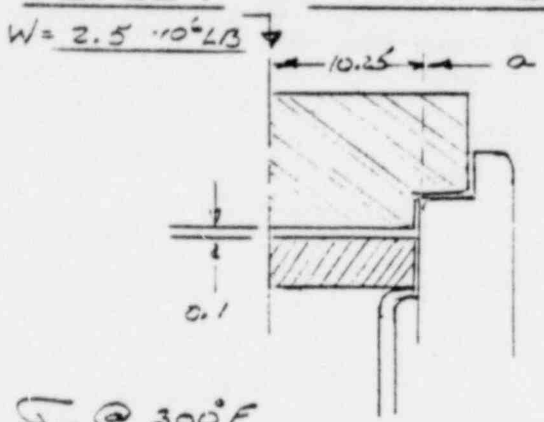
J.W. EVANS, "DESIGN AND ANALYSIS OF THE NEW BRUNSWICK LABORATORY HIGH LEVEL WASTE CASK", ORNL REPORT TM-4242 APPENDIX PG 94

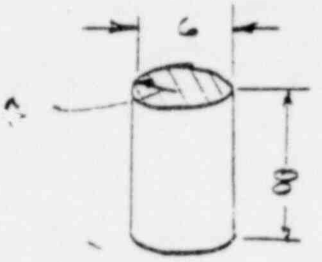
POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EP NO.	PROJ. NO.	CALC. NO.	PAGE OF
ARED BY JOHN GACHO	DATE 3-10-78	REF. DOCUMENTS: ROARK 5th Ed FORM. FOR STRESS AND STRAIN	
REVIEWED BY D. L.	DATE 5 May, 1978		
APPROVED BY	DATE		

COVER PLATE:

CASE I: THICK CASK LID (YIELD AND DEFLECTION)





MILD STEEL PIN
STRAINED HARDENED UP
TO σ_{PIN} = 88,600 PSI

σ_y @ 300°F

MAX PIN LOAD 2.50 × 10⁶ LBS = W

REF: ROARK TABLE 24 CASE 16

t SET ON ELASTIC BASIS SIMPLY SUPPORTED

$\sigma_0 = \sigma_R \leq \sigma_y$ $\quad y_c \leq .1$ INCH

$$M_R = \frac{W}{4\pi}\left[(1+\nu)\ln a/r_0' + 1\right], \quad \sigma = 6M_R/t^2$$

$$\sigma = \frac{6}{t^2}\,\frac{W}{\pi\,4}\left[(1+\nu)\ln a/r_0' + 1\right] = \frac{6}{t^2}\,\frac{2.50\cdot 10^6}{\pi\,4}\left[1.3\ln(10.25/3) + 1\right]$$

$$\sigma = 3.100257\times 10^6/t^2 = \underline{\underline{137{,}400\ \text{PSI}}}$$

or $\underline{\underline{t = (3.100257\times 10^6/\sigma)^{1/2}}}$, σ - MATERIAL LISTED

$$y_c = \left(\frac{Wa^2}{16\pi D}\cdot\frac{3+\nu}{1+\nu}\right) \qquad t = \left\{\frac{Wa^2}{16\pi}\;\frac{3+\nu}{1+\nu}\;\frac{12(1-\nu^2)}{y\,E}\right\}^{1/3}$$

$$D = Et^3/12(1-\nu^2)$$

$$y_c = \underline{4.82825/t^3}$$

MATERIAL / σ_y @ 300°F	t_{σ_y} INCHES	y_c INCHES
4340/150,000	4.75	.0152

σ_u = 175,000 PSI @ ROOM TEMP

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 3-13-78	REF. DOCUMENTS:	
REVIEWED BY D. H. Tomlinson	DATE [illegible] to Feb. 79		
APPROVED BY	DATE		

CASE 2 (COVER PLATE ANALYSIS CON'T)

PUNCH THROUGH PLATE

*MARKS
7 ED 13-24—26

$$E_s = P_s\, t\, f_p\,(1+f_f)$$

WHERE:

E_s = SHEAR ENERGY ~ IN LBS
P_s = MAX SHEAR FORCE
$= f_s L t = f_s \pi D t$
D = DIA ~ IN (5 IN)
t = PLATE THICKNESS
f_p = FRACTION OF PENETRATION BEFORE FAILURE
.39 SS .05* 4340 HT 150 000 PSI
f_s = MAX SHEAR STRESS 60% σ_y = 90,000 psi
f_f = CONTRIBUTION OF FRICTION TO RESISTING SHEAR ≅ .1 – .2 USE .15

$$E_s = f_s \pi D t^2 f_p (1+f_f)$$ REQ'D PUNCH THRU ENERGY

$$E_s = 90{,}000\,\pi\, 6\; 4.75^2\, .05\; 1.15 = \underline{2.20\times10^6 \text{ IN LB}}$$

AVAILABLE ENERGY $\underline{1.88\times10^6}$ IN LB

ENERGY MARGIN: $2.20/1.88 = \underline{1.17}$

FORCE REQD:

$$P_s = f_s \pi D t = 90{,}000\,\pi(6)\,4.75 = \underline{8.06\times10^6 \text{ LBS}}$$

FORCE MARGIN: $P_s / F_{PIN} = \dfrac{8.06\cdot10^6}{2.50\cdot10^6} = \underline{3.22}$

FORCE REQUIRED TO SHEAR PLATE IS GREATER THAN MAX FORCE PIN CAN DELIVER TO PLATE, ALSO THE ENERGY AVAILABLE IS INSUFFICIENT TO PUNCH THROUGH.
∴ PLATE IS SATISFACTORY
SEE SECTION E pg 5-124 CASE 3 PLATE CRUSH LOAD)

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GRENO	DATE 2-12-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb., 1979		
APPROVED BY	DATE		

1 FT SIDE DROP

(NO IMPACT LIMITER)

THIS SECTION SHOWS THE RESULTS OF A ONE FOOT SIDE FREE DROP OF THE CASK ON TO AN UNYIELDING SURFACE AND VERIFYS THE ADEQUACY OF THE CASK LID BOLTS' SHEAR AND CONTAINER LID BEARING STRENGTHS.

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 2-2-79	REF. DOCUMENTS: COMPUTER CODE SIDE DROP RUN 39370 FEB 8 1979	
REVIEWED BY P. L. Stanford	DATE 20 Feb., 1979		
APPROVED BY	DATE		

CASK LID 1 FT SIDE DROP LOADS
(W/O IMPACT LIMITER)

CASK LID WT ~ 777 LBS

$(\pi/4\ (27.13)^2\ 4.75\ (.283) = 777$ LBS)

LOAD FACTOR n_s ~ g's

REF COMPUTER CODE RUN 39370 (2-8-79)

$n_s = 302$ g's

SIDE LOAD F_s

$F_s = W\ n_s = 777\ (302) = 234,654$ LBS

CONTAINER LID BOLTS

24 1¼ 7UNC-2A × 4.5

BOLT AREA

$24\ A_{ROOT} = 24\ .892 = 21.408$ in²

BOLT SHEAR

$\sigma_s = F_s / A_B = \frac{234,654}{21.408} = 10,960$ psi

IF ONLY 50% BOLTS LOADED (NO REGISTER)

60% σ_y > $\sigma_s = 21,920$ psi

PRELOAD 6000 LB ~ $\sigma_x = 6725$ psi

$\tau_{max} = \frac{1}{2}\left(\sigma_x^2 + 4\tau_{xy}^2\right)^{1/2} = \frac{1}{2}\sqrt{6725^2 + 4(21,920)^2}$ 22,175 psi

MAX SHEAR

$\sigma_p = \sigma_x/2 + \tau_{max} = \frac{6725}{2} + 22,175 = 25,540$ psi

PRIN. STRESS

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY John Gacho	DATE 2-2-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb., 1979		
APPROVED BY	DATE		

CONTAINER LID 1 FT SIDE DROP LOADS

LID WT** 665 LBS (ALL DU ASSUM'D CONCENTRATED AT NODE)
PER NODAL CONSIDERATION
COMPUTER CODE* g's = 602
Ref* 39370 dtd 2-8-79

F_S LOAD = $W\ n_s = 665(602) =$ 400,330 LBS

12 BOLTS 1/2 13 UNC-2A

CONTAINER LID BOLTS NOT LOADED IN SHEAR
REF DWG 90-SK 5592
LID SIDE BEARING AREA

$A_B \quad D \times l = 20.5 \times 6 = \underline{123\ in^2}$

BEARING STRESS

$$\sigma_B = F_S / A_B = \frac{400{,}330}{123} = \underline{3255\ psi}$$

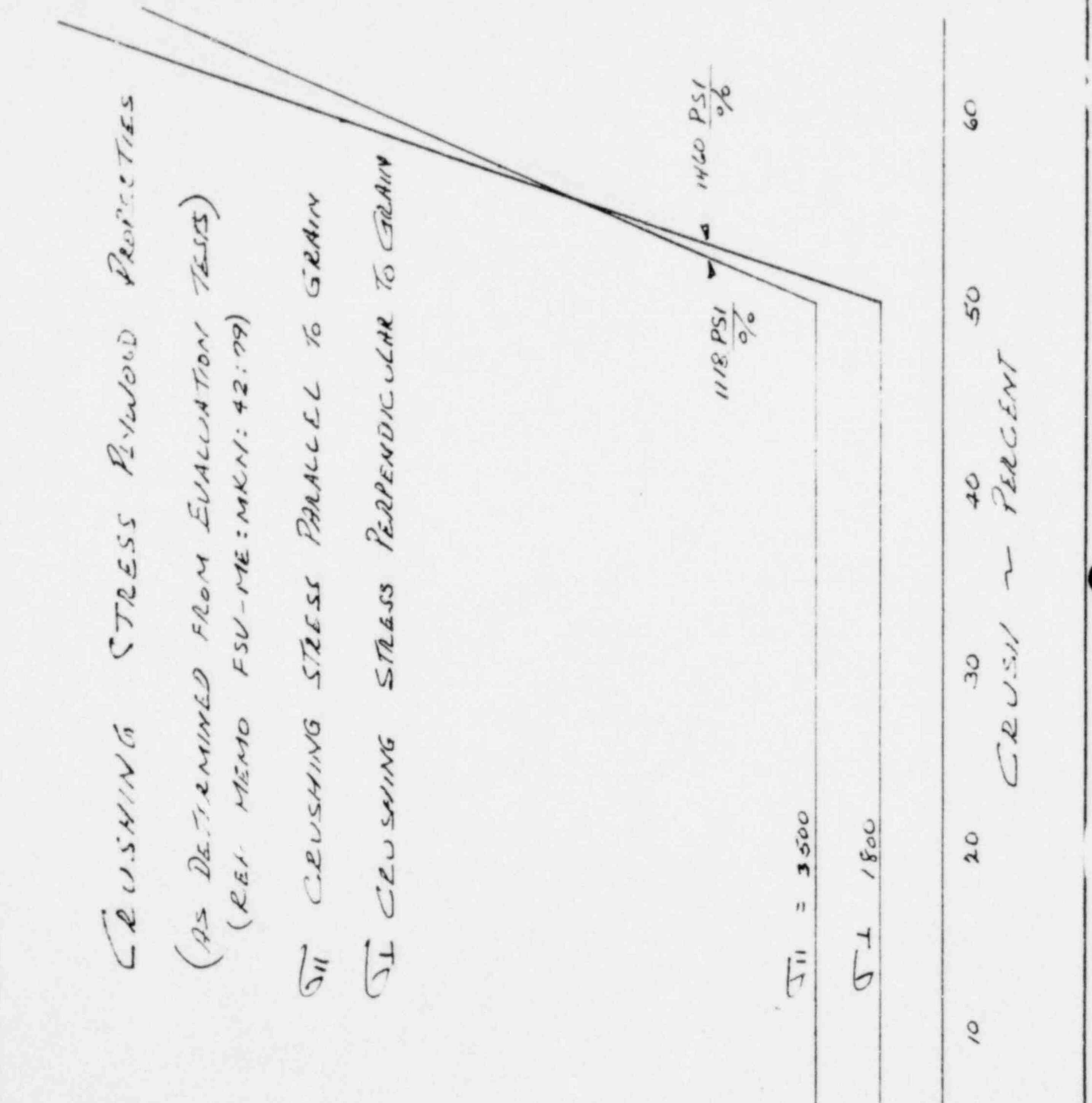
**NOTE: THE CONTAINER LID EXTENDS OVER TWO MASS STATIONS. THE DU OF MASS TWO AND THREE WERE SUMMED AND THE GREATER LOAD FACTOR OF THE NODE IS USED FOR LOADS ANALYSIS.

$WT = \pi/4\ 18.5^2\ (3+1.125)\ .6 = 665\ LBS$
REF. PG. 5-168 (PT. 2 & 3)

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 8 June, 1978	REF. DOCUMENTS:	
REVIEWED BY	DATE June 6-78		
APPROVED BY	DATE		

F. 30 FT HEAD DROP

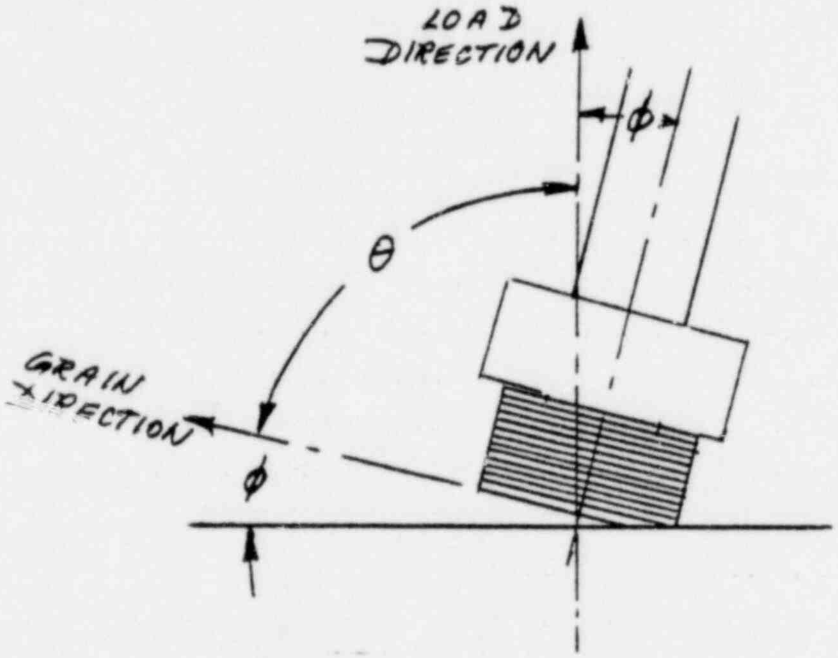
CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 3-20-79	REF. DOCUMENTS:	
REVIEWED BY CMM	DATE 4-2-79		
APPROVED BY	DATE		



CALCULATIONS FOR FSV FUEL SHIPPING CASK. IMPACT LIMITER.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 1 June, 1978	REF. DOCUMENTS:	
REVIEWED BY J S	DATE June 5-78		
APPROVED BY	DATE 20 Feb. -79 1-2-79		

PLYWOOD PROPERTIES FOR COMPUTER RUNS

30 FT HEAD & SIDE DROP



$$\phi = \frac{\pi}{2} - \theta$$

$\theta = 0;\quad \varphi = \pi/2,\quad \sigma_{\parallel} = 1800 + (\text{PERCNT} - 50) * \text{SLOPE}_{\parallel}$

(UNIFORM BELOW 50%)

$\theta = \frac{\pi}{2};\quad \varphi = 0,\quad \sigma_{\perp} = 3500 + (\text{PERCNT} - 50) * \text{SLOPE}_{\perp}$

FOR $0 < \theta < \frac{\pi}{2}$: IN COMPUTER PROGRAM USE FORMULA FROM REF. 3, PG. A-3 :

$$\text{CRUSHING STRESS}\quad \sigma = \left[1 - \left(1 - \frac{\sigma_{\perp}}{\sigma_{\parallel}}\right)\cos\phi\right]\sigma_{\parallel}$$

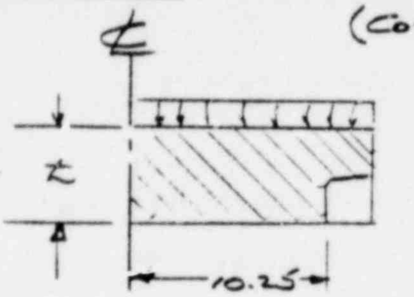
$$= \begin{cases} \sigma_{\perp} & \text{FOR } \phi = 0 \\ \sigma_{\parallel} & \text{FOR } \phi = \frac{\pi}{2} \end{cases}$$

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY John Gacho	DATE 3-13-78	REF. DOCUMENTS:	
REVIEWED BY P. L. Hamford	DATE 5 May, 1978		
APPROVED BY	DATE 4-2-79	Roark 5th Ed	

CASE 3 CRUSH LOAD RESISTANCE OF PLATE

(COVER PLATE ANALYSIS CON'T)



UNIFORM DIST. LOAD q^* PSI
(FROM PLYWOOD IMPACT LIMITER)
SIMPLY SUPPORTED CASE

$$M = q a^2 (3+\nu)/16$$ ROARK TBL 24 - 10a

AND $$\sigma = \frac{6M}{t^2} = \frac{6}{16} \frac{q a^2 (3+\nu)}{t^2}$$

for: $q = 3{,}200$ PSI
$a = 10.25$ IN
$\nu = .3$

*REF: FROM PAGE 5-122 IT IS DETERMINED THAT THE CASK DOES NOT BOTTOM DURING THE TOP END DROP. THEREFORE THE CONSERVATIVE VALUE OF PLYWOOD CRUSH STRESS IS USED.

$$\sigma = 6\,(3200)\,\overline{10.25}^2\,(3.3)/(16\,t^2) = 416{,}047/t^2$$

WITH $t = 4.75$

$$\sigma = 1.9415 \cdot 10^6/t^2 = 18{,}440 \text{ PSI} < \sigma_{yield} \text{ @ } 300°F = 150{,}000 \text{ psi}$$

SHEAR FORCE:

$$F_A = \pi R^2 q = \pi\,\overline{10.25}^2\,(3200) = 1.056 \times 10^6 \text{ LBS}$$

SHEAR AREA $= \pi D \cdot t = \pi\ 20.5\ 4.75 = 306 \text{ in}^2$

$$\tau = F_A/A_s = 1.056 \times 10^6/306 = 3450 \text{ psi}$$

$$\tau_{max} = 1.5\ \tau = 5175 \text{ psi} < .5\ \sigma_y = 65 \text{ KSI}$$

CALCULATIONS FOR F.S.V FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GAGNO	DATE 1-22-79	REF. DOCUMENTS:	
REVIEWED BY P. G.	DATE 20 Feb., 1979		
APPROVED BY	DMC [illegible] DATE		

PLYWOOD IMPACT LIMITER

THE IMPACT LIMITER WAS DESIGNED TO FIT AND PROTECT AN EXISTING FUEL CASK FROM EXCESS ACCIDENTAL DAMAGING LOADS THAT COULD COMPROMISE THE CASK CONTAINMENT SECURITY. THIS IMPACT LIMITER WAS ORIGINALLY SIZED TO PRECLUDE EXCEEDING 50% CRUSH BUT LATER ANALYSES EMPLOYING THE ACTUAL PLYWOOD EVALUATION TEST RESULTS INDICATES THE DIMENSIONS ARE SATISFACTORY AS THEY ARE SHOWN ON Pg 5-154.

THIS IMPACT LIMITER, SKETCHED IN Pg 5-154 IS MADE UP WITH SUFFICIENT 3/4 INCH PLYWOOD CIRCULAR SECTIONS GLUED TOGETHER TO ABSORB THE KINETIC ENERGY OF THE CASK WHEN DROPPED FROM A 30' HEIGHT. THESE PLYWOOD SECTIONS ARE THEN GLUED IN TURN TO AN ALUMINUM CYLINDER AND END CAP WHICH SERVE AS LOAD CARRYING MEMBERS. THE COMBINED LIMITER FITS SNUGLY OVER THE FUEL CASK HEAD AND IS SECURED IN PLACE TO A HOLD DOWN RING BY SIX STUDS. THIS CLAMPING ARRANGEMENT HOLDS THE IMPACT LIMITER IN PLACE DURING TRANSIT AND IS ADDITIONALLY DESIGNED TO WITHSTAND 10 g CENTRIPTAL OR AXIAL ACCELERATION LOADS.

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CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 1-23-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb., 1979		
APPROVED BY	DATE 4-3-79		

IMPACT LIMITER LOADS ANALYSIS

CONSIDERATIONS PERTAINING TO THE LOADS ANALYSIS OF THE IMPACT LIMITER ARE DISCUSSED BELOW FOR THE 90° SIDE DROP CASE. THE IMPACT LOADS, ALTHOUGH COMPLEX, WERE EXAMINED FIRSTLY FROM A MOST PROBABLE STANDPOINT AND SECONDLY, DISCUSSED FROM THE VIEWPOINT OF A LATER TIME INCREMENT.

THE FIRST LOADING IS THAT OF A SIMPLE 90° GROUND STRIKE INDUCING AN UNCAPPING MOMENT BY THE CRUSH FORCE THAT IS NOT BALANCED BY DIRECT REACTION LOADS. THIS UNCAPPING MOMENT MUST BE BALANCED BY TWO INTERNALLY GENERATED FORCES PRODUCING AN OPPOSING MOMENT. THE INTERNAL COMPRESSIVE REACTING LOAD IS GENERATED BY THE RESULTING UPPER CAP-HALF PRESSURE LOADING. THE LOWER OPPOSING TENSION LOADING IS ASSUMED TO ACT OVER THE PROJECTED HOLLOW ALUMINUM CYLINDER ARC SECTOR THAT REACTS THE COMPRESSIVE PLYWOOD CRUSH FORCE. OBVIOUSLY THIS PLYWOOD CRUSHING FORCE IS AT RIGHT ANGLES TO THE REQUIRED TENSION FORCE. THIS TENSION FORCE COULD BE REALIZED BY THE TIE DOWN STUDS AND RING BUT THIS ARRANGEMENT IS TOO OVERLY CONSERVATIVE. THIS IS EVIDENCED IN LIGHT OF THE LOW TENSION/NORMAL FORCE RATIO (OF 0.049)*. THIS IN ITSELF IS CONSERVATIVE AS THE ASSUMED ARC SECTOR OVER WHICH THE TENSION FORCE IS GENERATED IS IN REALITY JUST ABOUT HALF OF THE ACTUAL PROJECTED

*PG 5-135

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACNO	DATE 1-23-79	REF. DOCUMENTS:	
REVIEWED BY D. L. Stanford	DATE 20 Feb. 1979		
APPROVED BY	DATE 4-2-79		

IMPACT LIMITER LOADS ANALYSIS (CON'T)

ALUMINUM CYLINDER WIDTH. ANY TENSION LOAD TAILS OFF AS THE FULL DIAMETER IS APPROACHED. A JUDICIOUS USE OF APPROXIMATELY 8% OF THE REFERENCED STATIC FRICTION FACTOR WAS FOUND TO BE REQUIRED FOR GENERATION OF THE FRICTION OR TENSION FORCE. THIS IS FELT TO BE ACCEPTABLE AND WOULD IN EFFECT SUPPLY THE TOTAL TENSION FORCE; RESULTING IN NO NET TENSION FORCE REQUIRED BY THE TIE DOWN STUDS.

A SECOND CONSIDERATION OF IMPACT LIMITER REACTION LOADING TO THE 90° SIDE DROP CASE IS THAT DUE TO A JAMMING ACTION. THIS ACTION, INITIALLY, IS SIMILAR TO THAT FIRST DISCUSSED. THE DIFFERENCE, HOWEVER, IS THAT THE UNCAPPING MOMENT NOW IS CONSIDERED TO BE REACTED BY THE UPPER OUTER EDGE AND LOWER INNER CYLINDER CORNER EDGE LOADS. THIS LOADING IS DIFFICULT TO ANALYZE BUT APPEARS TO CAUSE LOCAL YIELDING OF THE UPPER OUTER CYLINDER EDGE. THE RESULTING YIELDING ALLOWS A REDISTRIBUTION OF STRESS BY SPREADING THE APPLIED LOAD OVER A GREATER EDGE OR BAND AREA. THIS ACTION TENDS TO INDUCE CYLINDER BENDING ALONG WITH CYLINDER HOOP TENSION STRESS. AT SOME LATER TIME INTERVAL, THE INNER STAINLESS STEEL CASK SECTION 'ROTATES' DOWNWARD (WITH RESPECT TO THE IMPACT LIMITER CAP) SINCE THE AFT CASK SECTION IS FREE. THIS ROTATION CAUSES A REVERSING AFFECT ON THE INTERNAL REACTION LOADING. BUT NOW THE PLYWOOD CRUSHING LOAD IS REDISTRIBUTED.

* REF PG 5-136.

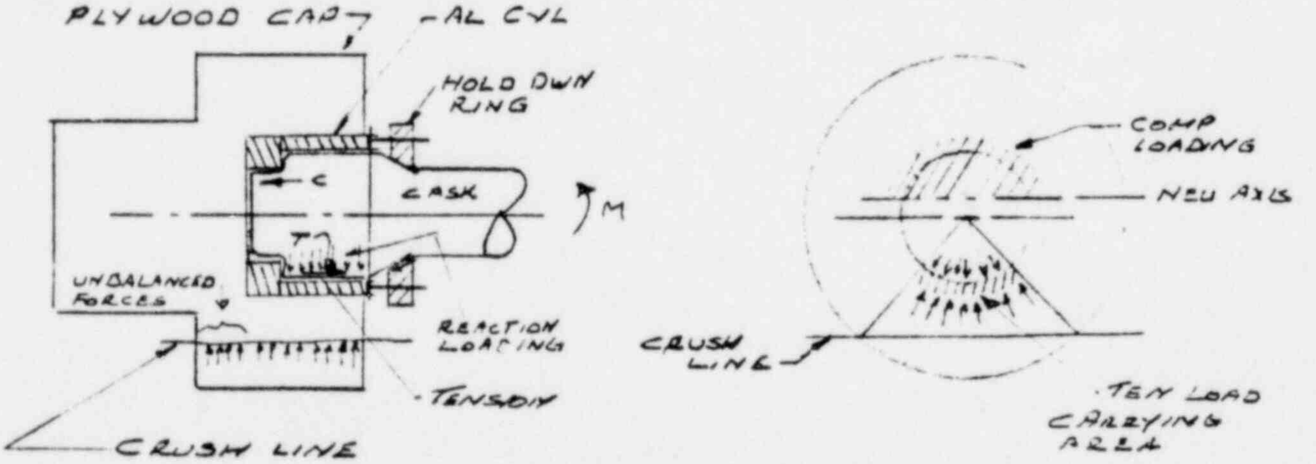
CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACNO	DATE 1-23-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb. 1979		
APPROVED BY	DATE 4-2-79		

IMPACT LIMITER LOADS ANALYSIS (CON'T)

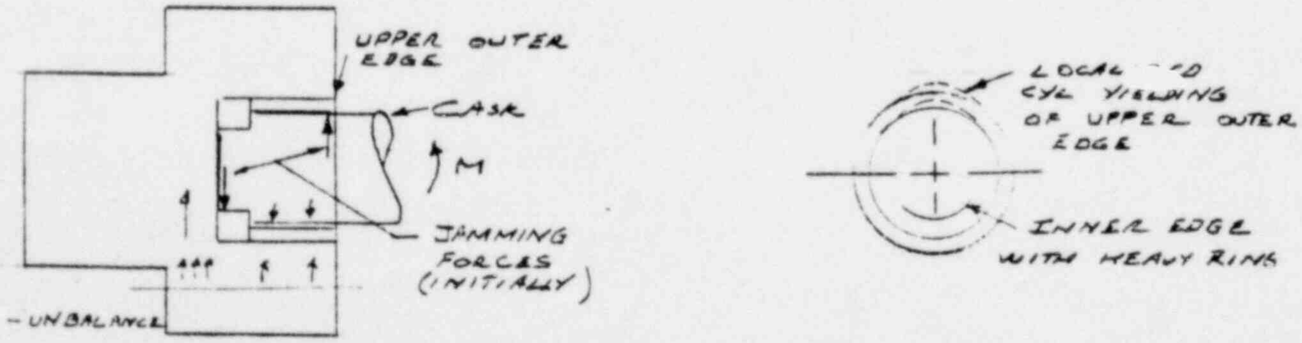
THE UNCAPPING MOMENT IS REDUCED SOMEWHAT AND MUST BE REACTED BY SIMILAR FORCES TO THOSE FIRST DISCUSSED.

A MOST PROBABLE OCCURRENCE IS THAT THE RESULTING REACTION LOADS ARE A COMBINATION OF BOTH THE ABOVE SCHEMES; COMPRESSION - TENSION (TENSION SUPPLIED BY FRICTION FORCES) AND JAMMING IT IS FELT HOWEVER THAT GREATER EMPHASIS AND CREDULITY BE PLACED UPON THE FORMER LOADING CONSIDERATION.

DIAGRAM DEPICTING LOADING CONSIDERATIONS



FRICTION SCHEME



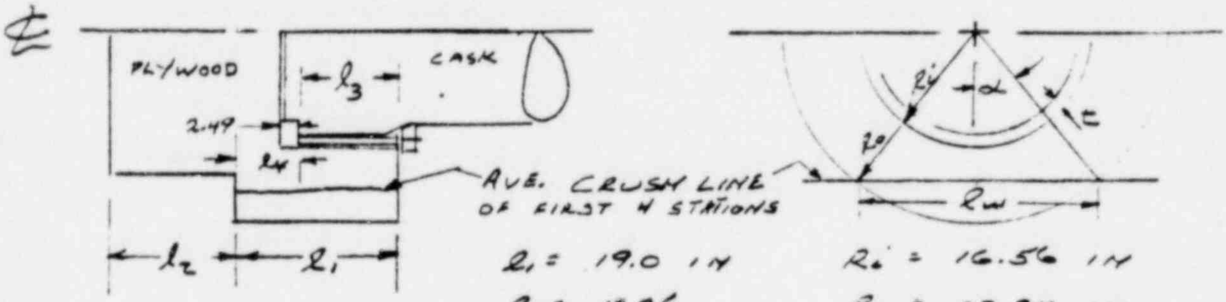
JAMMING SCHEME

CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 1-24-79	REF. DOCUMENTS: SIDE DROP CODE DZA 46967 3/27/79 10:49:28 CALC FILE DEC-15-002	
REVIEWED BY	DATE 20 Feb., 1979		
APPROVED BY	DATE 4-2-79		

IMPACT LIMITER LOADS ANALYSIS 30' SIDE DROP

THE SKETCH BELOW SHOWS AN AXIAL VIEW OF A 90° GROUND IMPACT WITH A PLYWOOD CRUSH AVERAGE OF 3.925 IN (58%)

$$\sigma_{58\%} = 3500 + 1118(58-50) = 12{,}444 \text{ PSI}$$



$l_1 = 19.0$ IN
$l_2 = 13.75$
$l_3 = 11.26$
$l_4 = 7.74$

$R_i = 16.56$ IN
$R_o = 23.34$ IN
$t = 1.0$ IN

$$\alpha = \cos^{-1}\left(\frac{R_o - 3.925}{R_o}\right) = \cos^{-1}\frac{23.34 - 3.925}{23.34} = 33.71^\circ \simeq \underline{(0.5884 \text{ RAD})}$$

$$l_w = 2R_o \sin\alpha = 2\,(23.34)\sin 33.71 \quad \underline{25.91 \text{ IN.}}$$

UNBALANCED LOAD OVER LENGTH l_4 (CRUSH << 50% OVER L_4)

$$P_u = q\, l_w (l_4 - 2.49) = 3500\,(25.91)\ 5.25 = \underline{4.761 \times 10^5 \text{ LB}}$$

CYLINDER MOMENT AT RING (l_4) (RING BOTTOM)

$$M = P_u \left(\frac{2.49 + l_4}{2} + l_w \frac{2.49^2}{2}(12{,}444)\right.$$

$$M = 4.761\cdot 10^5\left(\frac{2.49 + 7.74}{2}\right) + 26.21\left(\frac{2.49^2}{2}\right)12444 = \underline{3.446\cdot 10^6 \text{ IN LB}}$$

CYLINDER BENDING STRESS

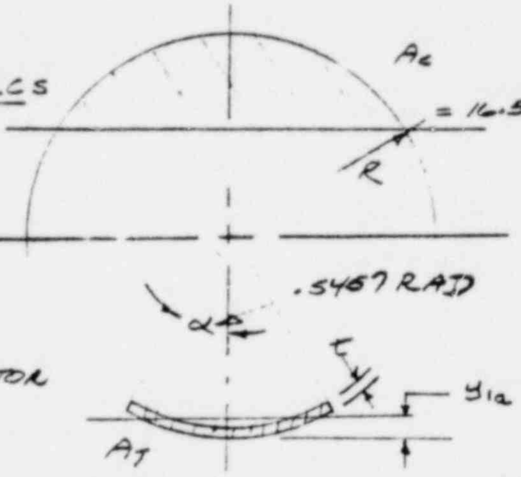
$$I_{cy} = \pi/4\,\left(R_i^4 - (R_i - t)^4\right) =$$
$$= \pi/4\,(16.56^4 - 15.56^4) = \underline{13{,}026 \text{ IN}^4}$$

$$\sigma_B = Mc/I_{cy} = 3.446\cdot 10^6\,(16.56)/13026 = \underline{4381 \text{ PSI}}$$

CALCULATIONS FOR FSV FUEL SHIPPING CASK				
EQUIP. NO.	PROJ. NO.		CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 1-19-79	REF. DOCUMENTS: ROARK 5th Ed FORM. FOR STRESS AND STRAIN		
REVIEWED BY P. L. Thurford	DATE 20 Feb 1979			
APPROVED BY cmc	DATE 4-2-79			

IMPACT LIMITER

NEUTRAL AXIS & INERTIA CALCS



COARSE CROSS HATCHED UPPER SECTIONS REACTS COMPRESSION FORCE; THE LOWER ALUMINUM ARC SECTOR DETERMINED FROM 50% PLYWOOD CRUSH & SUPPLIES THE REQUIRED TENSION TO REACT THE UN-CAPPING MOMENT.

END VIEW LOOKING INTO IMPACT LIMITER SHOWING LOAD AREAS FOR NEUTRAL AXIS CALCULATION

NOTE: THE ANGLE α WAS CALCULATED AS 0.5457 RAD WITH THE ORIGINAL HIGHER UNIFORM CRUSH PLYWOOD AND NEUTRAL AXIS CALCULATED ACCORDINGLY. REVISION 'B', USING TEST EVALUATION RESULTS, ALLOWED α TO INCREASE TO 0.5884 RAD. THIS WOULD RELOCATE THE NEUTRAL AXIS SOMEWHAT BUT THE SHIFT IS SMALL AND THE ORIGINAL NEUTRAL AXIS LOCATION IS USED IN THIS REVISION.

$$A_T = \alpha t\,(2R - t), \quad I_{y_{0T}} = I_{y_{(R-y_{1a})}}; \quad y_T = (R - y_{1a})$$

SECTOR CENTROIDAL AXIS: OF LOWER ARC ROARK TBL 1 # A

$$y_{1a} = R\left\{1 - \frac{2\sin\alpha}{3\alpha}\left(1 - \frac{t}{R} + \frac{1}{2 - t/R}\right)\right\}$$

$$I_{y_{(R-y_{1a})}} = R^3 t\left\{\left(1 - \frac{3t}{2R} + \frac{t^2}{R^2} - \frac{t^3}{4R^3}\right) \times \left(\alpha + \sin\alpha\cos\alpha - \frac{2\sin^2\alpha}{\alpha}\right) + \frac{t^2\sin^2\alpha}{3R^2\alpha(2 - t/R)}\left(1 - t/R + t^2/6R^2\right)\right\}$$

CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GRENO	DATE 1-18-79	REF. DOCUMENTS:	
REVIEWED BY P. Y. [illegible]	DATE 20 Feb., 1979		
APPROVED BY	DATE		

IMPACT LIMITER NEUTRAL AXIS CALC (CONT)

EQUATION DEVELOPMENT FOR THE COMPRESSIVE AREA IS EXPANDED ON THE FOLLOWING PAGES DUE TO THE MORE COMPLEXITY INVOLVED.

THE TENSION AREA PROPERTIES ARE NOTED BELOW AND NEED ONLY BE TRANSFERRED ABOUT THE NEUTRAL AXIS DEVELOPED IN THE FOLLOWING PAGES. THE LOWER TENSION AREA IS

$$A_T = .5457 \cdot 1 \cdot (2 \cdot (16.56) - 1) = \underline{17.52788 \text{ in}^2}$$

AND

$$I_{y_{o_T}} = I_{y_{1a}} = \text{Below} = \underline{9.865 \text{ in}^4}$$

$$y_T = \text{Below} = \underline{15.28 \text{ in}}$$

WHERE NUMERICS ARE SUBSTITUTED INTO PREV EQNS

$$I_{y_{o_T}} = 16.56^3(1)\left\{\left(1 - \frac{3(1)}{2\ 16.56} + \frac{1}{16.56^2} - \frac{1^3}{4(16.56)^3}\right) \times \right.$$

$$\left(.5457 + \sin .5457 \cos .5457 - \frac{2\sin^2 .5457}{.5457}\right)$$

$$\left. + \frac{1^2 \sin^2 .5457}{3(16.56)^2 .5457(2 - 1/16.56)} \left(1 - \frac{1}{16.56} + \frac{1}{6(16.56)^2}\right)\right\}$$

$$= (4541.308)\{.913012(.0020610) + .00030935(.94022)\}$$

$$(\quad '' \quad)\{.00188172 + .000290858\}$$

$$(\quad '' \quad)\{\{(.002172257)\}$$

$$= \underline{9.866 \text{ in}^4}$$

POOR ORIGINAL

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSU FUEL SHIPPING CASK
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PREPARED BY JOHN GACHO
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APPROVED BY
DATE

IMPACT LIMITER NEUTRAL AXIS CALC (CONT)

$$y_{1a} = 16.56\left\{1 - \frac{2\sin .5457}{3(.5457)}\left(1 - \frac{1}{16.56} + \frac{1}{2 - 1/16.56}\right)\right\}$$

$$16.56\left\{1 - .63407(1.4552)\right\}$$

$$16.56\,(.0773) = \underline{1.28036 \text{ in}}$$

$$R - y_{1a} = 16.56 - 1.28 = \underline{15.28 \text{ in}}$$

THE LOWER TENSION INERTIA IS CALCULATED AS

$$I_{TNA} = I_0 + A_T\,\bar{y}_T^{\,2}$$

$\bar{y}_T$ COMPUTED ON FOLLOWING PAGE

$$= 9.866 + 17.528(24.478)^2 = \underline{10{,}512 \text{ IN}^4}$$

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CALCULATIONS FOR FSV FUEL SHIPPING CASK			
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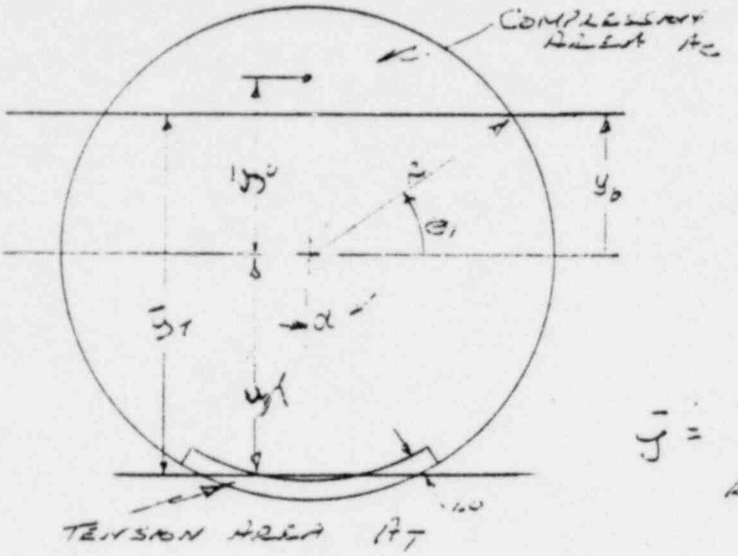
PREPARED BY JOHN GACHO	DATE 2-7-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb., 1979		
APPROVED BY	DATE		

NEUTRAL AXIS CALCULATIONS



$$\bar{y}_c = \frac{2\int_{0}^{x=\sqrt{R^2-y_b^2}}\int_{y_b}^{\sqrt{R^2-x^2}} dx\, y\, dy}{2\int_{0}^{x=\sqrt{R^2-x^2}}\int_{y_b} dx\, dy}$$

$$\bar{y} = \frac{\frac{2}{3}\left(R^2-y_b^2\right)^{3/2}}{R^2 \sin^{-1}\frac{\sqrt{R^2-y_b^2}}{R} - y_b\sqrt{R^2-y_b^2}}$$

AN ITERATION SCHEME WAS USED TO DETERMINE (y_b) THE NEUTRAL AXIS FOR THE TENSION/COMPRESSION AREAS i.e.,

$\longrightarrow A_c(\bar{y}_c - y_b) \overset{?}{=} A_T(\bar{y}_T + y_b)$; BY ASSUMING A VALUE FOR 'y_b' THEN CALCULATING '$\bar{y}_c$'. 'A_T' AND '$\bar{y}_T$' ARE KNOWN AND FIXED AS IS R

WITH $\underline{\underline{y_b = 9.198}}$ 'A_c' CALCULATED 142.611

$y_b + \bar{y}_T = \underline{24.478}$ '$\bar{y}_c$' WAS CALCUL'D 3.0085

$\longrightarrow$ 142.611 3.0085 $\overset{?}{=}$ 17.528 (15.28 + 9.198)

$\underline{429.050 \overset{?}{=} 429.050}$ ✓ OK

WITH 'y_b' EVALUATED, 'θ_1' MAY BE CALCULATED ALONG WITH I_{NA} ABOUT THE NEUTRAL AXIS

POOR ORIGINAL

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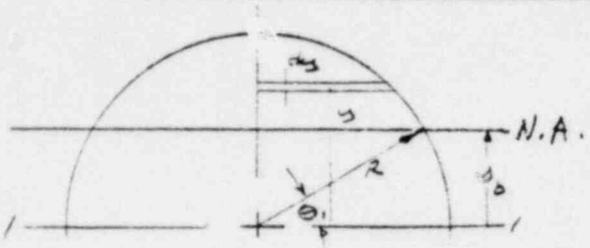
CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 2-12-79	REF. DOCUMENTS:	
REVIEWED BY R. L. Stanford	DATE 20 Oct., 1979		
APPROVED BY	DATE		

COMPRESSIVE AREA SECTION PROPERTIES



$$I_1 = 2\int y^2 x\,dy = 2\int y^2\left(R^2-y^2\right)^{1/2} dy$$

WITH $y = R \sin\theta$

$dy = R \cos\theta \; d\theta$

$$I_1 = 2\int_{\theta_1}^{\pi/2} R^2 \sin^2\theta \sqrt{R^2 - R^2\sin^2\theta}\,\left(R\cos\theta\, d\theta\right)$$

$$= \frac{R^4}{8}\left(\pi - 2\theta_1 + \sin 2\theta_1 - 4\sin^3\theta_1 \cos\theta_1\right)$$

$$I_1 = \underline{21,787 \text{ in}^4}$$

$$I_{N.A.} = I_{y_c} = I_1 - A_c\left(y_b + y_c\right)^2 - A_c\, y_b^2$$

$$= 21,787 - 142.64\left[(9.198 + 3.0085)^2 - 3.0085^2\right]$$

$$= 21787 - 142.64\left[149 - 9.05\right]$$

$$= \underline{1829}$$

TOTAL SECTION INERTIA

COMBINING I_{y_c} AND $\left(I_{y_{0T}} + A_T \bar{y}_T^2\right)$

$$I_{y_b} = I_{y_c} + I_{y_{0T}} + A_T\, \bar{y}_T^2$$

$$1829 + 9.87 + 17.528 \;\; 24.478^2$$

$$= \underline{12,341 \text{ in}^4}$$

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 1-24-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb. 1979		
APPROVED BY	DATE 4-2-79		

IMPACT LIMITER LOADS ANALYSIS

CYLINDER BENDING STRESS (CON'T)

IF MOMENT IS REACTED OVER THE CYLIINDER / CAP AND HOLLOW SECTOR OF THE CYLINDER

$\sigma = M C_{NA} / I_{yb}$, I_{yb} PREVIOUS PAGE

$C_{NA} = R_i + \bar{y} = 16.56 + 9.20 = \underline{25.76\ \text{in}}$

TENSION $\sigma_T = 3.446 \cdot 10^6\ 25.76 / 12{,}341 = \underline{7195\ \text{psi}}$

COMP $\sigma_c = 3.446 \cdot 10^6\ (16.56 - 9.20) / 12{,}341 = \underline{2055\ \text{psi}}$

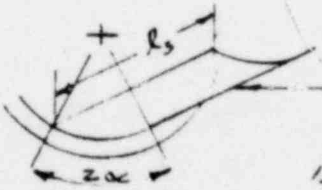
IMPACT LIMITER — STUD LOADS

PULL DOWN LOAD DERIVED FROM MOMENT:

$F(\bar{y}_c + y_T) = M$ $\bar{y}_c + y_T$ = CENTROID/CENTROID DISTANCE

$y = 12.2065 + 15.28 = 27.49$ in.

$F = M/(y) = 3.446 \times 10^6 / 27.49 = \underline{125{,}355\ \text{LBS}}$



INSIDE BEARING AREA OF AL CYL

NORMAL FORCE F_N AL CYL/SS CASK

AV CRUSH 3.925 $2\alpha = 1.1768$ RAD $\sigma_{5.9\%}$ 12444 psi

$F_N = R(2\alpha)\, l_3\, q = (15.56)\, 1.1768\, (11.26)\, 12{,}444$

$= \underline{2.566 \times 10^6\ \text{LBS}}$

$F/F_N = 125{,}355 / 2.566\,10^6 = \underline{.049}$

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CALCULATIONS FOR FSU FUEL SHIPPING CASK			
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PREPARED BY John Gacho	DATE 1-24-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 Feb., 1979	* MARKS MECH ENGR HNDBK	
APPROVED BY	DATE 4-2 7-79	6th Ed P234 TABLE 3	

IMPACT LIMITER LOADS ANALYSIS

STUD LOADS (CON'T)

COEFFICIENT OF FRICTION FOR FRICTION FORCE CALCULATION WAS TAKEN FROM THE TABULATION AT THE RIGHT WHICH IS LIFTED FROM STATED REF.* ABOVE.

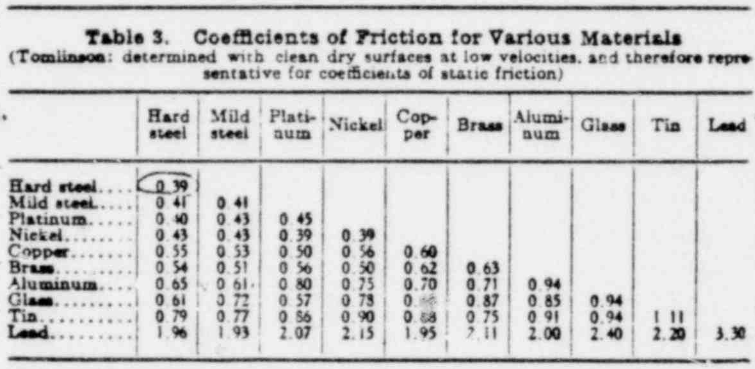

Table 3. Coefficients of Friction for Various Materials

(Tomlinson: determined with clean dry surfaces at low velocities, and therefore representative for coefficients of static friction)

	Hard steel	Mild steel	Platinum	Nickel	Copper	Brass	Aluminum	Glass	Tin	Lead
Hard steel	0.39									
Mild steel	0.41	0.41								
Platinum	0.40	0.43	0.45							
Nickel	0.43	0.43	0.39	0.39						
Copper	0.55	0.53	0.50	0.56	0.60					
Brass	0.54	0.51	0.56	0.50	0.62	0.63				
Aluminum	0.65	0.61	0.80	0.75	0.70	0.71	0.94			
Glass	0.61	0.72	0.57	0.78	[illegible]	0.87	0.85	0.94		
Tin	0.79	0.77	0.86	0.90	0.88	0.75	0.91	0.94	1.11	
Lead	1.96	1.93	2.07	2.15	1.95	2.11	2.00	2.40	2.20	3.30

THE COEFFICIENT OF FRICTION, μ, FOR MILD STEEL AND ALUMINUM, WHICH IS REPRESENTATIVE OF THE IMPACT LIMITER ALUM. CYLINDER AND THE STAINLESS STEEL CASK IS SEEN TO BE 0.61

THE FRICTION FORCE F_R THAT MAY BE REALIZED IS:

$$F_R = \mu F_N = .61 \quad 2.566 \cdot 10^6 = \underline{1.565 \cdot 10^6} \text{ LBS}$$

$$F \text{ REQUIRED} = \underline{125,355} \text{ LBS}$$

MARGIN: $F_R / F_{REQ} = 15.65/1.25 = \underline{12.5}$

OR APPROXIMATELY 8% OF THE AVAILABLE FRICTION FORCE IS REQUIRED. THEREFORE THE TIE-DOWN STUDS PROVIDE NO NET TENSION LOAD DUE TO THE 90° SIDE DROP

HOWEVER ROTATIONAL AXIAL LOADS DO NOT DEPEND ON FRICTION AND THE LOADS MUST BE TAKEN UP BY THE HOLD DOWN STUDS. ROTATIONAL LOADS ARE CALCULATED AS:

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 1-25-79	REF. DOCUMENTS:	
REVIEWED BY R. L. Heitmann	DATE 20 Feb., 1979		
APPROVED BY	DATE		

IMPACT LIMITER - STUD LOADS (CONT)

CENTRIPETAL FORCE DUE TO ROTATION:
ASSUMING TOTAL KINETIC TRANSLATIONAL IS CONVERTED TO ROTATIONAL ENERGY

$$KE = \tfrac{1}{2} M V^2 = \tfrac{1}{2} I \omega^2 \qquad I = I_0 + M (L/2)^2$$

$$V = \sqrt{2gh} = \sqrt{2\,(386.4)\,360} = \underline{5.275 \cdot 10^2} \text{ in/sec}$$

$$I = \tfrac{1}{12} M l^2 + M (l/2)^2$$
$$= \tfrac{1}{12}(120)\,210^2 + (20)\,105^2 = \underline{1.764 \cdot 10^6} \text{ LB sec}^2 \text{ in}$$

$$\omega^2 = MV^2/I = 120\,(5.275 \cdot 10^2)^2 / 1.764 \cdot 10^6 = \underline{18.93} \ \frac{\text{RAD}^2}{\text{SEC}^2}$$

CENTRIFUGAL ACCELERATION

$$n_z = l\,\omega^2/g = 210\,(18.93)/386.4 = \underline{10.29}\ g\text{s}$$

CENTRIPTAL FORCE ON STUDS

$$F = n_z W = 10.29\,(1060) = \underline{10\,910} \text{ LBS TOTAL}$$

STUD LOAD = $F/n = 10\,910/6 = \underline{1820 \text{ LB/STUD}}$

STUD STRESS $F/A_R = 1820/.1257 = \underline{14{,}480 \text{ psi}}$

STUDS:
$1/2$-13-NC-2, $A_R = .1257 \text{ in}^2$ ROOT AREA

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 1-26-79	REF. DOCUMENTS: AEROSPACE STRUCT. METALS HANDBOOK, AL ALLOYS WROUGHT HEAT TREATABLE, CODE 3206 PG 10 FIG 3.0215	
REVIEWED BY R. B.	DATE 20 Feb., 1979		
APPROVED BY	DATE		

IMPACT LIMITER INSERT STRENGTH

PER 'KEENSERT' CATLOG NO 200-A

MIN SHEAR CONTACT AREA × ULT SHEAR OF THE PARTICULAR MATERIAL

SHEAR ULT = 60% TEN ULT* | 300°F 10,000 HR (6061 T-6)

= .6 37,400 = 22,440 PSI

PULL OUT STRENGTH OF INSERT

CALCULATED PULL OUT STRENGTH } = MIN SHEAR STUD ENGAGE AREA × MIN ULT SHEAR STRENGTH OF PARENT MAT

= .7172 (22,400) = 16,065 LBS

PULL OUT MARGIN

PULL OUT / APPLIED =

16,065 / 1820 = 8.8

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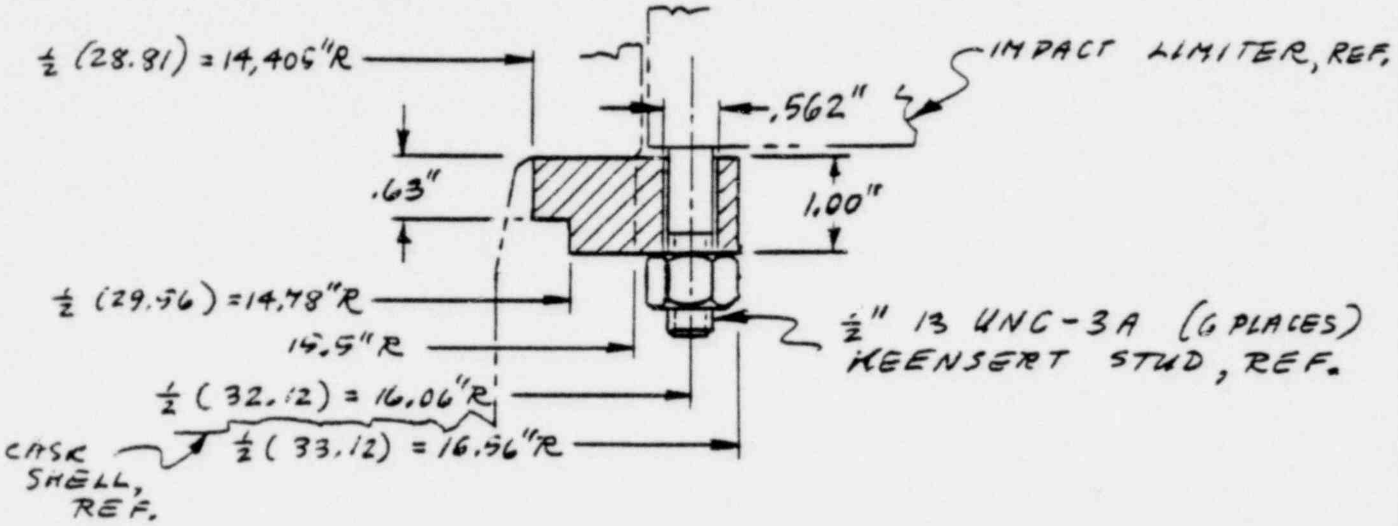
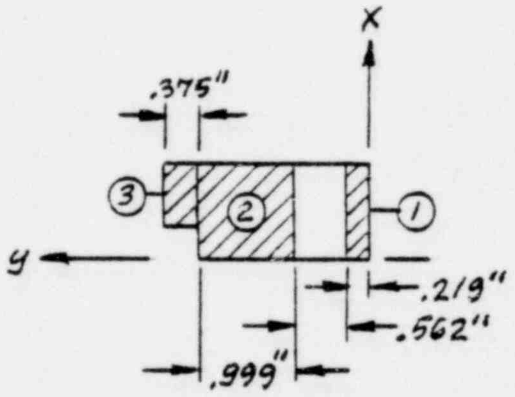
CALCULATIONS FOR FSV FUEL SHIPPING CASK. IMPACT LIMITER.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY Hmford	DATE 15 May, 1978	REF. DOCUMENTS:	
REVIEWED BY J. S. Gocko	DATE June 2-78		
APPROVED BY	DATE		

90 - H 1501 - 106 PROTECTIVE COVER MOUNTING RING

MAT'L : 6061-T6 AL. ALY.



SECTION PROPERTIES



$I_{xo} = \frac{1}{12} b h^3$

ITEM	A	x	x^2	AX	AX^2	I_{xo}	$AX^2 + I_{xo}$	y	Ay
①	.219	.50	.25	.1095	.05475	.01825	.07300	.1095	.02398
②	.999	.50	.25	.4995	.24975	.08325	.33300	1.2805	1.27922
③	.23625	.685	.4692	.1618	.11085	.00781	.11866	1.9675	.46482
Σ	1.45425	—	—	.7708	.41535	.10931	.52466	—	1.76802

$(\bar{x})(\Sigma A) = \Sigma(AX) = (\bar{x})(1.45425) = .7708 \quad ; \quad \bar{x} = \underline{.53005 \text{ IN.}}$

$I_{N.A.} = \Sigma(AX^2 + I_{xo}) - (\bar{x})(\Sigma(AX)) = .52466 - (.53005)(.7703) = \underline{.1161 \text{ IN.}^4}$

$(\bar{y})(\Sigma A) = \Sigma(Ay) = (\bar{y})(1.45425) = 1.76802 \quad ; \quad \bar{y} = \underline{1.21576 \text{ IN.}}$

$R = \frac{1}{2}(33.12) - \bar{y} = 16.56 - 1.21576 = \underline{15.344 \text{ IN.}}$

CALCULATIONS FOR FSV FUEL SHIPPING CASK. IMPACT LIMITER.			
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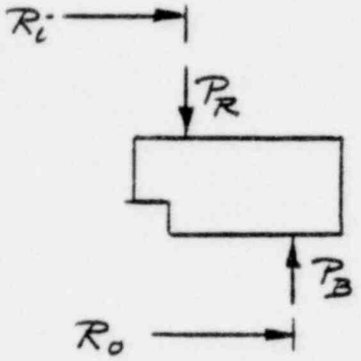
PREPARED BY P. L. Hanford	DATE 16 May, 1978	REF. DOCUMENTS:	
REVIEWED BY J. S. Grecko	DATE June 2-78		
APPROVED BY	DATE		

90-H1501-106 PROTECTIVE COVER MOUNTING RING, CONT'D.

INERTIA LOAD (PG. 5-114): $10350 \text{ LB} \sim \frac{10350}{2\pi(15.344)} = \underline{107 \frac{\text{LB}}{\text{IN}}}$



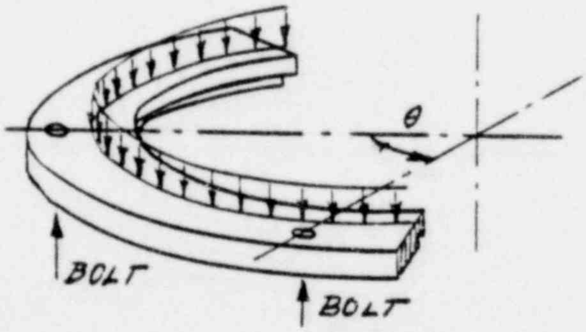
$R_i = \frac{1}{2}[14.405 + 15.5] = \underline{14.9525''}$

$R_o = \underline{16.06''}$

$\text{MOMENT ARM} = R_o - R_i$
$= 16.06 - 14.9525$
$= \underline{1.1075''}$

$M = (107)(1.1075) = \underline{118.5 \frac{\text{IN LB}}{\text{IN}}}$

RING BENDING MOMENT DUE TO COUPLE ON SECTION:
$\text{MOMENT} = MR = (118.5)(15.344) = \underline{1818 \text{ IN LB}}$



RING STRESS DUE TO REDISTRIBUTION OF BOLT LOAD AS INDICATED ON SKETCH:

ASSUME FOR SIMPLICITY A STRAIGHT BEAM UNIFORMLY LOADED AND FIXED AT BOTH ENDS.

$L = \theta R = (60)\frac{\pi}{180}(15.344) = \underline{16.07''}$

$p = \underline{107 \frac{\text{LB}}{\text{IN}}}$

$M_{max} = \frac{1}{2} p L^2 = \frac{1}{2}(107)(16.07)^2 = \underline{2310 \text{ IN LB}}$

TOTAL RING BENDING MOMENT $= 1818 + 2310 = \underline{4128 \text{ IN LB}}$

$\sigma = \frac{Mc}{I} = \frac{(4128)(.53005)}{.1161} = \underline{18846 \text{ psi}} < \sigma_{yield} = 30000 \text{ psi}$

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CALCULATIONS FOR FSV FUEL SHIPPING CASK. IMPACT LIMITER.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY P. L. Hinsford	DATE 16 May, 1978	REF. DOCUMENTS:	
REVIEWED BY J. S. Gracho	DATE June 2-78		
APPROVED BY	DATE		

90-H 1501-106 PROTECTIVE COVER MOUNTING RING, CONT'D.

BOLT PRE-LOADING

MAX. NUT INSTALLATION TORQUE SPECIFIED = 12 FT LB

$T = 12$ FT LB $= 12 \times 12 = \underline{144 \text{ IN LB}}$

13 UNC: COARSE THREADS ($\frac{1}{2}$ IN. DIA.).

WITH A FRICTION FACTOR OF $F = .15$ A K-VALUE OF $K = .098585$ IS FOUND FROM TABLE I OF "BOLT TORQUE FACTORS", BY R.H. LIPP, DESIGN NEWS, MARCH 8, 1971 ISSUE.

P = AXIAL LOAD OF BOLT $= \frac{T}{K} = \frac{144}{.098585} = \underline{1461 \text{ LB.}}$

TOTAL AXIAL LOAD $= 6P = 6 \times 1461 = \underline{8764 \text{ LB.}}$

BOLT STRESS AREA : $A = \underline{.1416 \text{ IN}^2}$

$\sigma_{BOLT} = \frac{1461}{.1416} = \underline{10\,315 \text{ psi}}$

BOLT PRE-LOADING TOTAL = 8764 LB. IS LESS THAN INERTIA LOAD 10350 LB :
IMPACT LIMITER WILL SLIDE FORWARD A SMALL AMOUNT DURING ROTATION OF CASK.

RING STRESS FOR PRE-LOADING OF BOLTS TO 12 FT LB:

$\sigma = (18846)\frac{8764}{10350} = \underline{15\,958 \text{ psi}} < \sigma_{yield} = 30\,000 \text{ psi}$

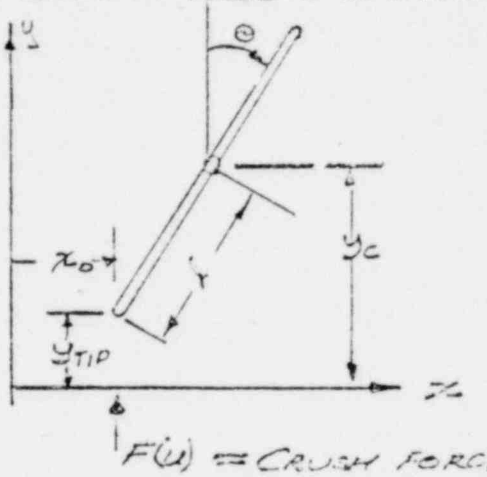
CALCULATIONS FOR FSV FUEL SHIPPING CASK

EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 3-14-78	REF. DOCUMENTS:	
REVIEWED BY R.K. [illegible]	DATE [illegible]		
APPROVED BY	DATE		

IMPACT LIMITER EQUATION DEVELOPMENT, TWO DEGREES OF FREEDOM: VERTICAL TRANSLATION AND PITCH ROTATION ABOUT C.G.

TRANSLATION: UPWARD FORCE - GRAVITY FORCE = m x APPAR'T ACCEL.

① $F(u) - mg = m\ddot{y}_c$



EXPRESSED IN TERMS OF THE TIP OR CONTACT POINT

$$y_{Tip} = y_c - l\cos\theta$$

RATES AND ACCELERATION MAY BE CALCULATED

$$\dot{y}_{Tip} = \dot{y}_c + l\dot{\theta}\sin\theta$$

AND

$$\ddot{y}_{Tip} = \ddot{y}_c + l\ddot{\theta}\sin\theta + l\dot{\theta}^2\cos\theta$$

SOLVING FOR $\ddot{y}_c$ AND REPLACING $\ddot{y}_{Tip}$ WITH $-\ddot{u}$

$$\ddot{y}_c = -\ddot{u} - l(\ddot{\theta}\sin\theta + \dot{\theta}^2\cos\theta)$$

SO THAT THE FORCE EQUATION ① MAY BE WRITTEN:

② $F(u) - mg = m(-\ddot{u} - l(\ddot{\theta}\sin\theta + \dot{\theta}^2\cos\theta))$

IN SIMILAR FASHION THE HORIZONTAL FORCE IS DESCRIBED AS:

$F(x) = m\ddot{x}_{cg}$ WHERE: $x_{cg} = x_0 + l\sin\theta$

$\dot{x}_{cg} = l\dot{\theta}\cos\theta$

THEN UPON SUBSTITUTING $\ddot{x}_{cg} = l\ddot{\theta}\cos\theta - l\dot{\theta}^2\sin\theta$

$$F(x) = ml(\ddot{\theta}\cos\theta - \dot{\theta}^2\sin\theta)$$

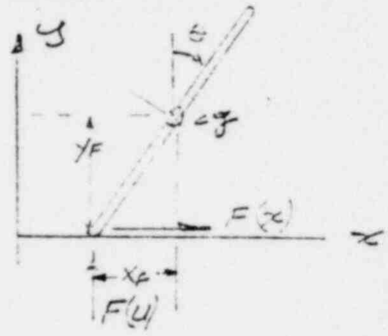
CALCULATIONS FOR FUEL SHIPPING CASK IMPACT LIMITER			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GALCHO	DATE 3-14-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 6 June 1978		
APPROVED BY	DATE		

THE PITCH ROTATION EQUATION IS DESCRIBED:

$$M = I\ddot{\theta}$$

IN TERMS OF PREVIOUSLY DESCRIBED FORCES

$$③\ F(u)\,x_F - F(x)\,y_F = I\ddot{\theta}$$



WHERE THE ARMS X_f AND Y_f ARE VARIABLES AND FUNCTIONS OF CRUSH DISTANCES AND ARE DESCRIBED SHORTLY.

SUBSTITUTING THE PREVIOUSLY DEVELOPED F(x) EXPRESSION INTO THE MOMENT EQUATION ③ ABOVE LEAD TO:

$$F(u)X_f - ml(\ddot{\theta}\cos\theta - \dot{\theta}^2\sin\theta)\,Y_F = I\ddot{\theta}$$

OR:

$$F(u)X_f + ml\dot{\theta}^2\sin\theta\,Y_F = \ddot{\theta}(I + mlY_F\cos\theta)$$

SOLVING FOR $\ddot{\theta}$ YIELDS:

$$\ddot{\theta} = \frac{F(u)X_f + mlY_f\dot{\theta}^2\sin\theta}{(I + mlY_f\cos\theta)}$$

THIS TERM MAY THEN BE SUBSTITUTED INTO THE VERTICAL FORCE EXPRESSION REPEATED BELOW

$$F(u) - mg = m(-\ddot{u} - l(\ddot{\theta}\sin\theta + \dot{\theta}^2\cos\theta))$$

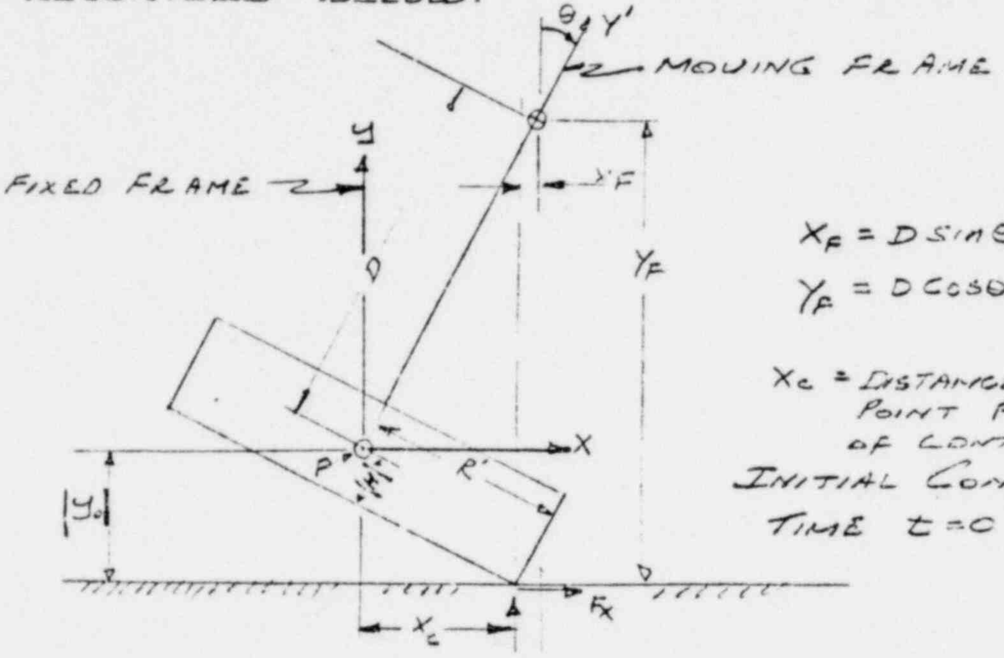
FROM WHICH $\ddot{u}$ IS DESCRIBED

$$\underline{\ddot{u} = g - F(u)/m - l(\dot{\theta}^2\cos\theta + \ddot{\theta}\sin\theta)}$$

POOR ORIGINAL

CALCULATIONS FOR			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY John Grcho	DATE 3-16-78	REF. DOCUMENTS:	
REVIEWED BY P. H. Winfield	DATE 6 June, '78		
APPROVED BY	DATE		

THE ARMS, X_F & Y_F OF THE TORQUE EQUATION ARE ARE DESCRIBED BELOW.

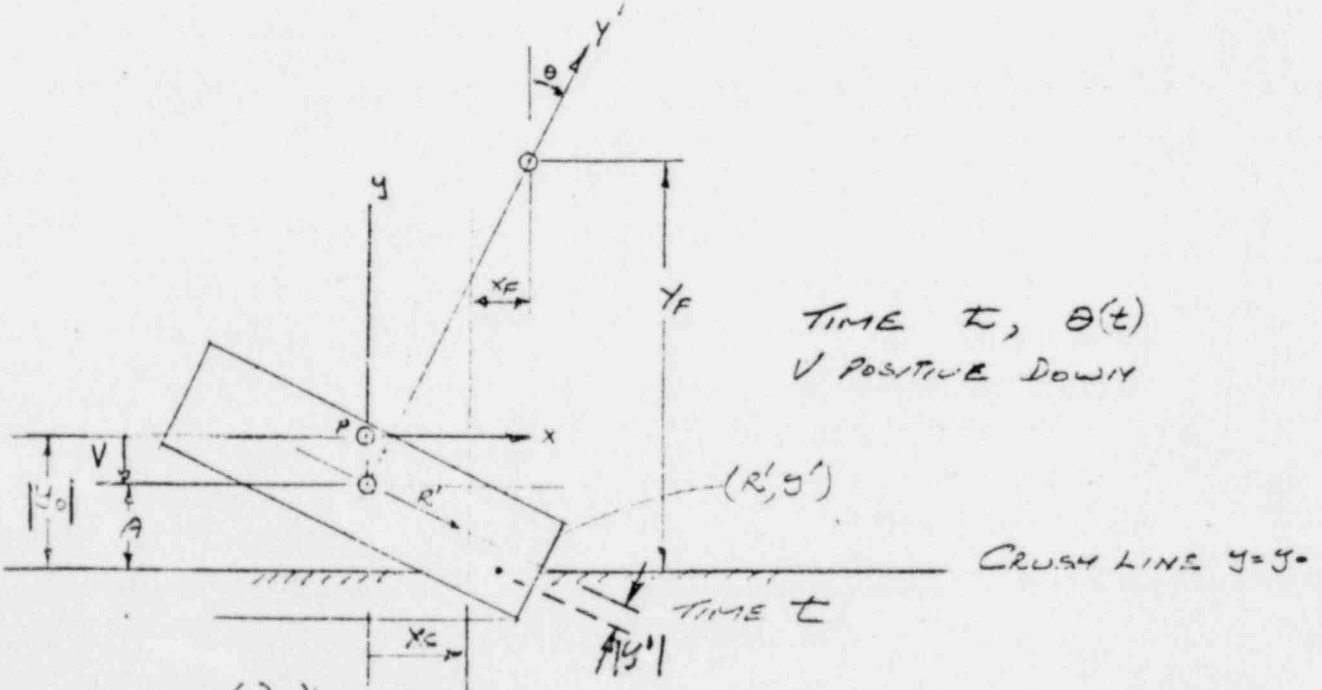


$$X_F = D\sin\theta - X_c$$

$$Y_F = D\cos\theta + R\sin\theta + |H|\cos\theta$$

X_c = DISTANCE x FROM REF POINT P TO CENTROID OF CONTACT AREA

INITIAL CONTACT, TIME $t=0$



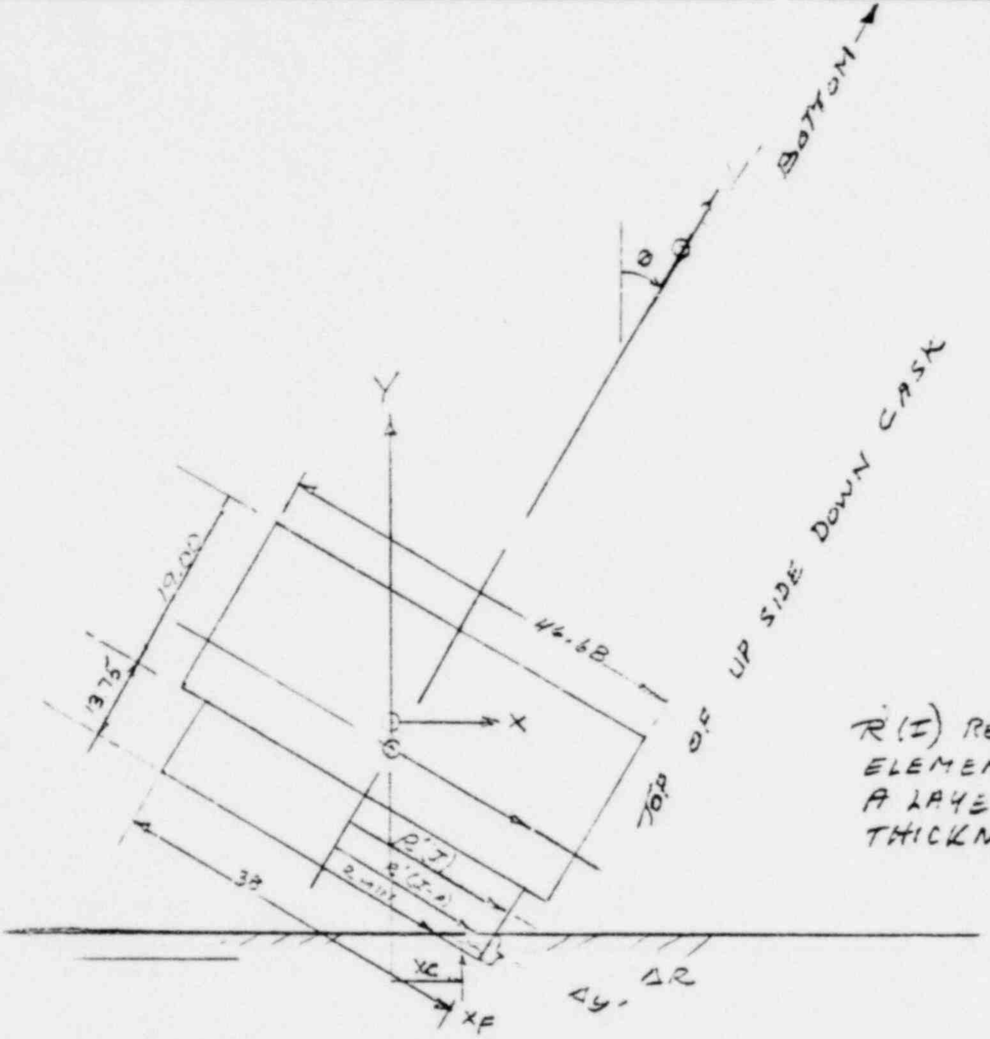
TIME t, $\theta(t)$
V POSITIVE DOWN

FOR A POINT (R', y') ON THE CRUSH LINE $(y=y_0)$:
DIMENSION $A = R'\sin\theta - y'\cos\theta = -y_0 - V$

SOLVING FOR: $R' = \dfrac{y_0 + V - y'\cos\theta}{-\sin\theta}$

POOR ORIGINAL

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GAGNO	DATE 3-16-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 6 June, 1978		
APPROVED BY	DATE		



R'(I) REPRESENTS AN ELEMENT = A LAYER OF 0.1 INCH THICKNESS.

R'(I) REPRESENTS AN ELEMENT OF THE RADIUS VECTOR AT PREASSIGNED INCREMENTAL DEPTHS. THESE VECTOR ELEMENTS BEGIN AT THE TOP AND CONTINUE EVERY 0.1 INCH TOWARD THE BOTTOM OF THE PLYWOOD IMPACT LIMITER.

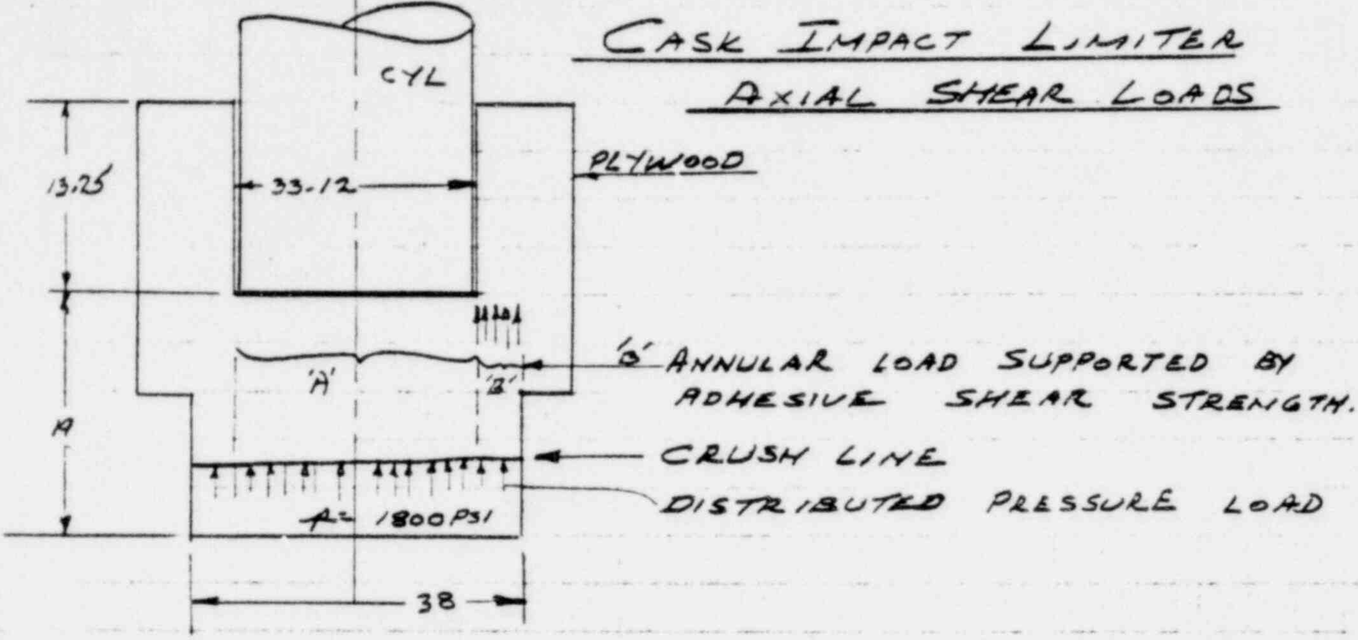
WHEN THE RADIUS VECTOR EQUALS THE RADIUS MAGNITUDE THE POINT IS SAVED AND DIFFERENCED WITH THE MIN RADIUS. BOTH OF THESE RADII ARE THE 'GROUND'-'RADIUS' COINCIDENT POINTS. THIS ALLOWS A ΔR CALCULATION AND KNOWING THE OTHER COORDINATE, I (DEPTH), A ΔY CALCULATION. THE IMPACT AREA IS NEXT CALCULATED WITH THE ACTION ARM XF PASSING THRU THE CENTROID OF THE AREA. THE RESULTING FORCES AND MOMENTS ARE THEN CALCULATED AND INTEGRATED; THE PROCESS REPEATED OVER THE ENSUING TIME STEPS TILL $\Theta = 90°$ OR $F(U) = 0$

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 4-12-78	REF. DOCUMENTS: HEAD DROP CODE	
REVIEWED BY P.K. Thrufvold	DATE 7 June, 1978	HEAD DIA 49667 3/19/79 9:27:59	
APPROVED BY	DATE 4-2-79	ROARK 5TH ED TABLE 38	

CASK IMPACT LIMITER AXIAL SHEAR LOADS



'A' CENTRAL AREA SUPPORTED BY CYLINDER TOP
'B' ANNULAR SECTION CONTRIBUTING TO GLUE SHEAR

CRUSH $\Delta = PE / A\sigma = 120\ (386)\ 360 / (\pi\ 38^2/4 \cdot 1800) = \underline{8.17\ in}$

$\% = 8.17/19 < 50\% \quad \therefore \sigma = 1800\ psi$

AVERAGE ACCELERATION $= \pi * \frac{38^2}{4} * 1800 / 46000 = 44$ g's

AREA B $= A_B = .25\pi(\overline{38}^2 - \overline{33.12}^2) = \underline{272.6\ in^2}$

SHEAR LOAD: $F_{scy} = p\ A_B = 1800\ (272.6) = \underline{490,680\ LBS}$

SHEAR STRESS—ADHESIVE

$\sigma_{SAD} = F_{scy} / \pi D \cdot l =$ (l IS GLUED LENGTH WOOD SHEAR IGNORED)

$490,680 / (\pi)(33.12)(13.75) = \underline{342\ PSI}$

$\underline{342 < 1000\ PSI^*}$ (SEE NOTE)

OK

NOTE: REF ROARK
ALLOWABLE SET AT LOWER OF ADHESIVE AND WOOD SHEAR PARALLEL TO GRAIN. PRINT CALL OUT FOR (AD) 1200 PSI

CALCULATIONS FOR FSV FUEL SHIPPING CASK
EQUIP. NO.
PROJ. NO.
CALC. NO.
PAGE OF
PREPARED BY JOHN GACKE DATE 4-19-78
REVIEWED BY P. L. DATE 7 June -78
20 Dec -79
APPROVED BY DATE 4-2-79
REF. DOCUMENTS: HEAD DROP CODE
HEAD 01 A 3/19/7?
PLYWOOD IMPACT LIMITER

CLOSURE HEAD BOLT LOADS

24 1¼ BOLTS (1¼-7-NC-2)

ROOT AREA = 0.8920 IN²

MAX IMPACT LOAD: AXIAL $4.929 \cdot 10^6$ LBS (DROP CODE) Pg 5-153

AXIAL LOADS SUPPORTED BY IMPACT PLATE:

FUEL, 1800; CANNIST., 1644; CAV LID, 983; & PLATE 657 LBS MAKING A TOTAL OF: 5084 LBS

L_T = TEN. LOAD = $n_A W$ = 106.6 (5084) = $5.420 \cdot 10^5$ LBS

WHERE n_A MAX WAS CALC AS 106.6g (REF Pg 5-153) 25° CASE

HEAD BOLT STRESS: $L_T / 24 A_R = 5.420 \times 10^5 / 24(.892) =$ 25,320 PSI

542,000 LBS PULLING ON BOLTS (SHEAR NEGLECTED)

4,929,000 LBS PUSHING ∴ NET LOAD = 0

BOLT LOAD IS ZERO IF PLYWOOD LOAD IS TAKEN INTO ACCOUNT. ADDITIONAL ANGLE LOADINGS ARE TABULATED ON PAGE 5-153.

LATERAL LOADING — BOLT SHEAR

BOLT SHEAR LOADS AND STRESS CALCULATED ON P 5-149

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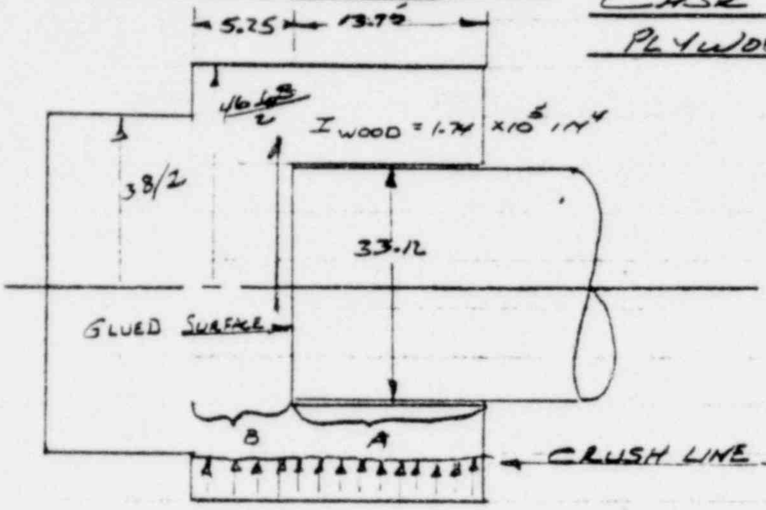
GENERAL ATOMIC COMPANY

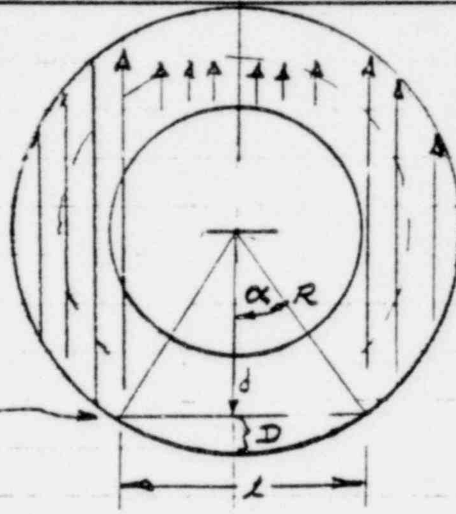
CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY John Gacmo	DATE 4-12-78	REF. DOCUMENTS: HEAD 01A 3-19-79 ~~CALC FILE DIC 15-002~~ ENGRNG MATERIAL HNDBK CL MANTELL 58 McGRAW	
REVIEWED BY R. H. Cornford	DATE 7 June 1978 20 ... -79		
APPROVED BY	DATE 4-2-79		

HEAD DROP (CON'T)

CASK IMPACT LIMITER

PLYWOOD SHEAR AND BENDING STRESS





D ~4.49 IN. CODE ESTIMATED DEPTH
(DMAX) IN (01A) HEAD DROP CODE 49667 3/19/79 8:27:59

$$l = 2R \sin\left(\cos^{-1} d/R\right)$$

$$= 2(23.34) \sin\left(\cos^{-1} 18.85/23.34\right) = \underline{27.527 \text{ IN}}$$

B CONTACT AREA $= l \cdot B = S$

$$= 27.527 (5.25) = \underline{144.5 \text{ IN}^2}$$

SECTION B SEES UNIFORM $\sigma_{11} = 3500$ PSI
CRUSH/DIA PERCENT VERY SMALL.

LOAD ON SECT 'B': $F_B = \sigma_{11} S = 3500(144.5) = \underline{5.058 \times 10^5}$ LBS

SHEAR STRESS:

$$\sigma_s = F_B / (\pi D_o^2/4) = 5.058 \cdot 10^5 / (\pi \, 46.63^2/4) = \underline{296 \text{ PSI}}$$

REF.* allowable WOOD SHEAR 1000 PSI

GLUE: PRINT CALL OUT 1200 PSI SHEAR

BENDING STRESS (WOOD)

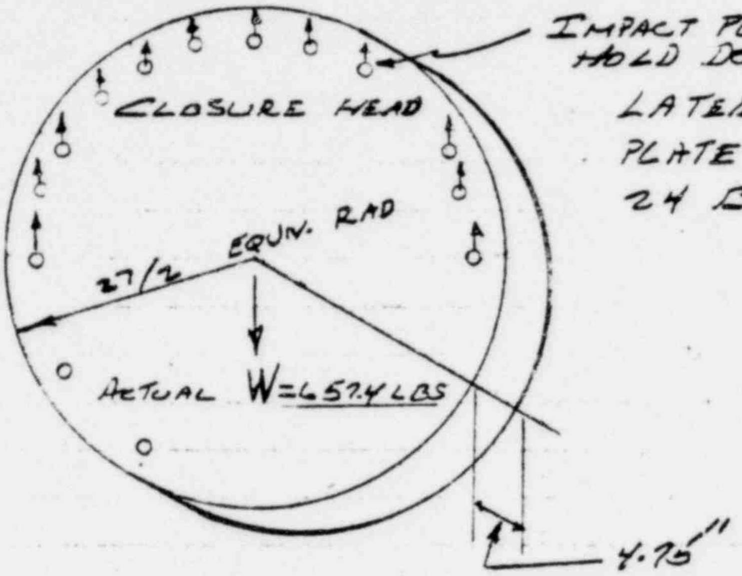
$$\sigma_B = \frac{Mc}{I_{wood}} = \frac{5.058 \cdot 10^5 (5.25)}{2} \frac{(23.34)}{1.74 \cdot 10^5} = \underline{180 \text{ psi}}$$

* PER REF ABOVE: TENSION PERP TO GRAIN: 340 PSI
MARGIN: 340/180 = 1.9

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY John Gacho	DATE 4-14-78	REF. DOCUMENTS: GADR-55 SECT II WEIGHTS	
REVIEWED BY R.L. Stanford	DATE 7 June 1978 20 Feb 79		
APPROVED BY	DATE 4-2-79	REF ROARK 5th Ed	

HEAD DROP (CON'T) TABLE 33 CASE 2-C

IMPACT PLATE LATERAL LOADING 95° HEAD DROP
HEAD DIA 3/19/79



LATERAL LOADING OF IMPACT PLATE SUPPORTED BY 24 BOLTS' SHEAR LOADING

IMPACT PLATE DOES NOT MOVE. IMPACT PLATE LATERAL LOADS SUPPORTED BY BOLT SHEAR

LATERAL LOAD: $L_L = n_y \sin\theta W = n_s W$

$$L_L = 272.1(657.4) = \underline{178,770 \text{ LBS}}$$

BOLT SHEAR:

$$\sigma_s = L_L / (24)(.8920) = \underline{8350 \text{ PSI}}$$

PRINCIPAL STRESS AND MAX SHEAR ARE TABULATED ON PG 5-153 FOR VARIOUS θ'S

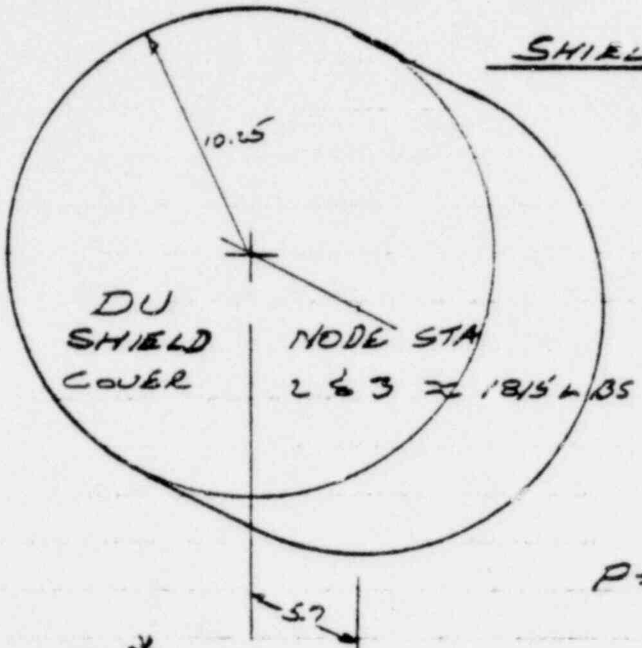
30' SIDE DROP LATERAL LOADING MAY BE GREATER. See page 5-151

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 4-14-78	REF. DOCUMENTS: HEAD DROP CODE 01 A 3/19/79 ROARK 5Ed TABLE 33 # 2 c	
REVIEWED BY P. B. Thresford	DATE 7 June 1978		
APPROVED BY	DATE 20 Feb. 79 4-2-79		

SHIELD LID—LATERAL LOAD



RAD = 10¼ IN
t = 5.7 IN
W = 1815 LBS 5-142 + 5-143
n_y = 272.1 gs ← 5-153

$P = \dot{W} \cdot n_y = 1815\,(272.1) = 4.939 \cdot 10^5$ LBS

$(D_1 - D_2)^* = 20\frac{5}{8} - 20\frac{1}{2} = \frac{1}{8} = .125''$

$K_D = D_1 D_2 / D_1 - D_2 = (20\frac{5}{8} \times 20\frac{1}{2}) / .125 = \underline{3382.5\ IN}$

$C_E = 2\ \frac{1-\nu^2}{E} = 2\ \frac{1-.3^2}{30 \cdot 10^6} = \underline{6.067 \cdot 10^{-8}}$

(E STAINLESS & URANIUM $= 30 \cdot 10^6$)

$\sigma_c = .798 \left\{ \frac{4.939 \cdot 10^5 \quad \cdot 10^8}{5.7 \quad 3382.5 \quad 6.067} \right\}^{1/2} = \underline{16,400\ psi}$

$< \sigma_{yield} = 31,500$ psi
@ 300°F
(REF. MATL'S DATA
FOR HONDO OUTPUT
PG. (5-47)

* GADR 55
NAT. LEAD Co DWG 70086 F

CALCULATIONS FOR	FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.		CALC. NO.	PAGE OF
PREPARED BY John Gacho	DATE MAY 22-78	REF. DOCUMENTS: GADR-55 SECT II		
REVIEWED BY P. E. Ainsford	DATE 4 June, -78	REF 5th ED		
APPROVED BY EMC	DATE 4-2-79	ROARK TABLE 23 # 2C		

30' SIDE DROP LOADING: (69 ELEMENT MODEL)

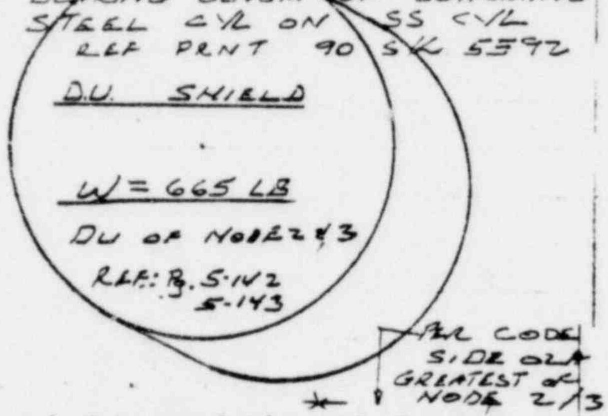
SIMULTANEOUS END AND IMPACT LIMITER (TOP) 'GROUND' CONTACT. MAX/MIN ACCELERATION NOTED FOR EACH ELEMENT EVERY CALCULATION TIME STEP.

$E_1 = E_2 = 3 \cdot 10^7$

$\sigma_{y_1} = 31.5$ ksi (SS @ 300°F) Pg 5-41

$\sigma_{y_2} = 48$ ksi (2% Mo-4R ALLOY 300°F)

L BEARING LENGTH OF SUPPORTING STEEL CYL ON SS CYL REF PRNT 90 SK 5592



LOAD FACTOR MAX 2094 g's

$D_1 = 20.635$ IN, $D_2 = 20.50$ IN

$K_D = \frac{D_1 D_2}{D_1 - D_2} = \frac{20.625 (20.50)}{.125}$

$= \underline{3382.5 \text{ IN}}$

$C_E = 2\left(\frac{1-\nu^2}{E}\right) = \frac{2(1-.3^2)}{30 \cdot 10^6} = 6.067 \times 10^{-8}$

$P = 2094 \, W = 1.3925 \times 10^6$ LBS

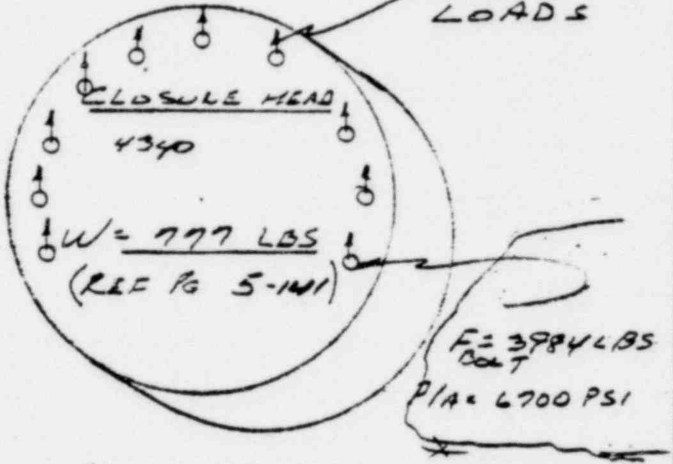
$\sigma_c = .798 \sqrt{P/L / K_D C_E}$

$= .798 \left\{ \frac{1.3925 \cdot 10^6 \cdot 10^8}{5.7 \quad 3382.5 \quad 6.067} \right\}^{1/2}$

$= \underline{27,100 \text{ psi} < 31,500 \text{ yield}}$

BOLT TORQUE 120 FT LB MAX

$\sigma = P/A = \frac{120 \times 12}{.24098 \quad .892} = \underline{6700 \text{ PSI}}$



MAX LOAD FACTOR AT THIS STATION 1351 g's. (SIDE 02A SIDE DROP CODE)

$L_L = n \, W = 1351 (777) = \underline{1,050 \cdot 10^6}$ LBS

BOLT SHEAR

$\sigma_s = L_L / 24 \, A_R$

$= 1.050 \cdot 10^6 / (24 \times .892)$

$\sigma_s = \underline{49,035 \text{ PSI}}$

$\tau_{max} = .5 \sqrt{(P/A)^2 + 4 \sigma_s^2}$

$= .5 \left\{ 6700^2 + 4(49035)^2 \right\}^{1/2}$

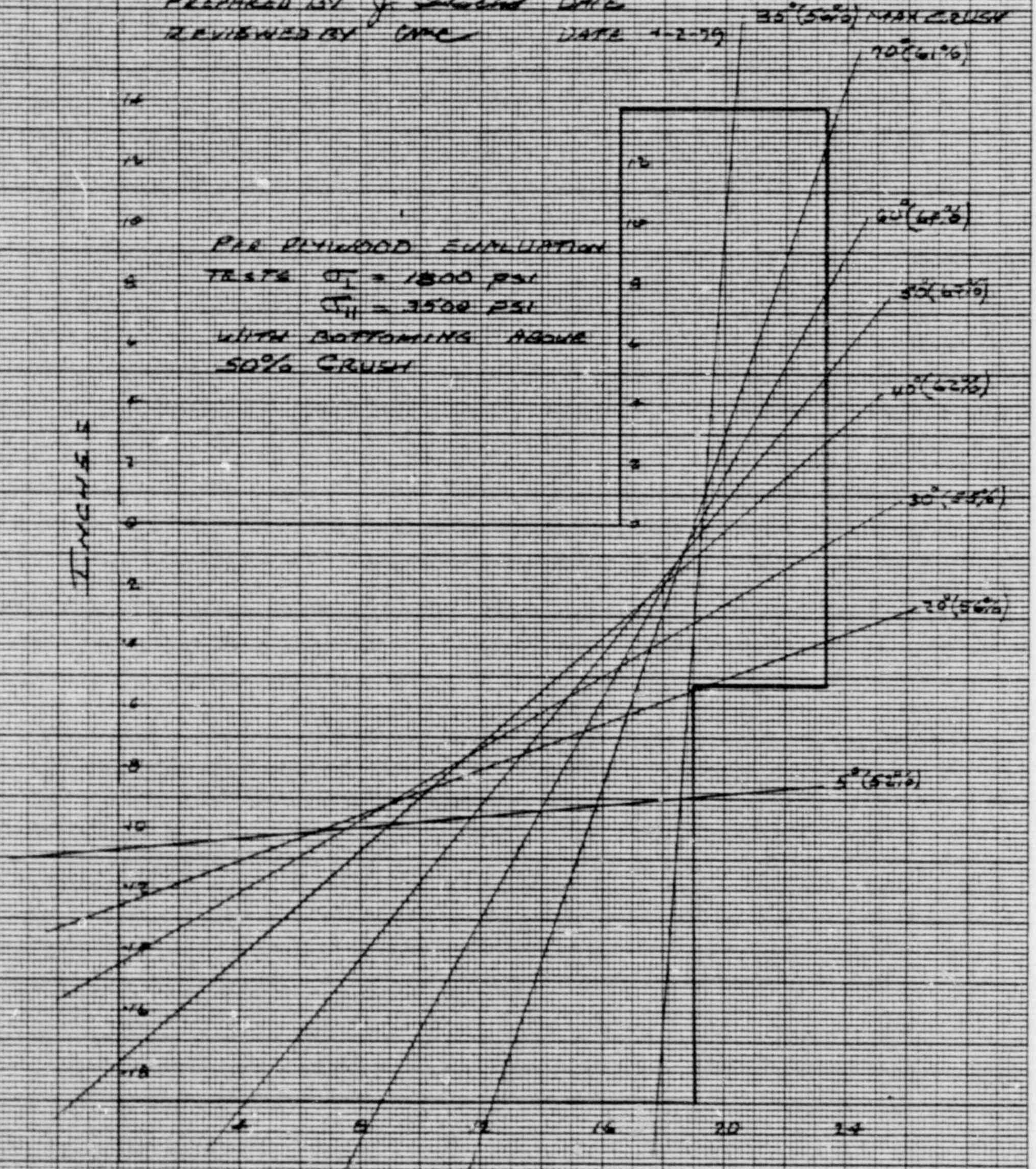
$= \underline{49,150 \text{ PSI}}$

*REF: DEC-15-002A (SIDE 02A) COMPUTER RUN

PLYWOOD IMPACT LIMITER

RESULTING CRUSH LINES AT VARIOUS IMPACT ANGLES

PREPARED BY J. Fischer DATE
REVIEWED BY GMC DATE 4-2-79



PER PLYWOOD EVALUATION TESTS $\sigma_{\perp}$ = 1800 PSI
$\sigma_{\parallel}$ = 3500 PSI
WITH BOTTOMING ABOVE 50% CRUSH

REF HEAD DROP CODE 49669 3/19/79 8:37:59

POOR ORIGINAL

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 3-22-79	REF. DOCUMENTS: HEAD DROP CODE 49667 3/19/79 8:27:59	
REVIEWED BY CMC	DATE 4-2-79		
APPROVED BY	DATE		

30 FT HEAD DROP – CASK LID BOLT LOADS

$\tau_{max} = .5\sqrt{\sigma_x^2 + 4\tau^2}$

$\sigma_p = \tau_{max} + .5\sigma_x$

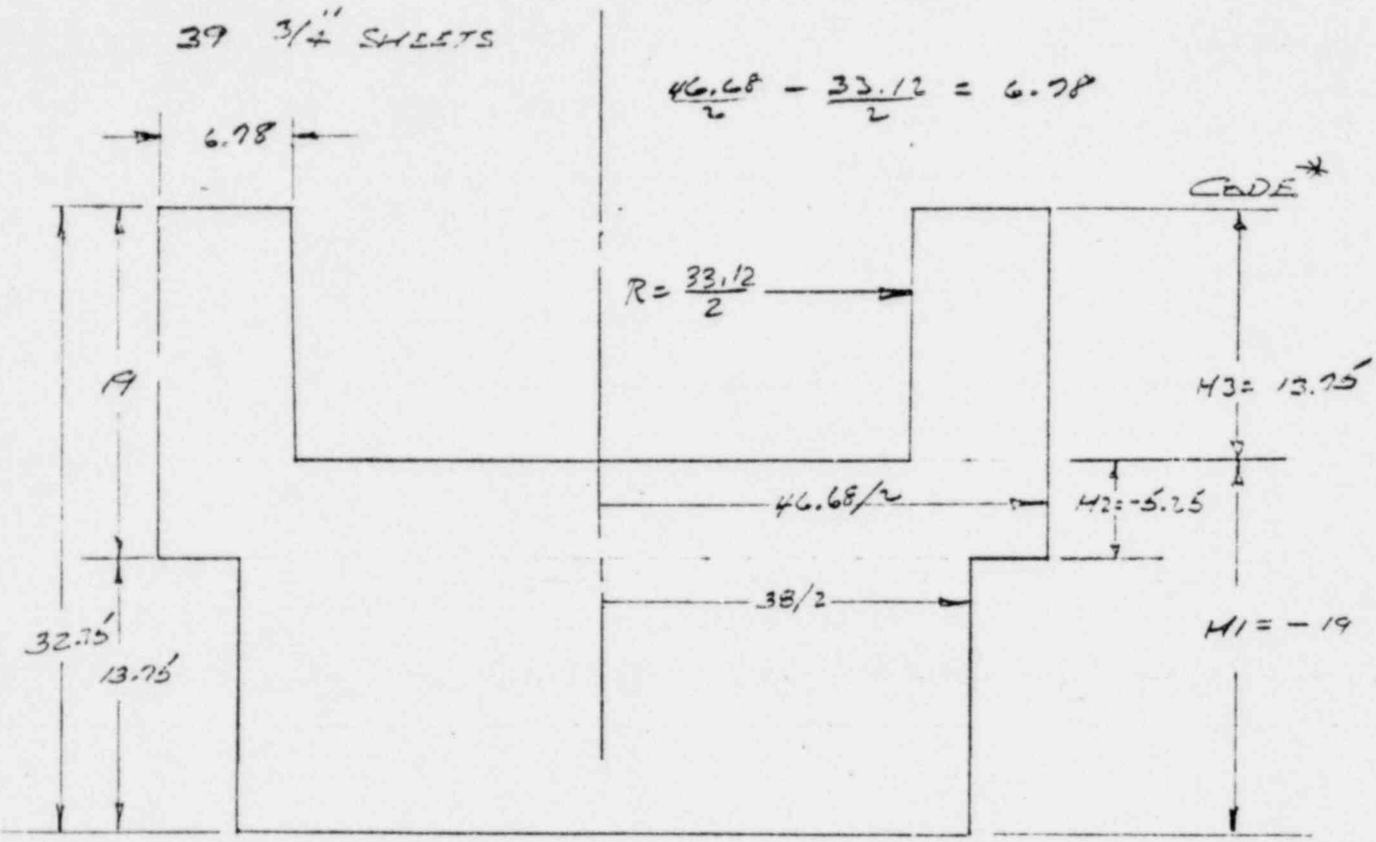
θ	F_A	F_s	ACCEL	n_y	n_A	n_s	BOLT LOAD L_A	BOLT STRESS	SIDE LOAD L_s	BOLT SHEAR	τ_{max}	σ_{PRIN}
					$n_y \cos\theta$	$n_y \sin\theta$	$.5084\ n_A$	σ $L/24 \times .892$	$.657\ n_s$	$2L_s/24 \times .892$	(PRINCIPAL)	(PRINCIPAL)
DEG	10^6 LB	10^6 LB	IN/SEC²	g's (386)	g's AXIAL	g's SIDE	10^5 LB	TENSION PSI	10^4 LBS	PSI	PSI	PSI
0	2.02	.0	16,980	44.*	44.	0	2.237	10,450	0	0	5,225	10,450
5	2.207	.09229	18,090	46.9	46.7	4.1	2.374	11,090	.269	250	5,550	11,095
10	3.295	.2736	27,570	71.4	70.3	12.4	3.574	16,695	.815	760	8,380	16,730
15	4.071	.4398	34,900	90.4	87.3	23.4	4.438	20,730	1.537	1,435	10,465	20,830
20	4.771	.6447	42,210	109.4	102.8	37.4	5.226	24,410	2.457	2,295	12,420	24,625
25	4.929	.8255	45,380	117.6	106.6	49.7	5.420	25,320	3.265	3,050	13,020	25,680
30	4.729	.9426	45,750	118.5	102.6	59.3	5.216	24,365	3.896	3,640	12,715	24,895
35	4.294	.9988	44,160	114.4	93.7	65.6	4.764	22,255	4.310	4,025	11,835	22,960
40	4.224	1.211	46,700	121.0	92.7	77.8	4.713	22,015	5.111	4,775	12,000	23,010
45	4.031	1.371	48,490	125.6	88.8	88.8	4.515	21,090	5.834	5,450	11,870	22,415
50	4.122	1.628	54,740	141.8	91.1	108.6	4.632	21,635	7.135	6,665	12,705	23,525
55	4.083	1.877	60,950	157.9	90.6	129.3	4.606	21,515	8.508	7,950	13,375	24,132
60	3.919	2.121	67,270	174.3	87.2	150.9	4.433	20,705	9.914	9,260	13,890	24,240
65	3.614	2.356	73,760	191.1	80.8	173.2	4.108	19,190	11.379	10,630	14,320	23,915
70	3.205	2.612	81,200	210.4	72.0	197.7	3.660	17,095	12.989	12,135	14,845	23,390
75	2.673	2.897	90,110	233.4	60.4	225.4	3.071	14,345	14.809	13,835	15,585	22,755
80	1.914	3.113	97,940	253.7	44.1	249.8	2.242	10,475	16.412	15,335	16,205	21,440
85	0.9572	3.299	105,400	273.1	23.8	272.1	1.210	5,650	17.877	16,700	16,935	19,760
90	SEE SIDE DROP		RESULTS	5-127								

τ's BASED UPON 50% OF BOLTS SUPPORT SHEAR

* SEE PAGE 5 146

CALCULATIONS FOR SPENT FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY John Gacho	DATE 3-6-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 8 June, -78		
APPROVED BY	DATE		

PLYWOOD IMPACT LIMITER
DESIGN SKETCH



*H1, H2, H3, USE IN CODE

5-155

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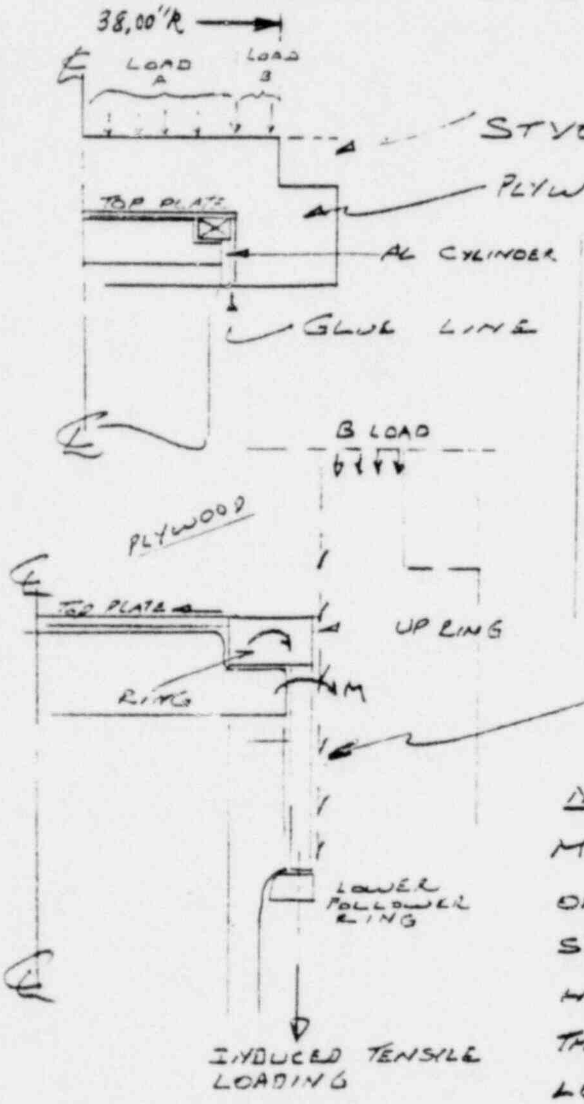
GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE MAY 24 1978	REF. DOCUMENTS: GAMD-9410, SAC MANUAL. PREPARED BY H.D. SHATOFF DTD. DECEMBER 1969	
REVIEWED BY	DATE 12 June 1978		
APPROVED BY	DATE 20 Feb. 79		

INTRODUCTORY REMARKS PERTAINING TO UPPER RING/CYLINDER LOAD ANALYSIS



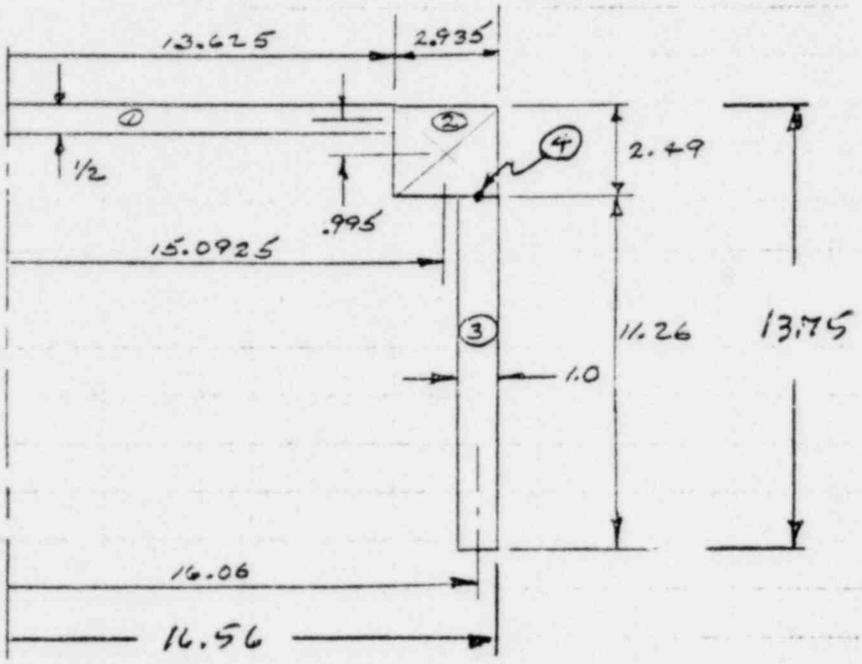
NOTES:
LOAD 'A' TRANSMITTED TO IMPACT PLATE. LOAD B INTRODUCES SHEAR LOAD TO GLUE LINE. THIS SHEAR LOAD INDUCES CYLINDER TENSILE LOADING. TENSILE LOAD REACTED BY UPPER RING AND ATTACHED ELEMENTS IE TOP PLATE & CYLINDER.

NOTES: ANALYSIS MADE WITH MOMENT (PER REF SAC CODE) AT TOP OF CYLINDER SET TO THE YIELD STRESS OF THE AL. CYLINDER AND HELD CONSTANT THERE AFTER SO THAT THE RING TAKES ADDITIONAL LOAD. WITH THIS LIMITATION THE RING LOAD WAS FOUND TO BE WITHIN THE YIELD STRESS OF THE AL T-6 MATERIAL

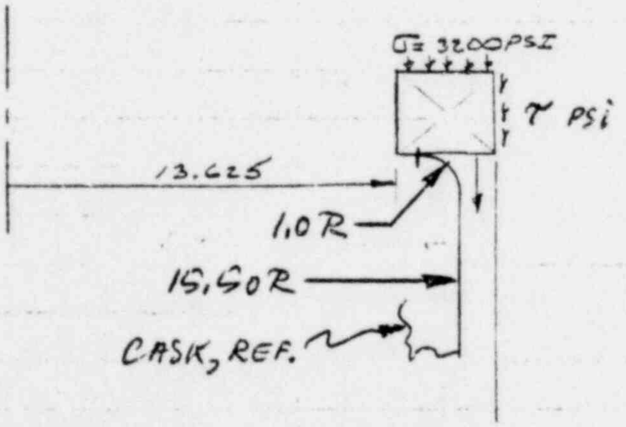
POOR ORIGINAL

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 16 June, 1978	REF. DOCUMENTS: DWG. 90-H1501-035	
REVIEWED BY	DATE June 16-78		
APPROVED BY	DATE		

30 FT HEAD DROP IMPACT LIMITER COVER



SHELL ANALYSIS CODE (SAC) MODEL



MAT'L:
6061-T6 ALUMINUM ALLOY

S_y = 30,000 psi @ 300 °F

④ = SHEAR TIE (HINGE)

DIMENSIONS IN INCHES.

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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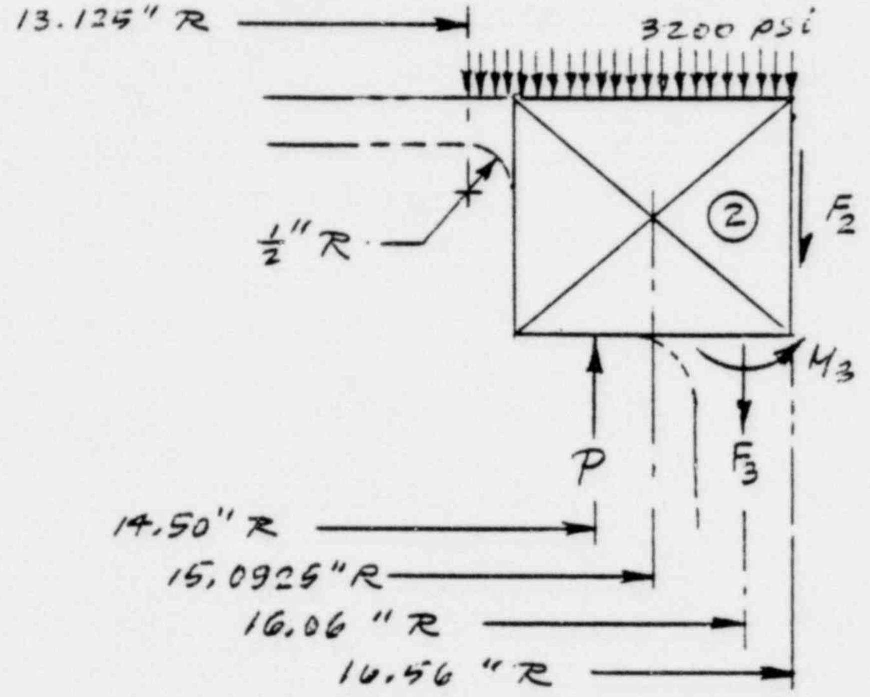
APPROVED BY	DATE		

30 FT HEAD DROP

IMPACT LIMITER COVER

RING ② LOADING



SCALE : 1/2

REF. PG. 5-131: LOAD B $= (3200)\,\frac{\pi}{4}\,(38^2 - 33.12^2)$

$= \underline{872\,271 \text{ LB}}$

$$\tau = \frac{\text{LOAD B}}{\pi\,(33.12)\,(13.75)} = \underline{610\ \frac{\text{LB}}{\text{IN}^2}}$$

$$F_2 = \tau \times 2.49 = \underline{1518\ \frac{\text{LB}}{\text{IN}}}$$

$$F_3 = \frac{(872271)\left(\frac{11.26}{13.75}\right)}{2\pi\,(16.06)} = \underline{7079\ \frac{\text{LB}}{\text{IN}}}$$

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
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PREPARED BY P. F. Thrsford	DATE 16 June, 1978	REF. DOCUMENTS	
REVIEWED BY John Glocker	DATE June 16-78		
APPROVED BY	DATE		

30 FT HEAD DROP. IMPACT LIMITER COVER

AT 300°F : $S_y = 30{,}000$ psi $= \dfrac{F_3}{t_3} + \dfrac{6 M_3}{(t_3)^2}$

$$30{,}000 = \frac{7079}{1.0} + \frac{6 M_3}{(1.0)^2}$$

$$M = \underline{3820 \ \tfrac{\text{IN LB}}{\text{IN}}}$$

STATIC BALANCE:

$$2\pi\,(14.50)\,P = \pi\,(16.56^2 - 13.125^2)(3200) + 2\pi\,(16.56)(1518) + 2\pi\,(16.06)(7079)$$

$$2\pi\,(14.50)\,P = 1\,025\,094 + 157\,960 + 714\,311 = 1\,897\,365$$

$$P = \underline{20\,826 \ \tfrac{\text{LB}}{\text{IN}}}$$

RING MOMENT:

$$\overset{\frown}{M} = (F_2)\left(\frac{16.56}{15.0925}\right)\left(\frac{2.935}{2}\right) + (P_3)\left(\frac{16.06}{15.0925}\right)(16.06 - 15.0925)$$
$$+ (P)\left(\frac{14.50}{15.0925}\right)(15.0925 - 14.50)$$
$$- (3200)(.5)\left(\frac{13.375}{15.0925}\right)\left(\frac{2.935}{2} + .25\right) - M_3\left(\frac{16.06}{15.0925}\right)$$

$$= 2444 + 7288 + 11\,855 - 2435 - 4065 = \underline{15\,087 \ \tfrac{\text{IN LB}}{\text{IN}}}$$

RESULT OF COMPUTER ANALYSIS:
MAX. STRESS IN RING ②: $\sigma_c = \underline{28\,234}$ psi $< S_y = 30000$ psi @ 300°F.

THERE MAY BE SOME YIELDING DUE TO LOCAL DISCONTINUITY STRESSES IN TRANSITION REGIONS BETW. COMPONENTS ① & ② AND ② & ③, BUT DISTORTIONS OF RING ② WILL BE SMALL. THE COVER IS STRUCTURALLY ADEQUATE.

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.				
EQUIP. NO.	PROJ. NO.		CALC. NO.	PAGE OF
PREPARED BY	DATE 8 June, 1978	REF. DOCUMENTS:		
REVIEWED BY	DATE June 16-78			
APPROVED BY	DATE			

G. 30 FT SIDE DROP

CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 2-5-79	REF. DOCUMENTS:	
REVIEWED BY VMR	DATE 2-20-79		
APPROVED BY	DATE		

FSU FUEL SHIPPING CASK
30 FT. SIDE DROP LOADING

THE ELEVEN ENCIRCLED POINTS REPRESENTING STRESS VS STRAIN SHOWN ON PAGE 5-138 WERE LINEARLY INTERPOLATED FOR USE AS INPUT FOR THE COMPUTER CODE "M VS PHI". THE OUTPUT OF THIS CODE IS THE MOMENT 'M' VERSUS THE TOTAL CURVATURE φ (WHERE φ IS DEFINED AS THE RATIO OF FIBER STRAIN AT RADIUS R_o DIVIDED BY R_o^* THE OUTSIDE CASK RADIUS). THE OUTPUT CONSISTING OF TWO CURVES IS SHOWN PLOTTED IN THE FIGURE ON PAGE 5-166. THESE M VS φ CURVES, REPRESENTING A SOLID CASK SECTION AND THE LOWER CURVE, A MORE COMPLEX CROSS SECTION (REF PG 5-173) ARE SHOWN WITH THE POINTS CONNECTED BY STRAIGHT LINE SEGMENTS. THESE POINTS ARE INPUT TO THE 'DYNAM' COMPUTER CODE WHICH INTEGRATES THE EQUATIONS OF ELEMENT MOTIONS OF THE FUEL SHIPPING CASK IMPACTING ON A RIGID SURFACE.

LOCAL RESETANCE OF THE CASK TO DEFORMATION IS ALSO COMPUTED WITH THE 'DYNAM' CODE. THIS RESISTANCE FUNCTION (R) IS DESCRIBED MATHEMATICALLY AS A DIFFERENTIAL FORCE ACTING ON A CASK ELEMENT; A SKETCH OF WHICH APPEARS ON PAGE 5-162: DEPICTS THE CONSIDERATIONS INVOLVED FOR THE COMPUTATION.

SIMULTANEOUS IMPACT OF THE TAIL AND THE PLYWOOD (LIMITER) COVERED HEAD SECTION

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 2-5-79	REF. DOCUMENTS:	
REVIEWED BY CMC.	DATE 2-20-79		
APPROVED BY	DATE		

30 FT SIDE DROP LOADING (CON'T)

AFTER RELEASE FROM A 30 FT HEIGHT INDUCES THE SIDE LOADING OF THE CASK ANALOGOUS TO THAT OF A SIMPLY SUPPORTED BEAM. THIS LOADING, FROM A BENDING STANDPOINT, IS THE MOST SEVERE LOADING CONDITION. ALL THE KINETIC ENERGY IS ABSORBED BY THE IMPACT DEFORMATION AND BEAM DEFLECTION.

THE CASK MODEL IS (SHOWN ON PAGE 5-137) MADE UP OF 69 DISK ELEMENTS WITH THE APPROPRIATE SECTION PROPERTIES.

THE COMPUTED STRAINS DUE TO IMPACT LOADING WERE COMPARED TO THOSE LISTED IN THIS ADDENDUM PART III - PROPERTIES OF MATERIALS. THESE PROPERTIES WERE STATED IN THE ORIGINAL GADR-55. THE DEPLETED URANIUM (DU) PROPERTIES QUOTED THEREIN WERE COMPILED BY NATIONAL LEAD COMPANY - NUCLEAR DIVISION. THE STRAINS COMPUTED ARE SHOWN ON PAGE 5-175 AND ON PAGE 5-176 THE SPLICED DU JOINTS SUPPORTED BY WELDS FALL WELL WITHIN THE STATED ELONGATION RANGE.

ALL EXTREME YIELDING WAS BELOW 35% BY A GOOD MARGIN IN THE CASE OF SS (REF COMPUTER CODE DEC 15 -004, SIDE DROP 02) AND BELOW 8% FOR URANIUM (SIDE DROP 04).

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
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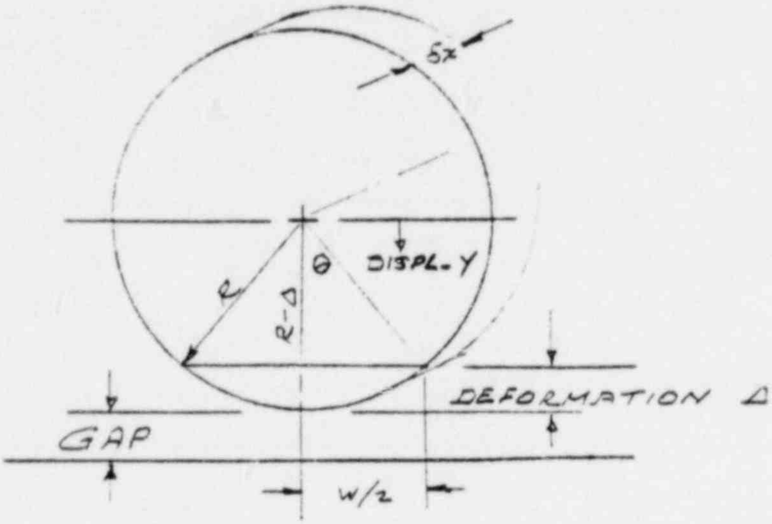
PREPARED BY JOHN GACNO	DATE 2-5-79	REF. DOCUMENTS:	
REVIEWED BY	DATE 7-20-79		
APPROVED BY	DATE		

RESISTANCE OF CASK TO DEFORMATION



$$\delta F = (W\ \delta x)\ \sigma_f$$

$$\theta = \cos^{-1}\{(R-\Delta)/R\}$$

$$W = 2\ R\ \sin\theta$$

$\Delta = Y - GAP$ (IF POSITIVE) OTHERWISE $\Delta = 0$

RESISTANCE FUNCTION PER CODE

FORCE = 2 * R * SINθ * SIGMA * DX

DEL = Y - G (IF POSITIVE)

THETA = ACOS((R-DEL)/R)

THE MAXIMUM VALUE OF 'DEL' IS SAVED TO BE COMPARED TO PREVIOUS VALUE TO SEE IF UNLOADING IS TAKING PLACE.

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
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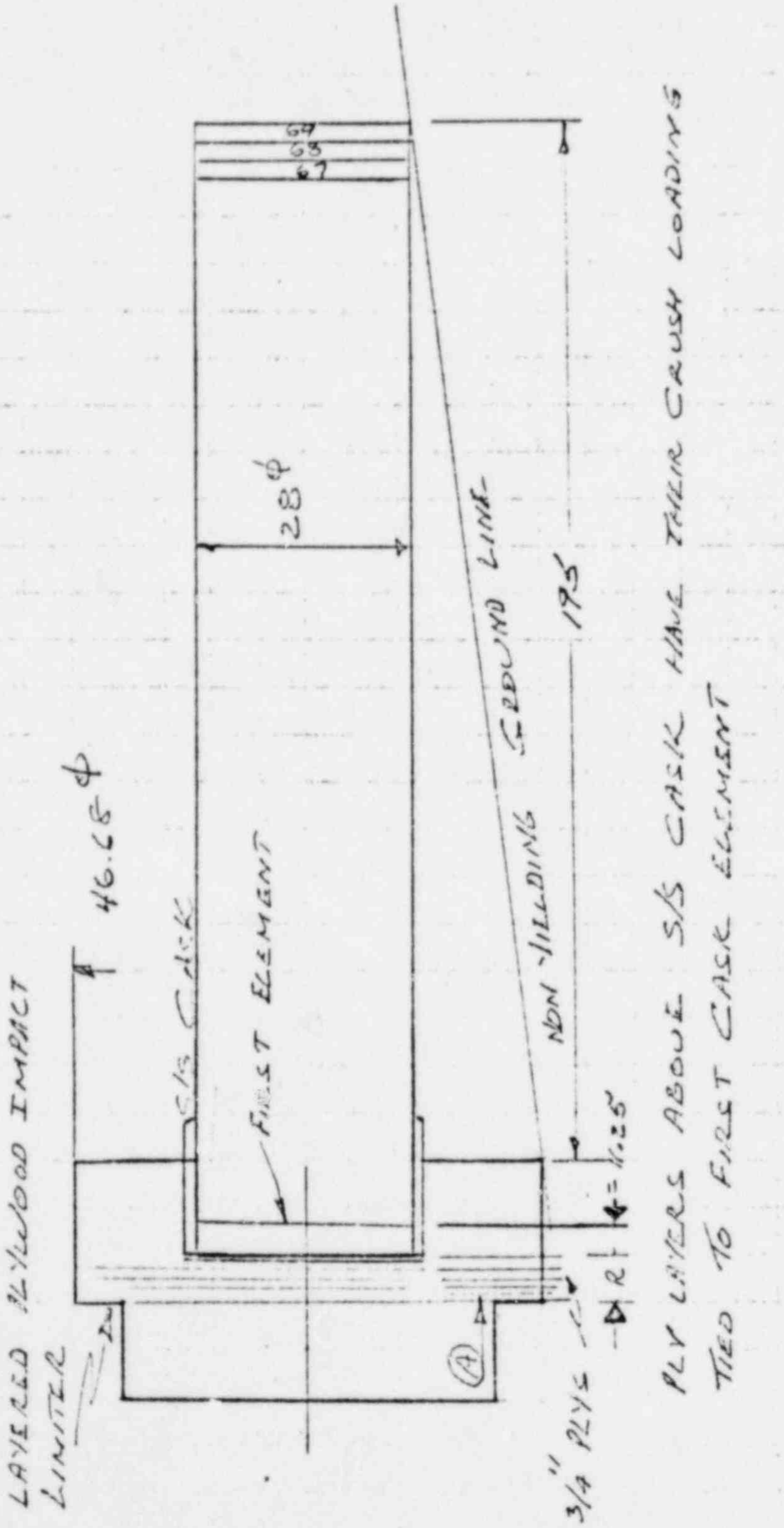
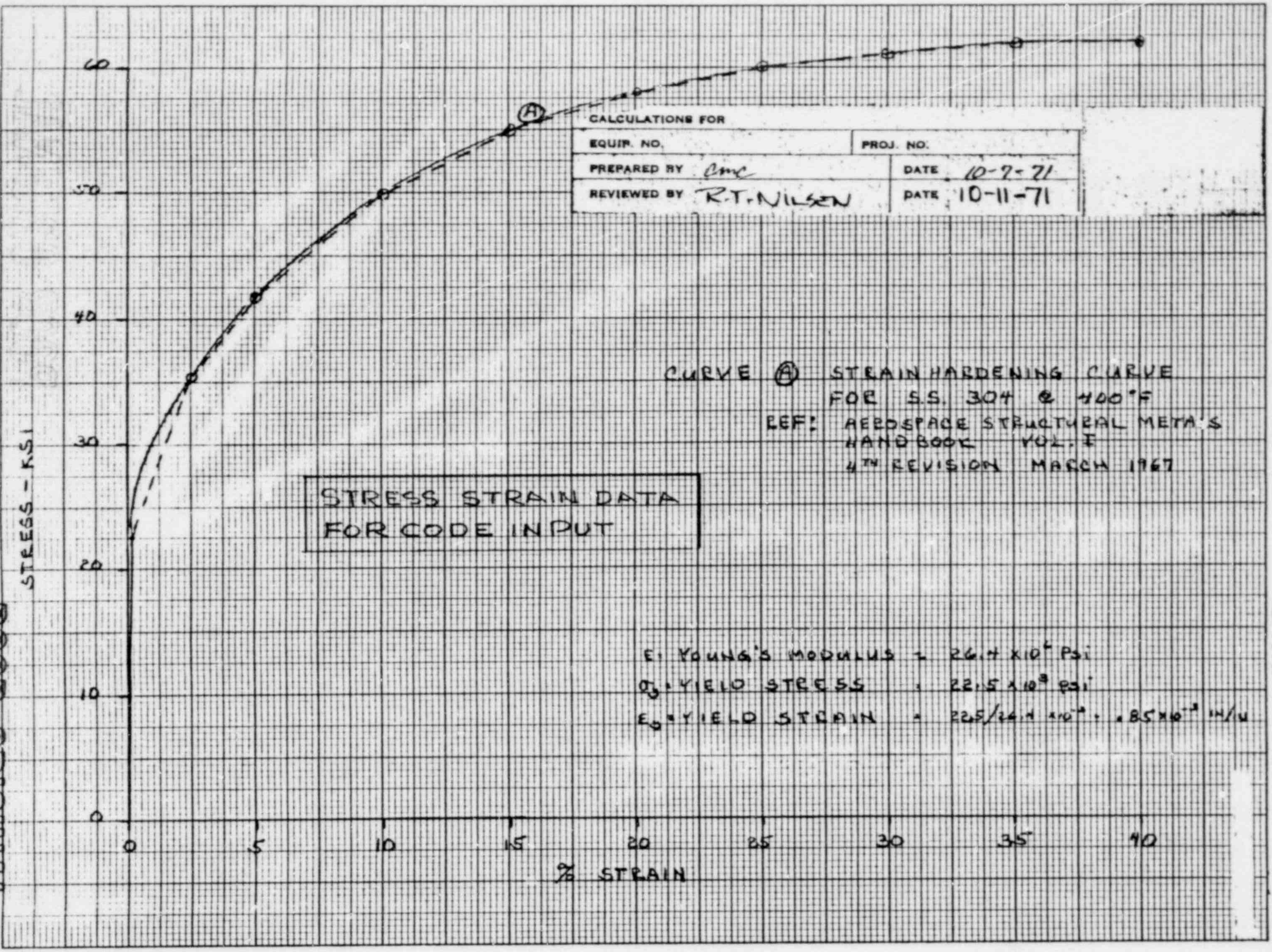
PREPARED BY JOHN GACHO	DATE JUNE 20-78	REF. DOCUMENTS:	
REVIEWED BY P. K.	DATE 20 June 78		
APPROVED BY	DATE		

CASK SIDE DROP GEOMETRY



POOR ORIGINAL



CALCULATIONS FOR

EQUIP. NO.

PROJ. NO.

PREPARED BY Cmc

DATE 10-7-71

REVIEWED BY R.T. NILSEN

DATE 10-11-71

STRESS STRAIN DATA FOR CODE INPUT

CURVE Ⓐ STRAIN HARDENING CURVE FOR S.S. 304 @ 400°F

REF: AEROSPACE STRUCTURAL METALS HANDBOOK VOL. I
4TH REVISION MARCH 1967

E: YOUNG'S MODULUS = 26.4×10^{6} PSI

σ_y = YIELD STRESS = 22.5×10^{3} PSI

ϵ_y = YIELD STRAIN = $22.5/26.4 \times 10^{-3}$ = $.85 \times 10^{-3}$ IN/IN

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
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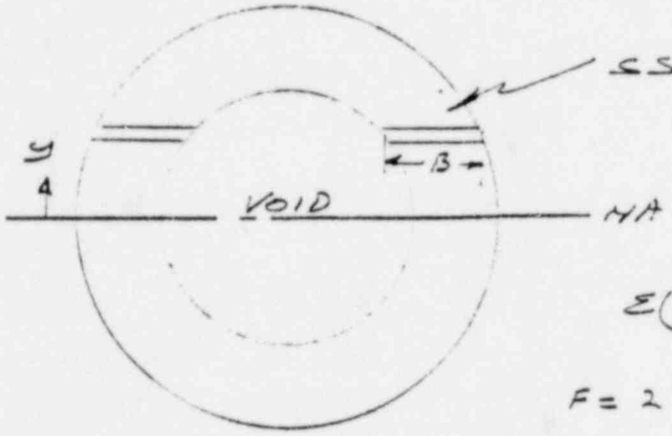
PREPARED BY JOHN GAGNO	DATE JUNE 8-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 2-20-79		
APPROVED BY	DATE		

SOLID SECTION

SINCE SS 304 ALLOY LACKS A PRONOUNCED YIELD STRESS, THE ACTUAL STRESS-STRAIN CURVE SHOWN ON Pg 5-167 WAS EMPLOYED FOR THE MOMENT CURVATURE CODES. THE STANDARD ASSUMPTION WAS MADE THAT THE STRAIN DISTRIBUTION REMAINS LINEAR



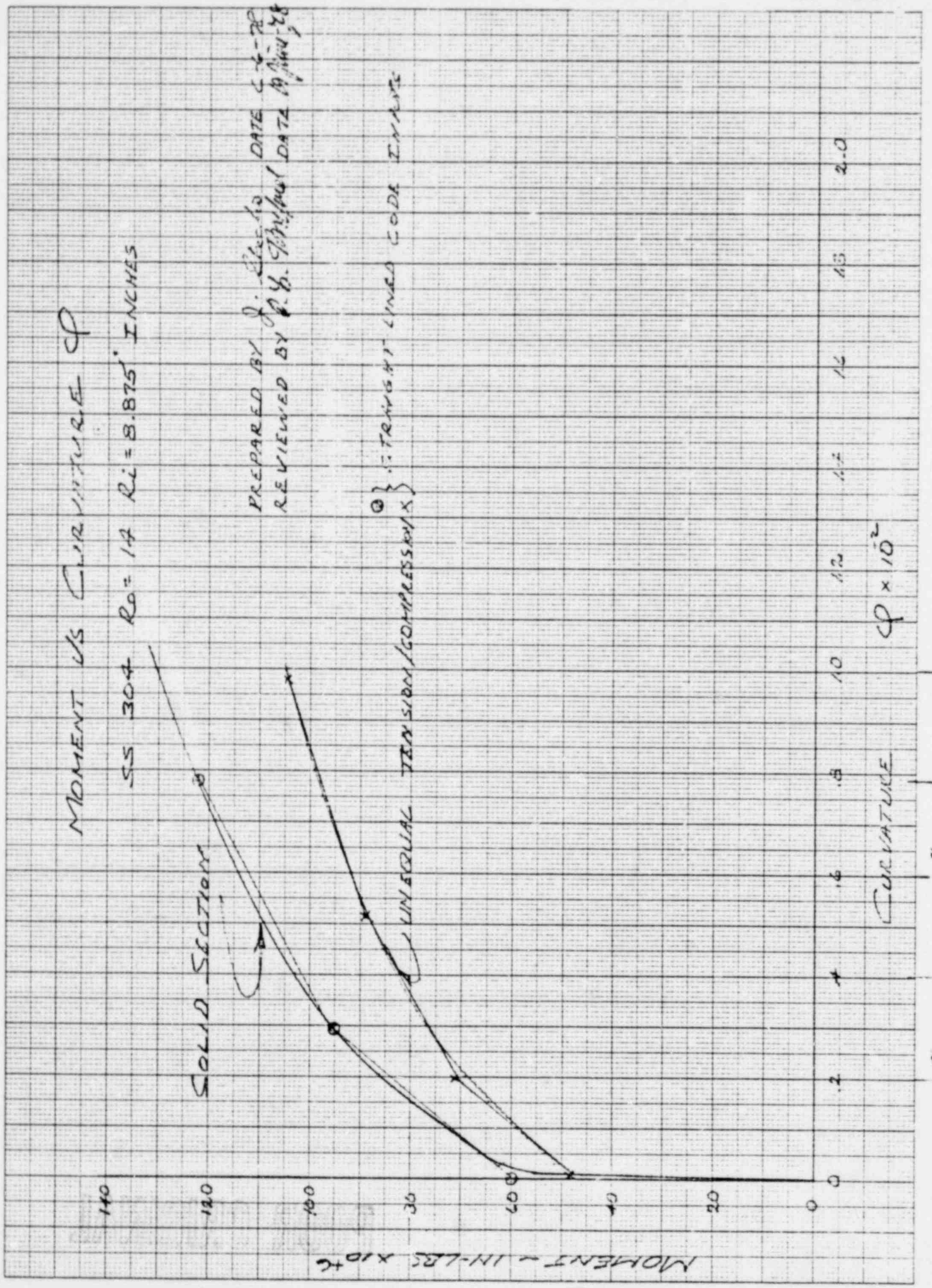
$$\varepsilon(y) = \varphi * y$$

$$F = 2\int_0^R \sigma\ \varepsilon(y) * B(y)\, dy = 0$$

$$M = \int_0^R y * \sigma(\varepsilon(y)) * B(y)\, dy$$

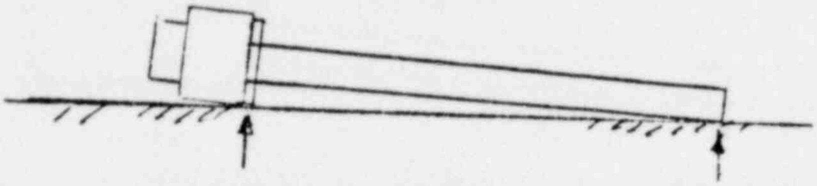
A COMPUTER SUBROUTINE WAS USED TO EVALUATE THE INTEGRAL IN THE ABOVE MOMENT EXPRESSION. THE STRESS-STRAIN CURVE WAS APPROXIMATED BY THE STRAIGHT LINE SEGMENTS SHOWN ON Pg 5-166. LINEAR INTERPOLATION WAS USED BETWEEN THE CIRCLED POINTS.

POOR ORIGINAL


MOMENT VS CURVATURE φ
SS 304 Ro = 14 Ri = 8.875" INCHES
PREPARED BY J. [illegible] DATE 6-?-78
REVIEWED BY P.Y. [illegible] DATE [illegible]-78
⊙ } STRAIGHT LINED CODE INPUT
UNEQUAL TENSION/COMPRESSION X }
SOLID SECTION
MOMENT - IN-LBS x10^4
140
120
100
80
60
40
20
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
CURVATURE φ x 10^-2
STRAIN
2.8%
6%
8.4%
11%
14%
Fig C

CALCULATIONS FOR SPENT FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 5-10-78	REF. DOCUMENTS:	
REVIEWED BY R. L. [illegible]	DATE 9 June, 1978		
APPROVED BY	DATE		

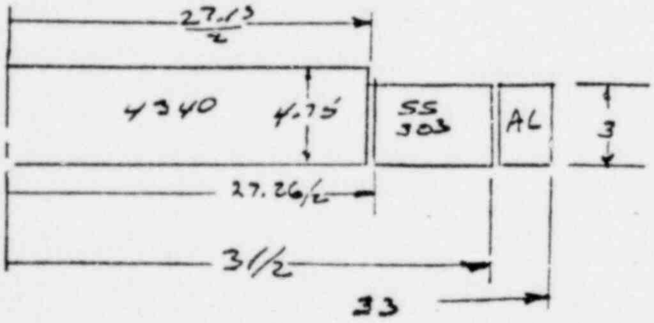
30 FT SIDE DROP



SIMULTANEOUS GROUND STRIKE

CALCULATION OF MASS POINT PROPERTIES

POINT 1 TOTAL IMPACT PLATE 4.75 IN + 3 IN SS



$$W = \frac{\pi}{4}\left(27.13^2 * 4.75 * .283 + (31^2 - 27.26^2) * 3 * .3 + (33^2 - 31^2)3 \times .1\right.$$

$$\pi/4\,(\quad 989.4 \quad 196.1 + 38.4\,) = \underline{961\ LBS}$$

$$M = W/g = 961/384 = \underline{2.50\ LB\ SEC^2/IN}$$

I SS ONLY $E = 27.7 \cdot 10^6$ PSI

$$I = \frac{\pi}{4}\left(R_o^4 - R_i^4\right) = \frac{\pi}{4}\left(15.5^4 - 13.63^4\right) \ \underline{18,227\ IN^4}$$

POOR ORIGINAL

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CALCULATIONS FOR FSV FUEL SHIPPING CASK			
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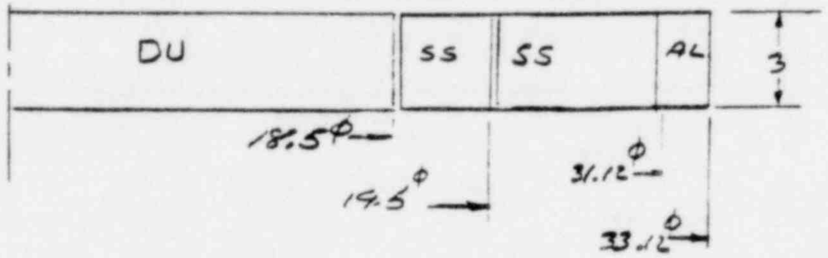
PREPARED BY John Gacho	DATE 5-10-78	REF. DOCUMENTS:	
REVIEWED BY P. L. Clough	DATE 4 June 1978		
APPROVED BY	DATE		

MASS POINT PROPERTIES (CON'T)

POINT 2



$$W = 3\frac{\pi}{4}\left[18.5^2 \times .6 + (19.5^2 - 18.5^2).3 + (31.12^2 - 19.5^2).3 + (33.12^2 - 31.12^2).1\right]$$

$$\frac{3\pi}{4}\left[205.35 + 11.4 + 176.46 + 12.85\right] = \underline{957 \text{ LBS}}$$

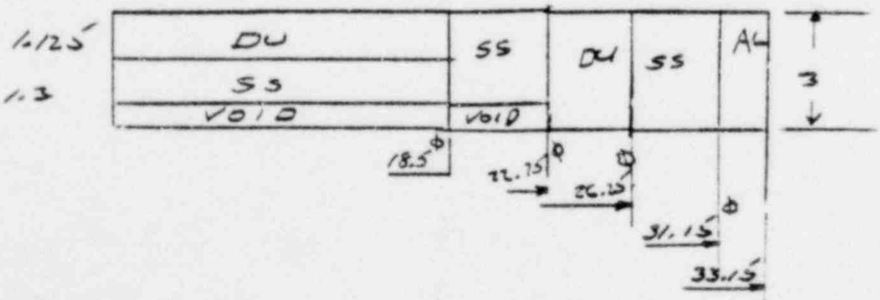
$$M = W/g = 957/384 = \underline{2.49 \text{ LB SEC}^2/\text{IN}}$$

$$E = 27.7 \times 10^6 \text{ psi}$$

I ~ (SS ONLY)

$$I = \frac{\pi}{64}\left\{(31.12^4 - 19.5^4) + (19.5^4 - 18.5^4)\right\} = \underline{40{,}289 \text{ IN}^4}$$

POINT 3



CALCULATIONS FOR FSV FUEL SHIPPING CASK			
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REVIEWED BY R. G. Stratford	DATE 9 June, 1978		
APPROVED BY	DATE		

POINT 3 (CON'T)

$$W = \frac{\pi}{4}\Big[18.5^2 \times (1.125 \times .6 + 1.3 \times .3) + (22.75^2 - 8.5^2)\,2.43 \times .3$$

$$+ (26.25^2 - 22.75^2) \times 3 \times .6 + (31.15^2 - 26.25^2) \times 3 \times .3$$

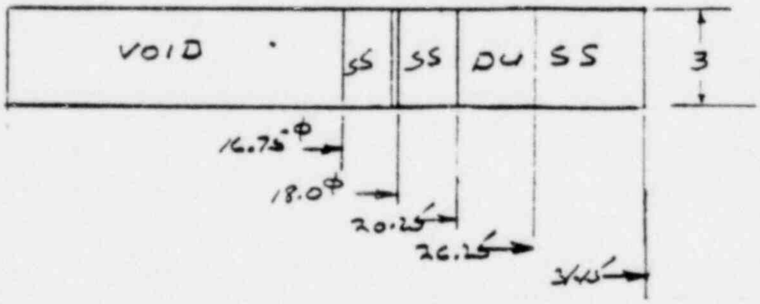
$$(33.15^2 - 31.15^2) \times 3 \times .1\Big] = \frac{\pi}{4}(1092.7) = 858.2 \text{ LBS}$$

$$M = W/g = 858.2/384 = 2.23 \text{ LB SEC}^2/\text{IN}$$

$$I = \frac{\pi}{64}\left\{(31.15^4 - 26.25^4) + (26.25^4 - 22.75^4) - (22.75^4 - 8.5^4)\right\}$$

$$\frac{\pi}{64}\{824391\} = \underline{40,467 \text{ IN}^4}$$

POINT 4



$$W = 3\frac{\pi}{4}\left\{(18^2 - 16.75^2).3 + (20.25^2 - 18.0^2).3 + (26.25^2 - 20.25^2).6 + (31.15^2 - 26.25^2).3\right\}$$

$$= \frac{3\pi}{4}(290.628) = \underline{685 \text{ LBS}}$$

$$M = W/g = 685/384 = \underline{1.78 \text{ LB SEC}^2/\text{IN}}$$

$$I = \frac{\pi}{64}(31.15^4 - 18.0^4) = \underline{41064 \text{ IN}^4}$$

POOR ORIGINAL

CALCULATIONS FOR FSU FUEL SHIPPING CASK			
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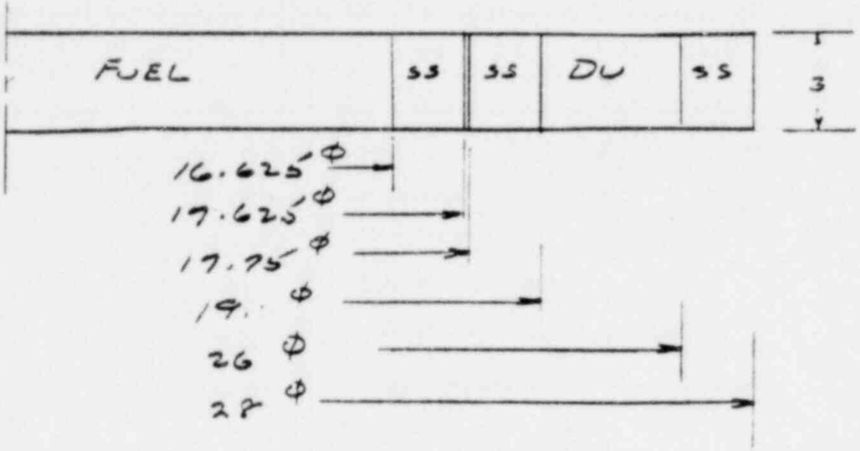
PREPARED BY JOHN GACHO	DATE 5-10-78	REF. DOCUMENTS:	
REVIEWED BY R.K. Hanford	DATE 9 June, 1978		
APPROVED BY	DATE		

POINTS 5-66



$$W = \frac{3}{4}\pi\left\{16.625^2 \times .046 + (17.625^2 - 16.625^2).287 + (19.^2 - 17.75^2).287 + (26^2 - 19^2).683 + (28^2 - 26^2).287\right\} = \underline{664\ \text{LBS}}$$

$$M = W/g = 664/384 = \underline{1.73\ \text{LB SEC}^2/\text{IN}}$$

$$I = \frac{\pi}{64}\left\{(28^4 - 26^4) + (26^4 - 19^4) + (19^4 - 17.75^4)\right\} = \underline{25{,}299\ \text{IN}^4}$$

POINTS 67−69

$$W = 3 \times \pi \times 14^2 \times .287 = \underline{530\ \text{LBS}}$$

$$M = W/g = 530/384 = \underline{1.38\ \text{LB SEC}^2/\text{IN}}$$

$$I = \frac{\pi}{4}\ 14^4 = \underline{30172\ \text{IN}^4}$$

POOR ORIGINAL

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE JUNE 20 78	REF. DOCUMENTS:	
REVIEWED BY cmc	DATE 2-20-79		
APPROVED BY	DATE		

SOLID SECTIONED CASK

CODE INPUT PLASTIC CURVATURE VS MOM

(CURVE POINTS)

POINT 1

$M = 60.E6$ $\varphi^P = 0$

POINT 2

$M = 95.E6$

$\varphi^P = .003 - 95 E6 / 27.7E6\ 30172$

$= .00296$

POINT 3

$M = 122.E6$

$\varphi^P = .0079 - 122 E6 / 27.7E6\ (30172)$

$= .00782$

POINT 4

$M = 142 E6$

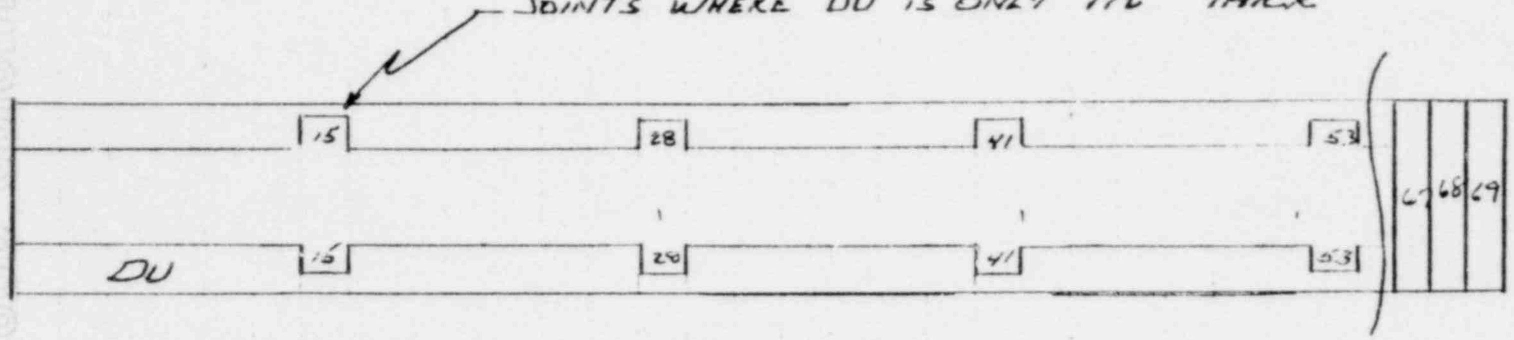
$\varphi^P = .0149 - 142 E6 / 27.7\ (30172)$

$= .01479$

POOR ORIGINAL

CALCULATIONS FOR FSV			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE JUNE 20 -78	REF. DOCUMENTS:	
REVIEWED BY	DATE June 20-78		
APPROVED BY	DATE		

CASK LAP JOINTS



JOINTS WHERE DU IS ONLY 1½" THICK

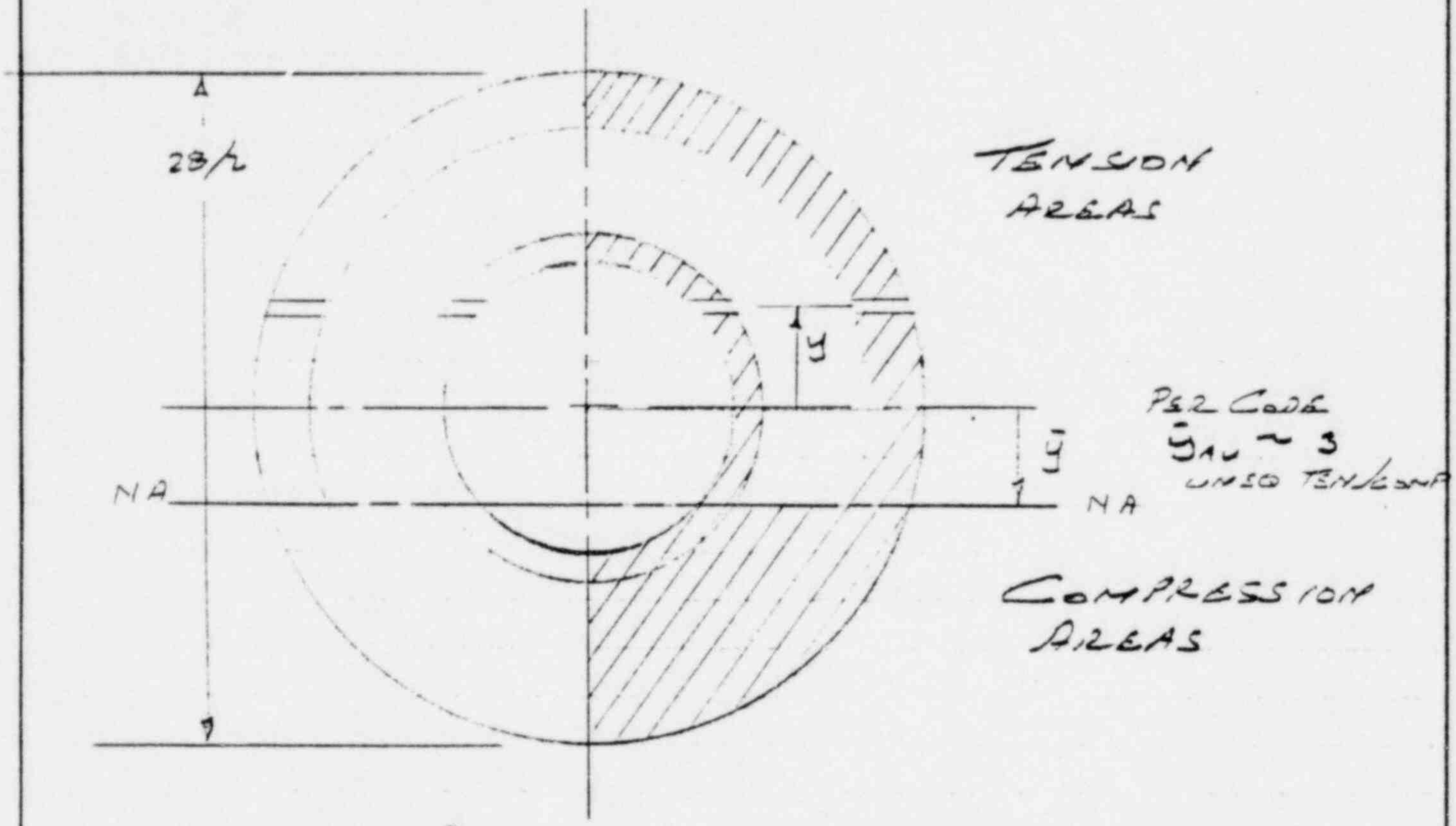
JOINTS 15, 28, 41 AND 53 URANIUM JOINTS

SEE CODE M VS Φ UNEQUAL TEN/COMP
FOR: I_{XAV} (21500 LB IN SEC²)
Y BAR (≈ 3 IN.)

POOR ORIGINAL

CALCULATIONS FOR			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE JUNE 20 -78	REF. DOCUMENTS:	
REVIEWED BY C Chairna	DATE June 20 -78		
APPROVED BY	DATE		

UNEQUAL SECTIONED CASK



$$M = \int_{-R_0}^{R_0} (y-\bar{y}) * \sigma(\varepsilon(y)) * B(y)\, dy$$

$$F = \int_{-R_0}^{R} \sigma(\varepsilon(y)) * B(y)\, dy = 0$$

$$\varepsilon(y) = \phi * (y-\bar{y})$$

MAX STRAIN: Pg 103 SIDE DROP UNEQ CASE

$2.848 E-3 * \{(28/2)+3\} = 4.84\% < 8\%$

CALCULATIONS FOR			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE JUNE 20-78	REF. DOCUMENTS:	
REVIEWED BY C. Charman	DATE June 20-78		
APPROVED BY	DATE		

UNEQUAL SECTIONED CASK (M vs Φ)

CODE INPUT PLASTIC CURVATURE VS MOM.

POINT 1

$M = \underline{48.0\ E+6}$ $\varphi^P = \underline{0.0}$

POINT 2

$M = \underline{71.5\ E+6}$

$\varphi^P = .0021 - 71.5E+6/(21500 * 27.7E+6)$

$= \underline{.00198}$

POINT 3

$M = \underline{89.5\ E+6}$

$\varphi^P = .0053 - 89.5E+6/(21500 * 27.7E+6)$

$= \underline{.00515}$

POINT 4

$M = \underline{105\ E+6}$

$\varphi^P = .010 - 105E+6/(21500 * 27.7E+6)$

$= \underline{.00982}$

CALCULATIONS FOR FSV SPENT FUEL SHIPPING CASK.			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY	DATE 14 June, 1978	REF. DOCUMENTS:	
REVIEWED BY	DATE June 16-78		
APPROVED BY	DATE 4-2-79		

CONTAINER LID & CASK BULKHEAD

30 FT SIDE DROP
(SOLID SECTION)

RESULTS OF COMPUTER ANALYSIS

.MAX. LOAD FACTORS:

URANIUM SHIELD (TOP LID) : 2017 g's
4340 ST'L TOP BULKHEAD : 1133 g's

URANIUM SHIELD (TOP LID):
$\sigma_c = \underline{26,100\ psi} < S_y = 48,000\ psi$ @ 300°F

4340 ST'L TOP BULKHEAD: BOLTS TAKE LOAD
$\sigma_{S_{BOLT}} = \underline{41,125 PSI} <\quad =$ SEE P 5-151

MAX STRAIN:
ELEMENT 15 PLASTIC CURV. = $2.033 \cdot 10^{-3}$
_03A SIDE DROP CODE (SOLID)

.STRAIN $= 2.033 \times 10^{-3} \cdot 14 = \underline{2.8\%} < 8\%$

$\left(\varphi = \frac{\varepsilon}{R_0}\right)$

OK
REF MAT PROP.
SECT. III Pg 3-1

CALCULATIONS FOR			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE JUNE 20-78	REF. DOCUMENTS:	
REVIEWED BY R. H. Stanford	DATE 21 June, 1978		
APPROVED BY	DATE 4-7-79		

CONTAINER LID & CASK BULKHEAD

30 FT SIDE DROP
UNEQUAL TEN./COMP.

RESULTS OF COMPUTER ANALYSIS

MAX LOAD FACTORS

URANIUM SHIELD (TOP LID) = -2094 g's
4340 STL TOP BLHD = -1351 g's

MAX STRESS

URANIUM SHIELD LID
σ_c = (SEE PG 5-151) = 27,100 PSI < S_y = 48KSI @ 300°F

4340 STL TOP BLHD

HOLD DOWN BOLTS TAKE LOAD IN SHEAR
SEE PG 5-151

$\sigma_{s_{BOLTS}}$ = 49,035 PSI

MAX STRAIN

ELEMENT 15 PLASTIC CURVATURE = $3.925 \cdot 10^{-3}$
PG 107 SIDE DROP CODE (UNEQ.)

STRAIN: $3.925 \cdot 10^{-3} \left(\frac{28}{2} + 3\right)$ = 6.7% < 8%
(NEUTRAL AXIS AVERAGES 3" BELOW ℄)

OK

$$\left(\varphi = \frac{\varepsilon}{R_0}\right)$$

REF MAT PROP
SECT III Pg 3-1

[illegible] SIDE [illegible] $3.925 \cdot 10^{-3}$

GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 6-22-78	REF. DOCUMENTS:	
REVIEWED BY CMC	DATE 7-12-78		
APPROVED BY	DATE		

CASK SIDE DROP EQUATION DERIVATION

THE DEVELOPMENT OF THE FUEL SHIPPING CASK SIDE DROP EQUATIONS USED IN THE COMPUTER CODE IS PRESENTED IN THE FOLLOWING WRITE UP.

THE CASK IS DIVIDED INTO 67 LUMPED MASSES JOINED BY A LINE BEAM WITH THE APPROPRIATE REPRESENTATIVE SECTION PROPERTIES; E, I. THE INITIAL CASK DROP VELOCITY IS THAT REALIZED WHEN DROPPED 30 FT HEIGHT, MAKING A SIMUTANEOUS HEAD TAIL GROUND STRIKE. AS THE CASE HAS A PLYWOOD IMPACT LIMITER OF LARGER DIAMETER THAN THE BODY PROPER ONLY THE HEAD AND TAIL SECTION MAKE INITIAL GROUND CONTACT. THEN AS THE BEAM DEFLECTS ADDITIONAL BASE REACTIVE FORCES ARE IMPARTED TO THE BEAM AS SHOWN IN THE LINE ELEMENT SKETCHED BELOW.

THE BEAM ELEMENT FORCE AND THE DYNAMIC EQUILIBRIUM OF EACH MASS ELEMENT IS GENERATED IN TERMS OF THE BENDING MOMENT AT THE MASS POINT. A SECOND CENTRAL DIFFERENCE IS USED TO APPROXIMATE THE CURVATURE OF THE BEAM SEGMENTS. THE BENDING MOMENT IS RELATED TO THE CURVATURE THROUGH A ONE DIMENSIONAL YIELD CRITERIA AND ASSOCIATED FLOW RULE.

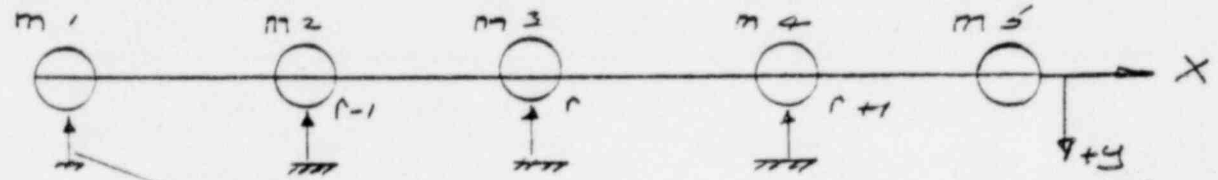
GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 6-20-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 20 July 1978		
APPROVED BY	DATE		

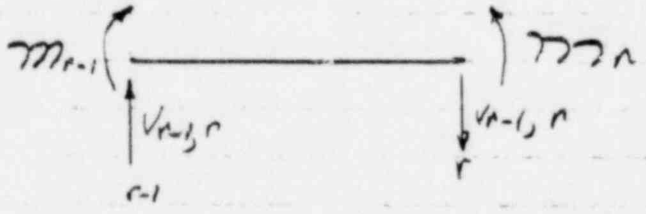
GENERAL DEVELOPMENT

DERIVATION OF DYNAMIC RESPONSE OF BEAM

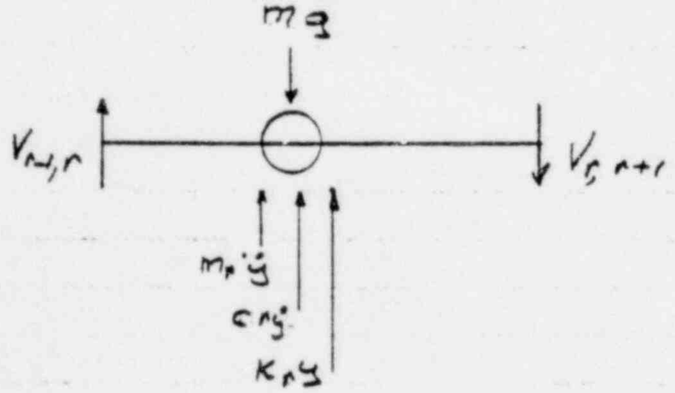


BASE REACTIVE FORCE AT TIME 't'

BEAM ELEMENT (BETWEEN MASSES) FORCES



DYNAMIC EQUILIBRIUM OF MASS r



GA 268 Rev. 1-74

GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSU FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACMO	DATE 6-20-78	REF. DOCUMENTS:	
REVIEWED BY D.B. Stanford	DATE 10 July 1978		
APPROVED BY	DATE		

(GENERAL)

THE CURVATURE AT POINT r IS APPROXIMATED BY THE SECOND CENTRAL DIFFERENCE FOR INTERIOR POINTS

$$\left(\frac{d^2y}{dx^2}\right)_r \approx -\frac{1}{\Delta x^2}\left(y_{r+1} - 2y_r + y_{r-1}\right)$$

THE MOMENT $\mathfrak{M}$ IS DEFINED

$$\mathfrak{M}_r = EI\,\frac{d^2y}{dx^2} \approx -\frac{EI}{\Delta x^2}\left(y_{r+1} - 2y_r + y_{r-1}\right) \quad ①$$

INTERIOR NODES' DYNAMIC EQUILIBRIUM

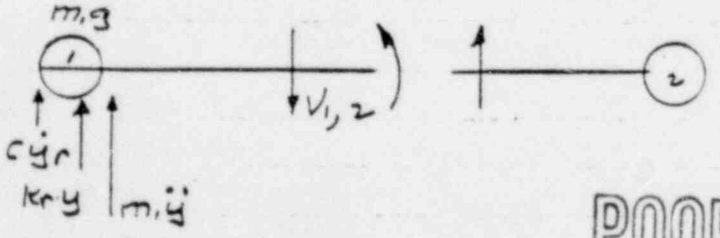
$$V_{r-1,r} = \frac{\mathfrak{M}_r - \mathfrak{M}_{r-1}}{\Delta x}$$

$$m_r\ddot{y} + V_{r-1,r} - V_{r,r+1} + c\dot{y}_r + k\,y_r = mg$$

SUBSTITUTING THE SHEAR EXPRESSION IN THE ABOVE YIELDS:

$$m_r\ddot{y}_r - \frac{\left(\mathfrak{M}_{r-1} - 2\mathfrak{M}_r + \mathfrak{M}_{r+1}\right)}{\Delta x} + c\dot{y}_r + ky_r = mg \quad ②$$

AT THE FIRST NODE



POOR ORIGINAL

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GENERAL ATOMIC COMPANY

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 6-22-78	REF. DOCUMENTS: JOHN M BIGGS INTRODUCTION TO STRUCTURAL DYNAMICS, McGRAW-HILL 1964	
REVIEWED BY R.L. Timlin	DATE 4 July 1978		
APPROVED BY	DATE		

(GENERAL)

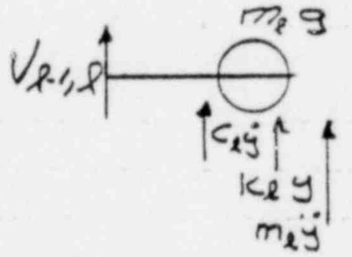
THEN FOR NODE 1

$$m_1\ddot{y} - V_{1,2} + C_1\dot{y} + k_1 y = m_1 g$$

SUBSTITUTING AS BEFORE BUT WITH THE MOMENT ON ONE SIDE ONLY OF THE MASS.

$$m_1\ddot{y} - \frac{M_2}{\Delta x} + C_1\dot{y}_1 + k_1 y = m_1 g \qquad ③$$

AND IN SIMILIAR FASHION, THE LAST MASS



EQUATION IS DEFINED:

$$m_\ell\ddot{y}_\ell - \frac{M_{\ell-1}}{\Delta x} + C\dot{y}_\ell + Ky_\ell = m_\ell g \qquad ④$$

THE SECOND DIFFERENCE SCHEME AND PREDICTING ALGORITHM ARE INDICATED BELOW (REF. BIGGS ABOVE) FOR THE Δt TIME STATIONS

$$y^{(s+1)} = 2y^{(s)} - y^{(s-1)} + \ddot{y}^{(s)}\Delta t^2 \qquad \text{(REF. PG. 30)} \qquad ⑤$$

AND

$$\dot{y}^{(s)} = \frac{y^{(s)} - y^{(s-1)}}{\Delta t} + \ddot{y}^{(s)}\frac{\Delta t}{2} \qquad \text{(REF., PG. 19)} \qquad ⑥$$

SUBSTITUTING EQN ⑥ INTO EQN ②

CALCULATIONS FOR FSV FUEL SHIPPING CASE			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GHCHO	DATE 6-22-78	REF. DOCUMENTS:	
REVIEWED BY P. H. Hamford	DATE 10 July, 1978		
APPROVED BY	DATE		

(GENERAL)
GIVES THE FOLLOWING:

⑦ $$\ddot{y}_r^{(s)} = \frac{mg - k y^{(s)} - c\left(y^{(s)} - y^{(s-1)}\right)/\Delta t + \left(\frac{M_{r-1} - 2M_r + M_{r+1}}{\Delta x}\right)}{\left(m_r + c\,\Delta t/2\right)}$$

TO START ASSUME (REF pg 6)

⑧ $$y^{(2)} = \frac{1}{6}\left(2\ddot{y}^{(1)} + \ddot{y}^{(2)}\right)\Delta t^2 - \dot{y}^{(1)}\Delta t$$

AS $\ddot{y}^{(2)}$ IS NOT KNOWN THE FIRST VALUE IS ASSUMED AND THEN EQN ⑦ MAY BE SOLVED FOR A CORRECTED $\ddot{y}^{(2)}$ THIS PROCESS IS REPEATED UNTIL NO CHANGE IS NOTED IN $\ddot{y}^{(2)}$.

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CALCULATIONS FOR FSU FUEL SHIPPING CASK

EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 6-22-78	REF. DOCUMENTS: ELASTO-PLASTIC STRESS ANALYSIS, NAYAK/ZIENKIEWICZ UNIVERSITY OF WALES SWANSEA, WALES	
REVIEWED BY cmc	DATE 7-12-78		
APPROVED BY	DATE -		

INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGR VOL 5 113-135, (1972)

DETERMINATION OF STRESSES DURING ELASTO-PLASTIC STRAINING

CONSIDERING THE ELASTIC STRAIN

$d\epsilon_e = D^{-1}\, d\sigma$ D = ELASTIC CONSTANT MATRIX

IF YIELD IS REACHED

$F(\sigma, \epsilon_p, K) = 0$, AND: σ RELEVANT STRESS COMP,
ϵ_p ACCUMULATED PLASTIC STRAIN,
K STRAIN HARDENING PARAM.

PLASTIC STRAINING MAY OCCUR AND THE TOTAL STRAIN CHANGES ARE GIVEN AS:

$$\underline{d\epsilon = d\epsilon_e + d\epsilon_p}$$

FOR ADDED GENERALITY THE PLASTIC POTENTIAL TO WHICH THE NORMALITY PRINCIPLE IS APPLICABLE

$Q(\sigma, \epsilon_p, K_0) = 0$ WHERE $F \equiv Q$

DURING PLASTIC DEFORMATION BY THE NORMALITY RULE:

$$d\epsilon_p = d\lambda \frac{\partial Q}{\partial \sigma} = d\lambda\, \bar{a} \quad ; \quad \bar{a} = \left\{ \begin{matrix} \partial Q/\partial x \\ \vdots \end{matrix} \right\} = \frac{|M|}{M}$$

AND IS A VECTOR DEFINED AT ANY STRESS STATE. DURING PLASTIC DEFORMATION F = 0 AND

$$dF = (\partial F/\partial \sigma)^T d\sigma + \partial F/\partial K\, dK + \{\partial F/\partial \epsilon_p\}^T d\epsilon_p = 0$$

IF $a = \left\{ \begin{matrix} \partial F/\partial x \\ \vdots \end{matrix} \right\}$ AND $A = -\frac{1}{d\lambda}\left(\frac{\partial F}{\partial K} dK + \{\partial F/\partial \epsilon_p\}^T d\epsilon_p \right)$

dF MAY BE DEFINED: $dF = a^T d\sigma - A\, d\lambda = 0$
SO THAT $\underline{d\epsilon = D^{-1} d\sigma + d\lambda\, \bar{a}}$

CALCULATIONS FOR FSV FUEL SHIPPING CASK			
EQUIP. NO.	PROJ. NO.	CALC. NO.	PAGE OF
PREPARED BY JOHN GACHO	DATE 6-22-78	REF. DOCUMENTS:	
REVIEWED BY	DATE 7-12-78		
APPROVED BY	DATE		

PREMULTIPLYING THE AFOREMENTIONED $d\sigma$ EXPRESSION BY $a^T D$ AND ELIMINATING $d\sigma$ BY NOTING $dF = 0$, THE FOLLOWING IS OBTAINED

$$d^T d\epsilon = A\,d\lambda + d\lambda\,\bar{\beta}$$

WHERE $d \equiv D a$, $\bar{\beta} = a^T \bar{d}$ $\bar{d} \equiv D\bar{a}$, NOW THE PLASTIC MULTIPLIER IS:

$$d\lambda = \frac{1}{A+\bar{\beta}}\, d^T d\epsilon$$

SUBSTITUTING $d\lambda$ IN THE $d\epsilon$ EXPRESSION AND REARRANGING

$$d\sigma = (D - D_p)\,d\epsilon = D_{ep}\,d\epsilon$$

WHERE $D_p = \frac{1}{A+\bar{\beta}}\, \bar{d} d^T$ $\quad (D_p\,d\epsilon \equiv d\lambda\,\bar{d}$

IN THE $d\sigma$ EXPRESSION ABOVE, THE STRESSES ARE UNIQUELY DETERMINED DURING ANY ITERATION IN WHICH KNOWN FINITE CHANGES OF STRAIN ARE IMPOSED.

<u>ISOTROPIC HARDENING</u> ASSUMES A UNIFORM EXPANSION OF THE INITIAL YIELD SURFACE, ASSUMMING $\partial F/\partial S_p \equiv 0$ WITH K DEFINED $dK = d\bar{\epsilon}_p$. THEN FOR THE ISOTROPIC WORK HARDENING $A = \frac{1}{d\lambda} H' \frac{d\epsilon_u^p}{dk} dk = H'$ WHERE H' IS THE SLOPE OF THE CURVE RELATING THE UNIAXIAL STRESS AND THE CORRESPONDING PLASTIC STRAIN.

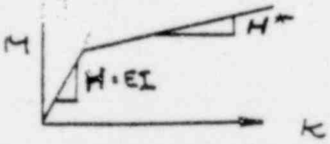
$a = \text{ABS}(M)/M$

$d\lambda = \frac{1}{A+\bar{\beta}}\, d^T dk = \frac{1}{H'+\bar{\beta}}\, d^T dk$ $\qquad$ WITH $d^T = D a$, $D = H = EI$

$\bar{\beta} = a^T \bar{d}$, $\bar{d} = D\bar{a}$

$d\lambda = \frac{H\ \text{ABS}(M)/M}{H' + H}\, dk$ $\qquad$ $d = H\ \text{ABS}(M)/M$

$H' = \frac{H^* H}{H - H^*} = \frac{H^*}{1 - \frac{H^*}{H}}$



H. ANALYSIS OF THE LIDS FOR THE LOAD CONDITIONS SPECIFIED BY 10 CFR § 71.31(d)(1).

A static force applied to the C.G. of the package with a component equal to 10.W in the direction of vehicle travel, a lateral component equal to 5.W and a vertical component equal to 2.W will not generate any significant stresses in either the container lid or in the cask lid. The tie-down reactions and stresses resulting from this load do not transmit any significant loads to the cask lid and container lid.

I. ANALYSIS OF LIDS FOR THE LOAD CONDITIONS OF VIBRATION NORMALLY INCIDENT TO TRANSPORT (10 CFR 71, APP. A, CONDITION 4)

RDT F8-9T suggests the following design equation for the package response

$$G = 2.5\sqrt{f_n} \qquad \text{Spring mounted truck, 0.03 damping.}$$

From p. 5-20 of Ref. 4 (p. 5-58), the natural frequency of the cask is given as

$$f_n = 41.2 \text{ Hz}$$

for the original cask weight of 46,500 lbs.

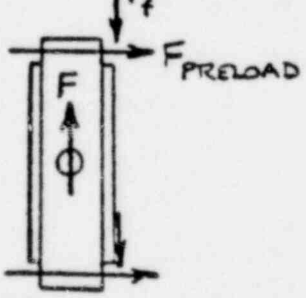
Adjusting the natural frequency for the modified cask weight of 47,587 lbs. results in

$$f_n = \sqrt{\frac{46,500}{47,587}}\,(41.2) = 40.73 \text{ Hz}$$

The appropriate G load response to design for is

$$G \approx 2.5\sqrt{40.73} = 16G$$

The forcing function is primarily a vertical load resulting from the interaction of the trailer suspension with the irregularities of the road bed. This results essentially in an inertial shearing load of the cask lid against the bolts.



Cask Lid Bolts

$$W_{LID} = 657 \text{ lbs.}$$

$$F = 657\,(16G) = 10,512 \text{ lbs.}$$

Determine max frictional resistance, F_f,

$$F_{BOLT} = \frac{T}{K} \quad T = \text{Torque} \quad K = \text{Factor}$$

For 1¼ - 7 UNC, f=.15; K = .24098

$$T_{MIN} = 80 \text{ Ft-lb} = 960 \text{ in-lb}$$

$$F_{BOLT} = \frac{960}{.24098} = 3984 \text{ lbs}$$

$$F_{PRELOAD} = 24 \text{ Bolts } (3984 \ \frac{\text{lb}}{\text{Bolt}})$$

$$= 95616 \text{ lb. minimum}$$

From MARKS, 6th Ed., friction coefficient is

$$\mu \text{ Static} = .74 \text{ Mild Stl./Mild Stl.}$$
$$= .78 \text{ Hard Stl./Hard Stl.}$$

Use μ = 0.7 (conservative)

F_f = .7 (95,616 lb) = 66,931 lb

Since F_f = 66.9K > F = 10.5K

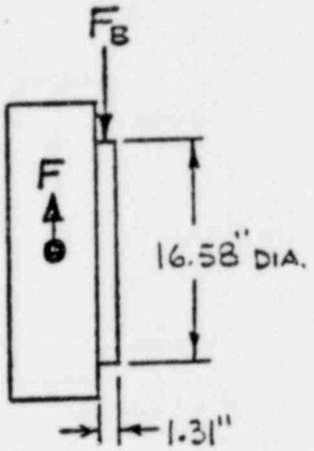
Lid is tightly secured and no damage due to vibration will result.

CONTAINER LID

Container lid will react vibration load against shoulder.

$F = 983(16) = 15{,}728\ \text{lb}$

Assume bearing on 1/2 of projected shoulder area.



$$A_{BEARING} = \frac{16.58\ (1.31)}{2} = 10.86\ \text{in}^2$$

$$\sigma_{BEARING} = \frac{15{,}728\ \text{lb}}{10.86\ \text{in}^2} = 1{,}450\ \text{psi}$$

Due to the high cycle nature of vibration, the appropriate allowable stress is the endurance limit of the material. The endurance limit may be conservatively estimated as 40% of the ultimate strength.

$$S_E = 0.4\ Su$$

$$S_u = 63{,}500\ @\ 300F\ \text{for Type 304 (SA - 240)}$$

$$S_E = 0.4\ (63{,}500) = 25{,}400\ \text{psi}$$

$$\sigma_{\ BEARING} = 1{,}450\ \text{psi} < S_E = 25{,}400\ \text{psi}$$

Therefore both lids are adequate and will be unaffected by vibration.

SECTION VI

DIFFERENTIAL THERMAL EXPANSIONS

DIFFERENTIAL THERMAL EXPANSIONS

A. CLEARANCES

The container lid is made of depleted uranium encased in type 304 stainless steel. Gaps exist between the stainless and the depleted uranium to allow for installation of the uranium during assembly of the lid.

B. COEFFICIENTS OF EXPANSION

Coefficient of expansion used is 6.5×10^{-6} in./in. °F for uranium. This value is obtained from records of National Lead Company's Albany plant and refer specifically to as-cast .2% molybdenum uranium.

Stainless Steel values are from Section III, table N-426 of the Nuclear Code, as follows:

A = instantaneous values at given temperature
B = mean coefficient (from 70°F to indicated temperature)

A	B	Temp. °F
9.11	9.11	70
9.73	9.47	300
10.43	9.82	600
10.90	10.05	800

C. TEMPERATURE DISTRIBUTION

The depleted uranium portion of the container lid is supported by the stainless case with small gaps (.030 in. average) between the stainless and the uranium on the top and sides. The stainless and the uranium temperatures are within 25°F of each other during both the steady state conditions and during the transient condition of the hypothetical fire accident.

D. DIMENSIONAL CHANGES

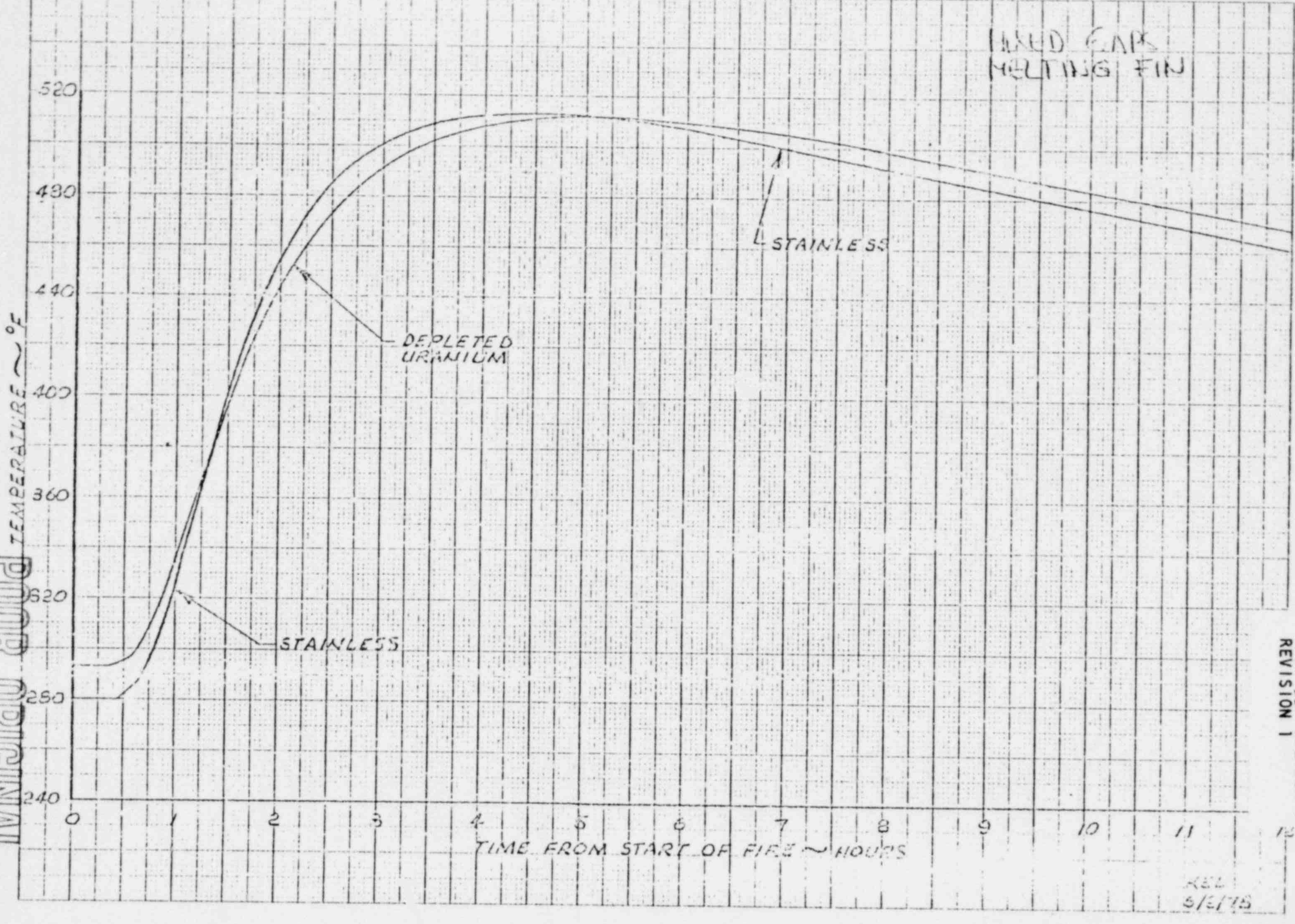
The stainless case and depleted uranium shielding of the container lid both expand with increasing temperature. Since the thermal expansion coefficient of the stainless is greater than that of the depleted uranium, the stainless container will expand at a greater rate and the uranium to stainless gap will tend to grow with increasing temperature. There will be no tendency for the uranium to apply thermal expansion stress load to its stainless container.

The crystal structure of uranium is orthorhombic. This material may exhibit nonuniform crystal lattice growth upon thermal cycling. This growth may result in dimensional growth for hot or cold worked materials with orientated grain structure. "The thermal cyclic growth (of uranium) is negligible if peak temperatures of cycling never exceed 299 - 349°C (570 - 660°F)."[1] From Figure VIII-4a of this report for the fire accident analysis, the maximum hot day temperature of the uranium is 270°F while the peak temperature during the fire accident is 480°F. These temperatures are well below the 570 to 660°F range and therefore thermal cyclic growth will be negligible.

---

[1] Ref: Nuclear Systems Materials Handbook, Vol. 1. Design Data Part IV Nuclear Fuel Materials, Group 2 - Metals, Section 1 Uranium, Revision 1, 12/1/74.

[illegible] [illegible] LINER [illegible] TEMPERATURES DURING FIRE TRANSIENT



SECTION VII

SHIELDING ANALYSIS

SHIELDING ANALYSIS

A. SUMMARY

Gamma dose rates have been calculated at several locations on or near the Fort St. Vrain fuel shipping cask with an alternate closure system. A tractor and trailer combination is used to transport one shipping cask as its only load. The dose rates were determined to be within the 10CFR173.393 limits of not more than 10 mrem/hr at a distance of 6 feet from the trailer and 2 mrem/hr in any normally occupied position in the vehicle.

B. GEOMETRY AND SOURCES

The cask is designed to hold six 14.22-inch hexagon by 31.22-inch long fuel blocks in a single column. The cask is made of depleted uranium encased in steel plate. Table VII-1a summarizes the important data used in the shielding design. The total activity of isotopes of importance to shielding design is approximately 580,000 curies. The locations and values for the calculated dose rates are shown in Figure VII-3a.

Sources for fuel that had decayed for 100 days were used as input for the calculations and are listed in Table VII-2a. Isotopes emitting low energy gammas were not considered. The sources represent the highest fission product inventory a fuel block will have accumulated after scheduled burnup in the equilibrium core.

C. RESULTS

The dose rates and locations of the dose points are shown in Fig. VII-1a. The limit of accuracy in the calculations is ± 50%. Shielding thickness should not be increased to reflect this limit of accuracy. If dose rates exceed the calculated values, the storage time of the blocks may be increased to as long as 200 days.

It should be noted that the cask is designed to handle peak fuel from an equilibrium core. Some fuel blocks that are unloaded during the approach to equilibrium may have experienced even higher peaking factors during operation. It is expected, however, that their shutdown gamma activity will not be significantly higher, because of the shorter exposure time and hence reduced buildup of the longer-lived fission products.

D. CALCULATIONS

The GAC PATH Code was used to calculate dose rates that were then adjusted to account for buildup factors in laminated shields. The PATH Code is described in Attachment VII-1 of GADR-55, April 17, 1969. Isotopes and their activities shown in Table VII-2a were used as input data for the shielding calculations. The activity was assumed to be uniformly distributed in each fuel block.

In order to calculate a dose rate for a laminated shield composed of uranium and steel, the dose rate is calculated using buildup factors for steel and then calculated using buildup factors for uranium. The actual dose rate results from adjusting these dose rates by an interpolation technique for buildup factors in a laminated shield, as described in subsections E, F, and G. The dose rates at points 1, 2 and 11 were conservatively calculated by using the buildup factors for iron without further adjustment to the PATH results. No credit was taken for the shielding effect of the impact limiter.

TABLE VII - 1a

DATA FOR PSC-SPENT-FUEL SHIPPING CASK AS ASSUMED FOR RADIATION ANALYSIS

Inside radius of steel liner	21.11 cm
Thickness of fuel container plus inner liner	2.86 cm
Thickness of uranium at side	8.89 cm
Density of uranium	18.9 gm/cc
Thickness of outer shell liner	2.54 cm
Height of fuel column	476. cm
Average density of fuel (assumed to be carbon only)	1.54 gm/cc
Steel thickness on cask bottom	27.94 cm
Shield thickness on cask top*	
Steel (next to fuel)	3.35 cm
Uranium	10.52 cm
Steel (top of cask)	12.70 cm

*Only these dimensions at the cask top are different for the alternate closure system. All other cask dimensions have not changed but are included in this table for completeness.

TABLE VII - 2a

SOURCE DATA FOR ONE FUEL BLOCK*

Isotope	Curies**
Y-91	11,900
Zr-95	13,600
Nb-95m	270
Nb-95	13,600
Ru-103	2,700
Rh-106	1,600
Ba-137m	2,080
Ba-140	186
La-140	186
Ce-144	25,200
Pr-144	25,200

*This table has not changed for the alternate closure system but is repeated here for completeness.

** Curie quantities are for a fuel element with the maximum inventory of fission products after 100 days decay.

LOCATION	DOSE RATE MR/HR
1	NIL
2	1
3	61
4	66
5	268
6	11
7	6
8	7
9	54
10	3
11	0.4

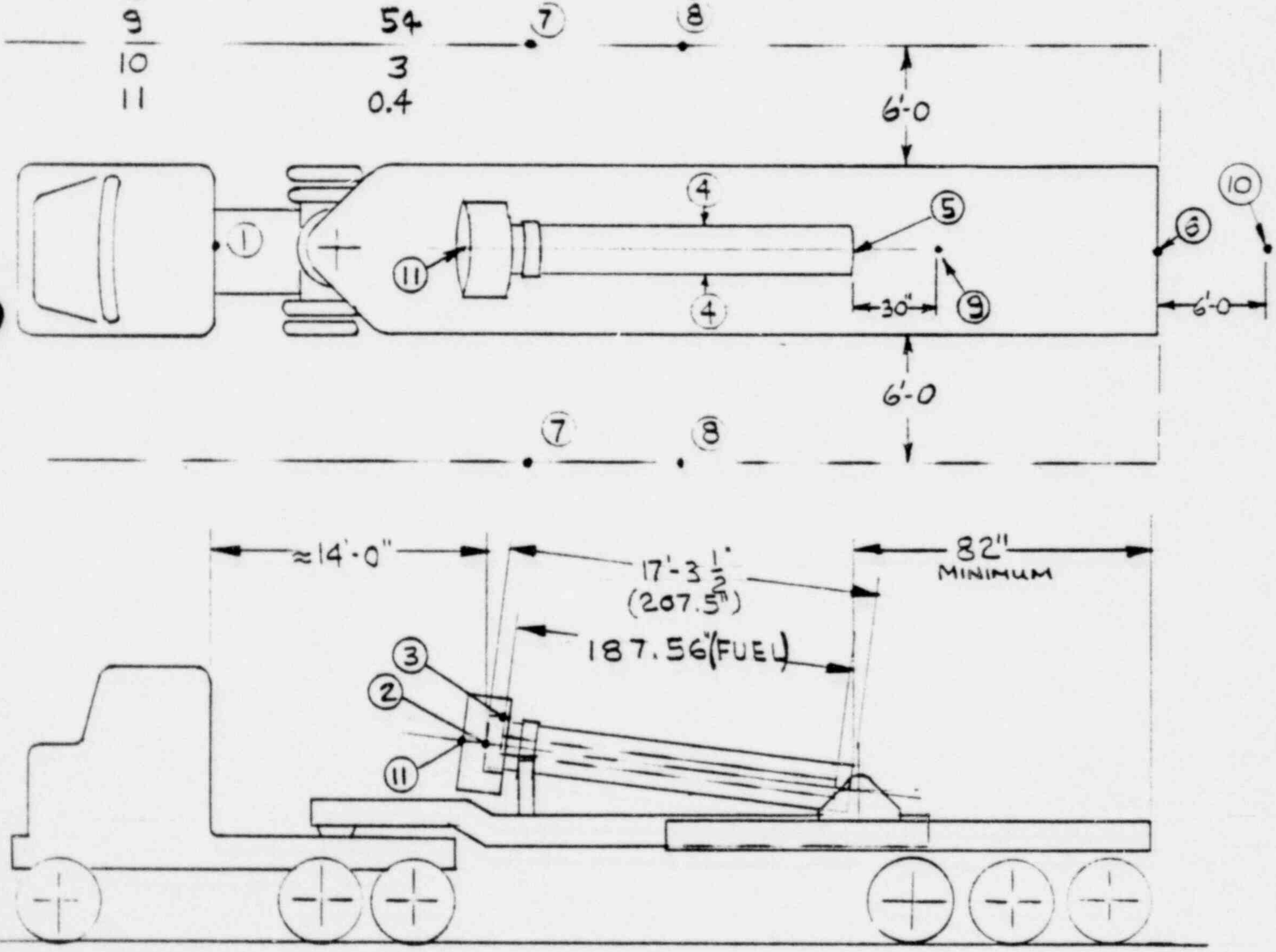


Fig. VII-3a Radiation Levels During Transit of FSV-1 Fuel Shipping Cask

SECTION VIII

HEAT TRANSFER ANALYSIS

HEAT TRANSFER ANALYSIS

A. INTRODUCTION

The fuel shipping cask is designed to safely contain the irradiated fuel elements under a variety of potentially damaging conditions. This part of the report summarizes the thermal analysis for the alternate closure system which was performed to insure adequate cask performance during several extreme conditions including a fire accident.

B. CRITERIA FOR THE ANALYSIS

The following three situations were used to define the boundary and initial conditions for the analyses:

Condition 1A. Maximum temperature day. This condition assumes an ambient temperature of 130°F around all parts of the cask. Radiation and natural convection are the mechanisms by which heat is removed from the cask. Solar heating is imposed with an effective intensity of 96 Btu/hr-ft^2 on the cylindrical portion of the exposed cask surface and half of it on the exposed vertical surfaces. Heat generation rates simulating conservative fuel conditions 100 days after reactor shutdown were used.

Condition 1B. Same as condition 1A except that fuel conditions 200 days after reactor shutdown were used.

Condition 2. Minimum temperature day. This refers to a condition of -40°F ambient temperature without solar heating. 200 day fuel heat generation was used for comparison with Condition 1B.

Condition 3. Fire accident. This accident assumes a 1475°F fire completely surrounding the cask for a period of 30 minutes on the maximum temperature day (Condition 1). A convection heat transfer coefficient of 300 Btu/hr-ft^2-°F was added during the fire to simulate a severe convection condition due to hot, blowing gases. After the fire, the cask is returned to Condition 1, the 130°F day.

These conditions are obtained from Reference 1; Conditions (1) and (2) from Appendix A, Items 1 and 2, respectively; and Condition (3) from Appendix B, Item 3.

C. SUMMARY OF RESULTS

Steady-state and transient thermal analyses were conducted with the aid of two models representing each end of the cask extending far enough along the length of the cask to ascertain valid results. No unexpected or in any way critical results were obtained from the analysis of the relatively simple lower end. Results for the lower end are reported in Reference 2 where the details of that portion of the analysis are also described. Results pertaining to the upper end of the cask including the effect of the impact limiter are summarized in Table VIII-1. The analytical model of the cask's thermal behavior is described in the following sections.

Three gap combinations (discussed further in paragraph E.2 of this section) have been constructed and employed in this analysis. The minimum gap and maximum gap combinations refer to extreme geometrical situations whereas the mixed gap combination refers to a set of gaps which was considered likely to cause high temperatures in the top of the cask under the insulating impact limiter where the critical seal assemblies are located. Temperature histories of two fire accident transients are shown on Figure VIII-4, where the corresponding calculated seal life reduction due to the fire is also listed. Based on the similarity of these two results, it was concluded that other gap combinations would yield temperatures within the basic computational tolerance of those reported.

Figures VIII-5 to VIII-8 show the complete temperature maps from the computer output for representative steady state conditions for the extreme gap configurations.

D. METHOD OF ANALYSIS

Temperatures were calculated by a finite-difference method. A digital computer code, TAC2D described in Reference 3, was used to perform the numerical calculations concerning the upper half of the cask. The lower end was originally analyzed with the aid of RAT (Reference 2). The cask system was modeled in a form suitable for both of these codes.

TAC2D is a digital computer code that is capable of calculating temperature transients for a two-dimensional network of points. It may also be used to

TABLE 1

SUMMARY OF RESULTS
TEMPERATURES AT SELECTED LOCATIONS OF THE FSV FUEL SHIPPING CASK

	CONDITION 1A			CONDITION 1B	CONDITION 2		CONDITION 3		
	130°F AMBIENT AIR SOLAR IRRADIATION				-40°F AMBIENT AIR		ACCIDENT: FIRE OF 30 MIN. DURATION		
	100 DAY FUEL* (2322 Btuh/block)			200 DAY FUEL** (1101 Btuh/block)	200 DAY FUEL		100 DAY FUEL (Peak Values)		
	MIN GAPS	MAX GAPS	MIXED GAPS	MAX GAPS	MIN GAPS	MAX GAPS	MIN GAPS	MAX GAPS	MIXED GAPS
1) CASK SEAL	242	234	244	202	30	23	517	463	522
2) CONTAINER SEAL	270	274	284	224	50	51	484	454	485
3) LID SHIELDING	282	274	299	224	59	51	482	452	486
4) BARREL SHIELDING	266	275	274	227	36	46	839	831	830
5) FUEL CENTER LINE	392	422	420	311	140	170	562	574	572
6) FUEL SURFACE	384	414	412	307	137	166	555	567	565
7) CONTAINER WALL	327	362	361	275	80	115	587	581	579
8) INNER BARREL SHELL	296	324	322	253	57	83	656	646	645
9) EXPOSED CASK SURFACE	227	227	228	203	6	7	1440	1442	1442
10) CASK TOP CENTERLINE	247	236	247	203	33	24	481	431	487

* 100 Day Fuel Equivalent Heat Generation 2322 Btu/hr-block.

** 200 Day Fuel Equivalent Heat Generation 1101 Btu/hr-block.

obtain steady-state solutions asymptotically by carrying a transient calculation to the point where the time dependence of the result becomes negligible. The code version used for the present analysis differs only in array dimension statements from a certified version evaluated in Reference 4. All other program adaptations relate to the particular problem at hand and are documented with the actual computer runs in Reference 5.

The network is specified by establishing a grid system, assigning individual materials within that grid system, and identifying the applicable thermal parameters that represent those materials. The grid system consists of two sets of grid lines parallel to the axes in a cylindrical coordinate system.

Material blocks are defined by four bounding grid lines and a label which identifies the material they contain. Parameters that characterize each material are the pertinent thermal properties as well as the volumetric rate of heat generation within the material. Material blocks may be separated by narrow gaps that contain stagnant gases which are identified by numbers allocating the proper thermal conductivities. Heat transfer across these gaps is one-dimensional by conduction and radiation.

The various material regions and gap configurations are illustrated on Figures VIII-1 and VIII-2.

Boundary conditions at external boundaries are imposed either by prescription of a sink temperature and surface conductance or by simulation of a flowing coolant of given properties and flow conditions. In the present case, the interface between the plywood and the metal support structure of the impact limiter was assumed to constitute in effect an adiabatic boundary. Through the remaining cask surfaces, heat is exchanged with the surroundings by convection, radiation and, when applicable, as a prescribed heat flux due to solar irradiation.

The thermal parameters for the materials, gases in the gaps and coolants have been incorporated in the computer code in functional form. Certain dependent variables are available for use in these functions thereby permitting a nonlinear representation of the problem.

The cask and container seal assemblies contain material of limited lifetime under exposure to high temperature. A calculation of the seal life reduction during the fire transient was made an integral part of the thermal transient analysis on the following basis.

The probability that the seal fails within a given time interval is assumed to be represented by the ratio of this time interval and the lifetime of the material where this lifetime is temperature dependent. The probability that the seal fails at any time during the entire transient is obtained as the sum of the interval failure probabilities. The functional relationship between seal life and operating temperature is illustrated on Figure VIII-3, which is based on Reference 6.

E. ANALYSIS

1. Ambient Conditions

a. Maximum Temperature Day: The maximum temperature day is defined as sunny and having an air and radiation background temperature of 130°F. The net solar irradiation is assumed to be constant and amount to 96 Btu/hr-ft^2 on the cylindrical portion of the exposed cask surface and to 48 Btu/hr-ft^2 on the exposed vertical surfaces of the cask and impact limiter. (This assumption permits the calculation of a representative steady state solution in lieu of a temperature cycle for a 24 hour period.) Further, it was assumed that the cask is surrounded by still air so that convective cooling is limited to free convection. Using a correlation for free convection around a horizontal cylinder, the following function was derived to calculate the surface heat transfer coefficient (Reference 7):

$$h = .221 (S_t - T_a)^{.25}$$

where: S_t = the cask surface temperature,

T_a = the ambient temperature.

Thermal radiation from the cask to its surroundings was included utilizing a cask surface emissivity of 0.85 (Reference 8) and a background absorbtivity of 1.0.

b. Minimum Temperature Day: The minimum temperature day was defined as having an air and radiation background temperature of -40°F and no solar heating. The heat exchange between the cask and its surroundings is calculated on the same basis as that of the maximum temperature day.

c. Fire Accident: The fire accident is defined as a temporary radiation source of 1475°F whose interaction with the cask is based on a fire emissivity of 0.9 and a cask surface adsorptivity of 0.8. An additional surface heat transfer contribution resulting from strong convection was assumed. Heat transfer coefficients representing hot, flowing gases are expected to reach at most 300 Btu/hr-ft^2-°F. The impact limiter, largely made from plywood, protects the cask from the fire. Its plywood bulk is assumed to perfectly insulate the major portion of the structural aluminum elements. There is no heat input due to solar irradiation during the fire.

2. Cask Dimensions

Since the thermal analysis is performed with cask dimensions determined from manufacturing drawings, gaps cannot be defined exactly. Their actual size will fall into a range bounded by extremes which can be deduced from specific manufacturing tolerances. Sets of extreme combinations (such as all gaps of the largest possible size) as well as a mixed set which tends to affect the seal temperatures in an adverse manner have been utilized in the calculation of the results presented here. Thermal expansion of materials and the associated variation in gap sizes were considered insignificant and therefore disregarded in the analysis.

3. Spent Fuel Heat Generation

The fuel blocks to be shipped in this cask will have been irradiated and the original fissionable material partly consumed. Due to residual isotope activity in blocks that have been removed from the reactor, there is a continuing "after-heat" generation which decreases with time. It takes place predominantly in the fuel and graphite blocks and to a lesser degree in cask shielding components. This heat generation is predictable and has been used in the calculations.

It is assumed that the spent fuel is loaded into the shipping cask no sooner than 100 days after the reactor has been shut down. This represents the maximum heat generation that the cask need be designed for.

The fuel element behavior after reactor shut-down and the associated after-heat generation were evaluated at GAC in unrelated analyses. The heat generation rates recommended for thermal analysis of short duration processes are listed in Table VIII-1. Of these quantities, 88% are realized within the fuel block and the remaining 12% are generated within the first inch of the surrounding shielding. For the present analysis, all heat generation was assumed to be confined to the fuel blocks and distributed uniformly through their entire volume.

4. Thermal Properties of the Materials

Table VIII-2 lists the thermal properties of the materials which constitute the cask as they were used in the analysis. In the formulas shown, T represents the temperature in °R and t in °F.

TABLE VIII-2
THERMAL PROPERTIES OF MATERIALS

Helium Conductivity

$K = 0.00129\ T^{.674}$ (Btu/hr-ft-°F) Reference 9

Air Conductivity

$K = 0.0146 + 1.695\ E\text{-}05\ t$(Btu/hr-ft-°F) Reference 10

Helium-Air Mixture (50% by Volume) Conductivity

$K = 0.341 \cdot K_{He} + 0.659\ K_{Air}$ Reference 11

Stainless Steel (Type 304)

Conductivity

$K = 8.0 - 0.004433\ t$(Btu/hr-ft-°F) Reference 12

Heat Capacity per Unit Volume

$C = 55. + 0.011458\ t$(Btu/ft^3-°F) Reference 12

Emissivity

$\epsilon = 0.85$ Reference 8

Aluminum (Type 6061)

Conductivity

$K = 100$ Btu/hr-ft-°F Reference 13

Heat Capacity per Unit Volume

$C = 39.$ (Btu/ft^3-°F) Reference 13

Emissivity

$\epsilon = 0.2$ Reference 7

$\epsilon = 0.85$ (with surface treatment for exposed surface)

Depleted Uranium Shielding Material

Conductivity

K = 14.8 (Btu/hr-ft-°F) Reference 2

Heat Capacity per Unit Volume

C = 38. (Btu/ft^3-°F) Reference 2

Emissivity

ε = 0.5 Reference 2

Spent Fuel Blocks

Conductivity

K = 10.0 (Btu/hr-ft-°F) Reference 2

Heat Capacity per Unit Volume

C = 32. (Btu/ft^3-hr) Reference 2

Emissivity

ε = 0.8 Reference 2

Alloy Steel (4340)

Conductivity

K = 20.0 (Btu/hr-ft-°F) Reference 12

Heat Capacity per Unit Volume

C = 60. (Btu/ft^3-hr) Reference 12

Emissivity

ε = 0.1 Reference 7

References

1) U.S. Nuclear Regulatory Commission: Packaging of Radioactive Material for Transport and Transportation of Radioactive Material Under Certain Conditions; 10CFR, Part 71, Appendices A and B, April 30, 1975.

2) Davis, C. R. et al: Final Design Report for Fort St. Vrain Fuel Shipping Cask With "As-Built" Information; General Atomic Report GADR-55, including Supplements A, B and C.

3) Boonstra, R. H.: TAC2D a General Purpose Two-Dimensional Heat Transfer Computer Code - User's Manual; General Atomic Report GA-A14032, July 15, 1976.

4) Morcos, S. M., Williams, K. A.: The TAC2D Code, Version TFMABC-75-1, Part C: Code Verification and Benchmark Problems; General Atomic Report GA-A13415, June 1975.

5) Freudiger, F. S., McKelvey, T. E.: Cask Thermal Analysis Computer Runs; GAC Calculation File No. DEC 15001, 1978.

6) Anonym.: O-Ring Handbook; Parker Seal Company - Lexington KY 40509, January 1977 Edition (Page A3-36).

7) McAdams, W. H.: Heat Transmission; McGraw-Hill Book Company, Inc., 1954.

8) Shappert, L. B. et al.: A Guide for the Design, Fabrication, and Operation of Shipping Casks for Nuclear Applications; Oak Ridge National Laboratory, Oak Ridge, Tenn., February 1970.

9) Goodman, J., Jovanovic, V., Ganley, J. T., Covert, R. E.: The Thermodynamic and Transport Properties of Helium, General Atomic Report GA-A13400, October 1975.

10) Kreith, F.: Principles of Heat Transfer; International Textbook Company, Section 1958.

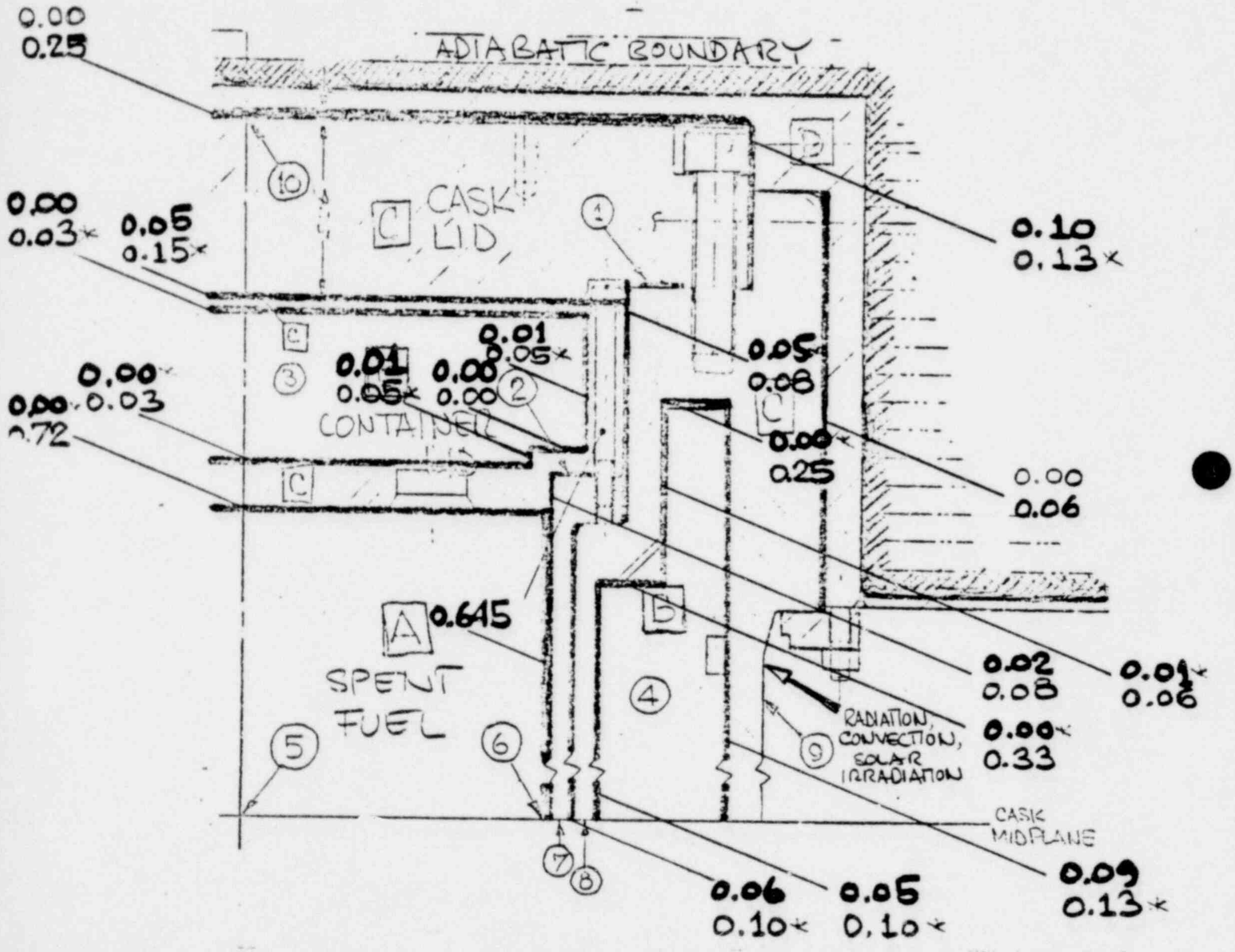
11) Perry, R. H. (ed.): Chemical Engineer's Handbook, 4th Edition, McGraw-Hill Book Company, Inc., New York, 1963.

12) ASME Code: Section III, Appendix I.

13) Brown, W. F., Jr., in Aerospace Structural Metals Handbook, Volume III, Department of Defense, Washington, DC, 1972.

Figure VIII-1

Gap Configuration



ASTERISKS POINT OUT THE
"MIXED GAPS" CONFIGURATION.

(DIMENSIONS IN INCHES: ROUNDED
TO NEAREST 1/100, DOWN FOR
MINIMA, UP FOR MAXIMA)

POOR ORIGINAL

Figure VIII-2

Shipping Cask Model

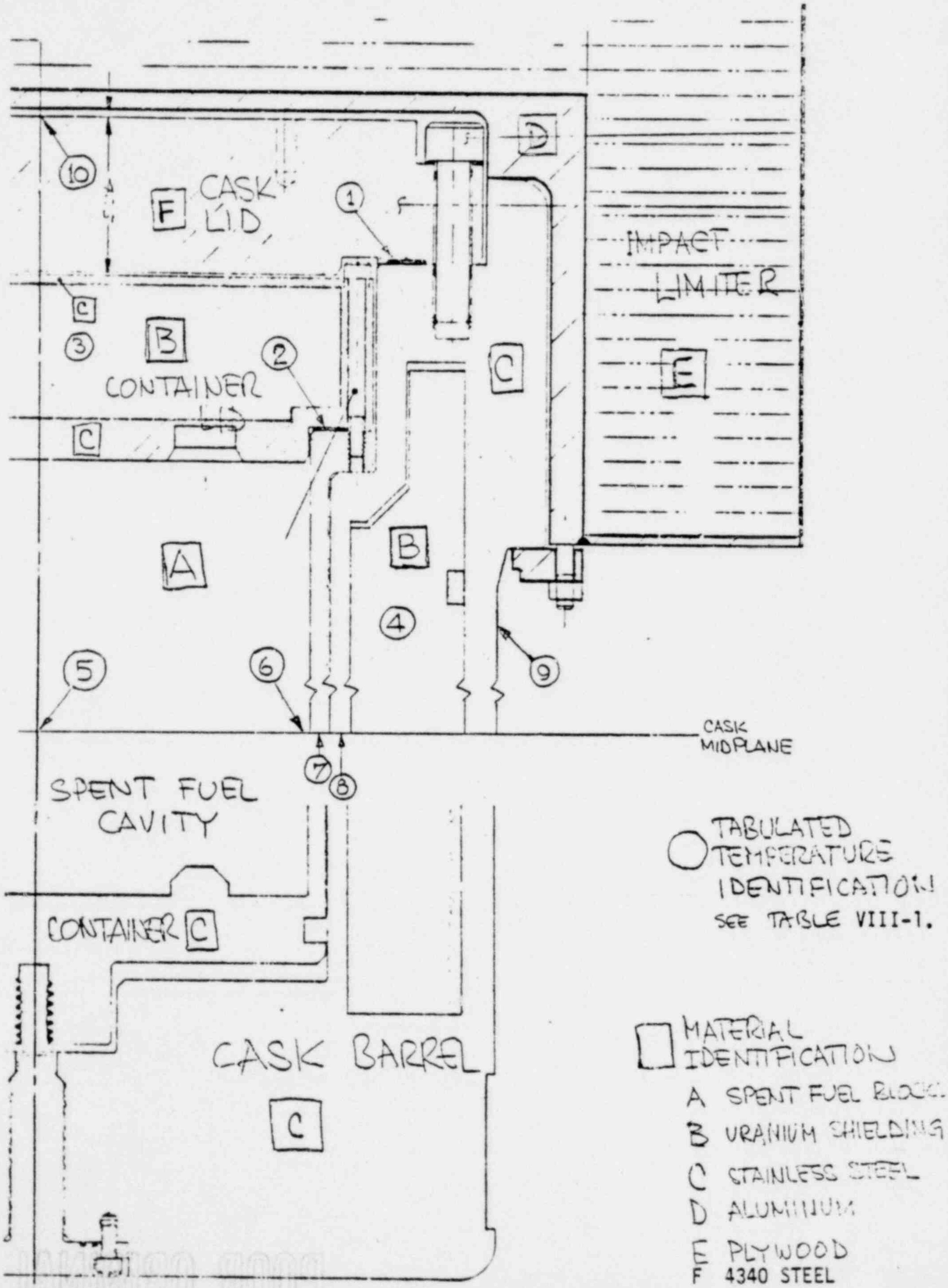
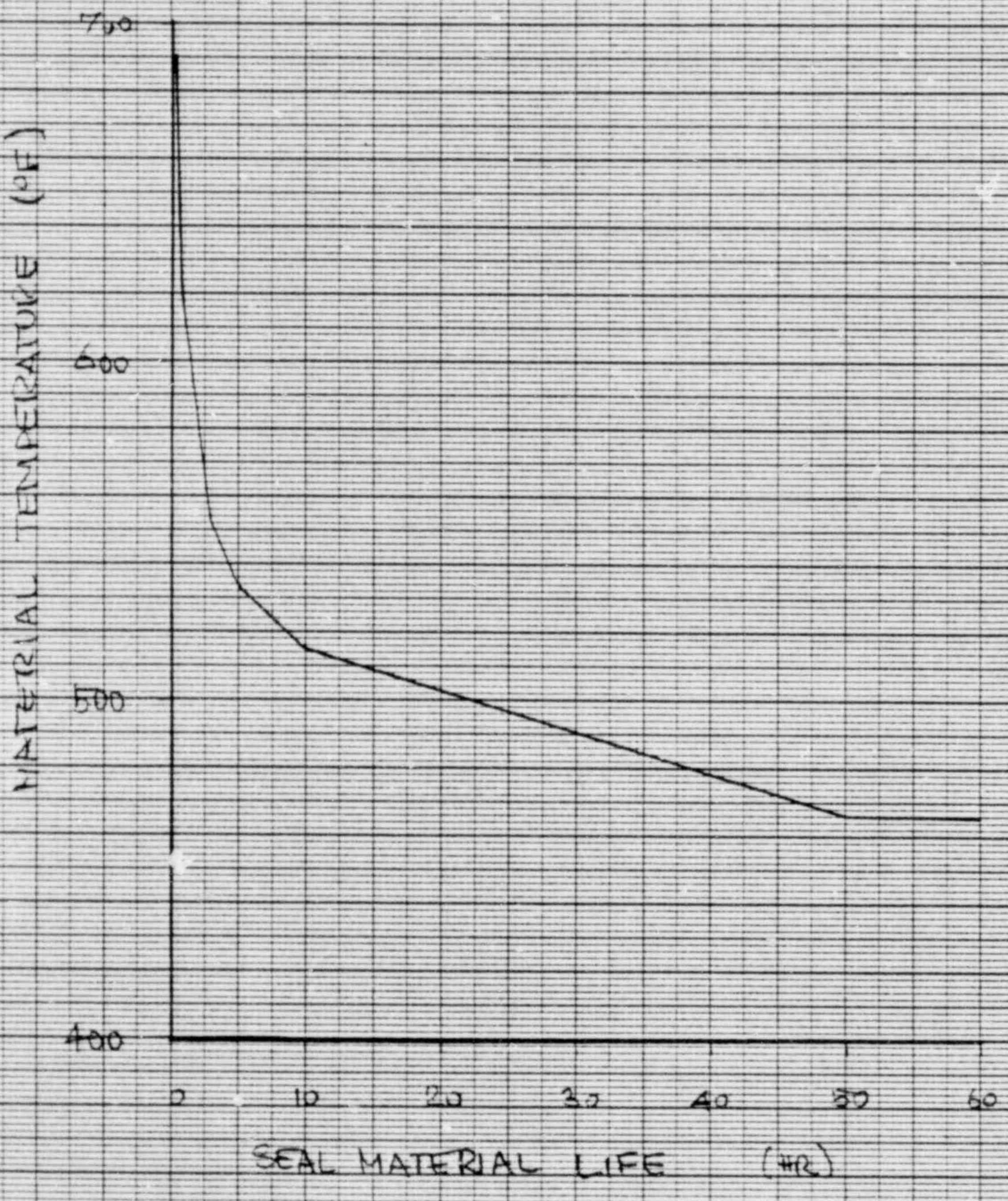


Figure VIII-3

Seal Material Temperature Limitations

(Reference 6)



POOR ORIGINAL

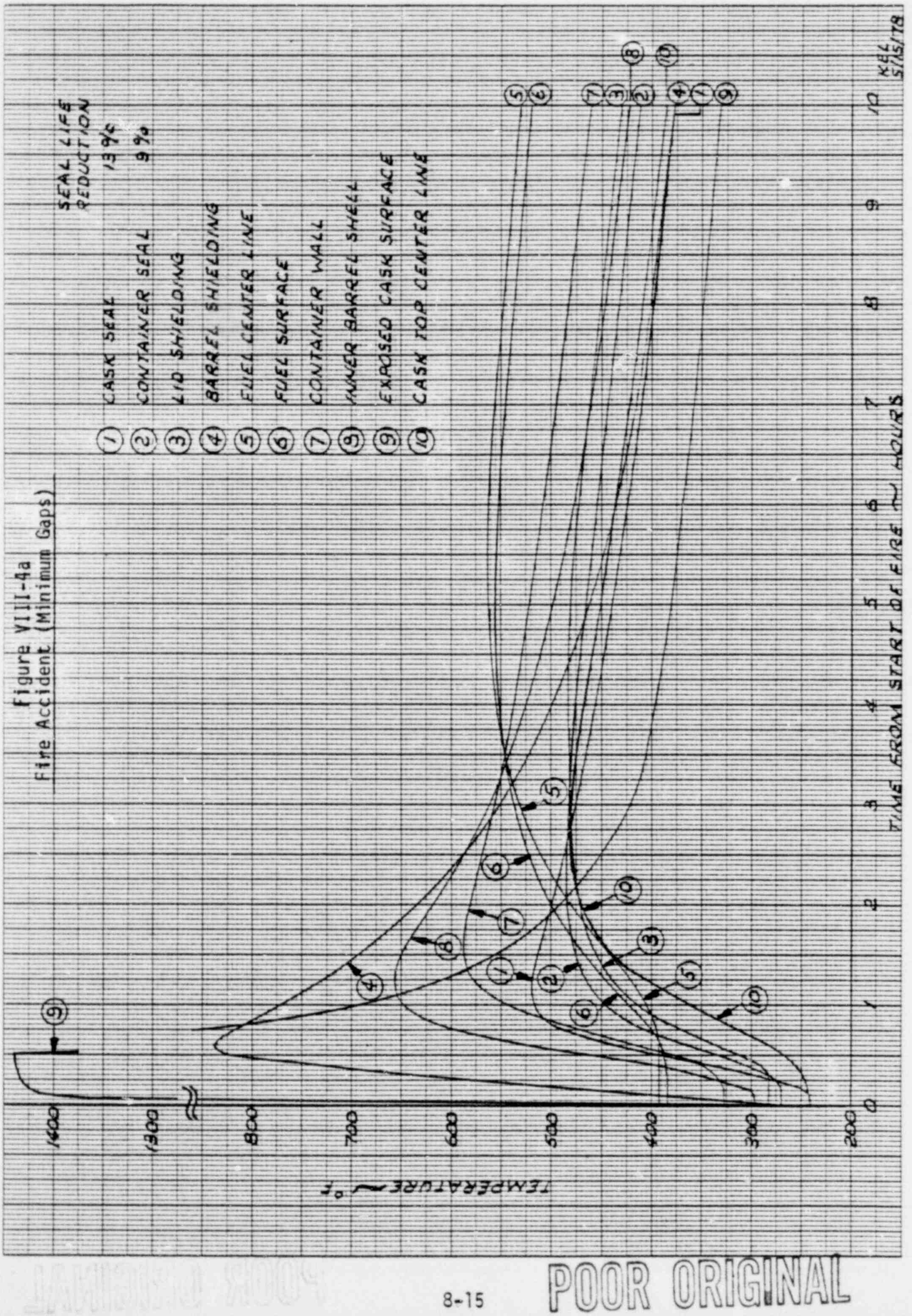


Figure VIII-4a
Fire Accident (Minimum Gaps)

POOR ORIGINAL

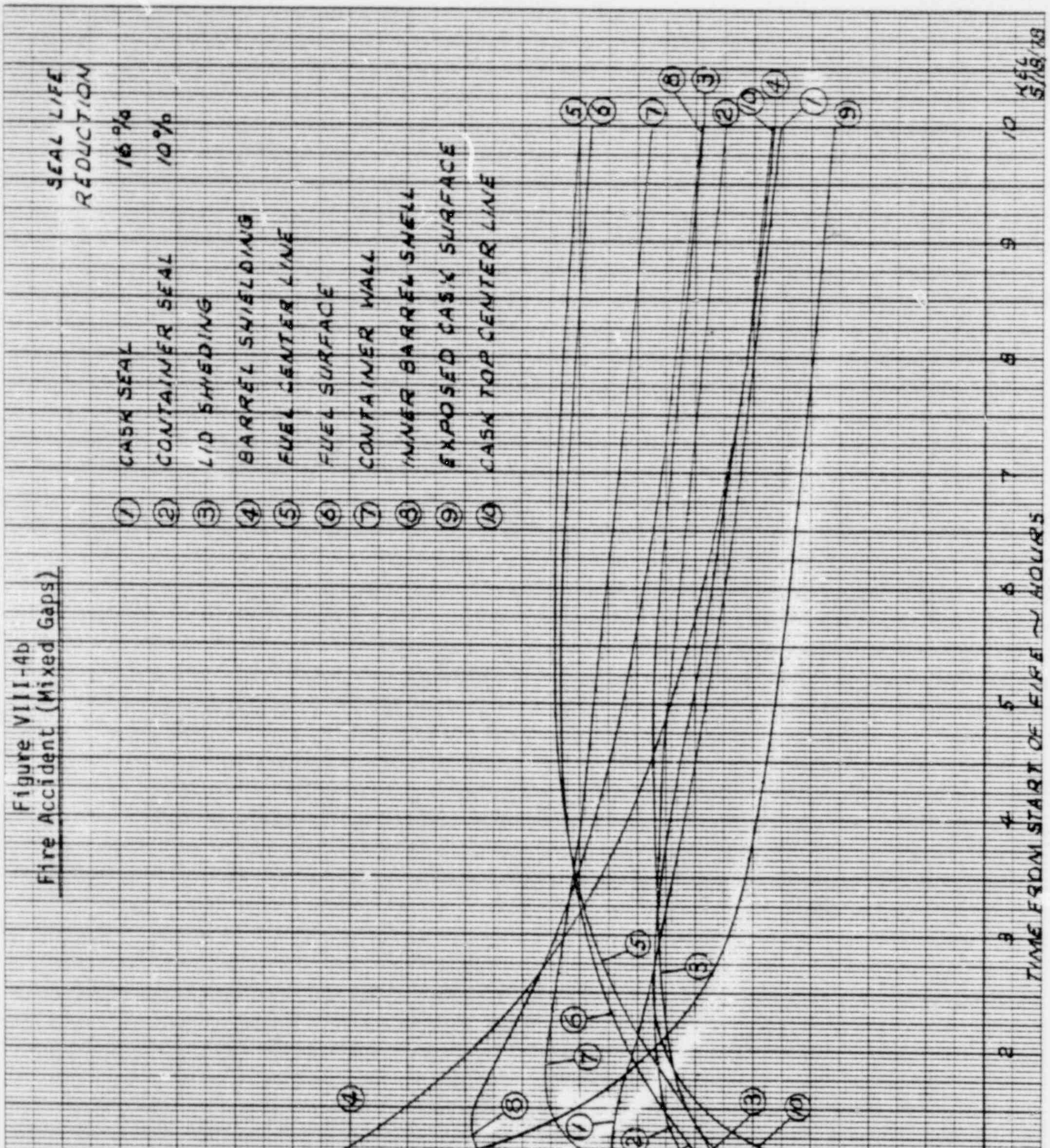


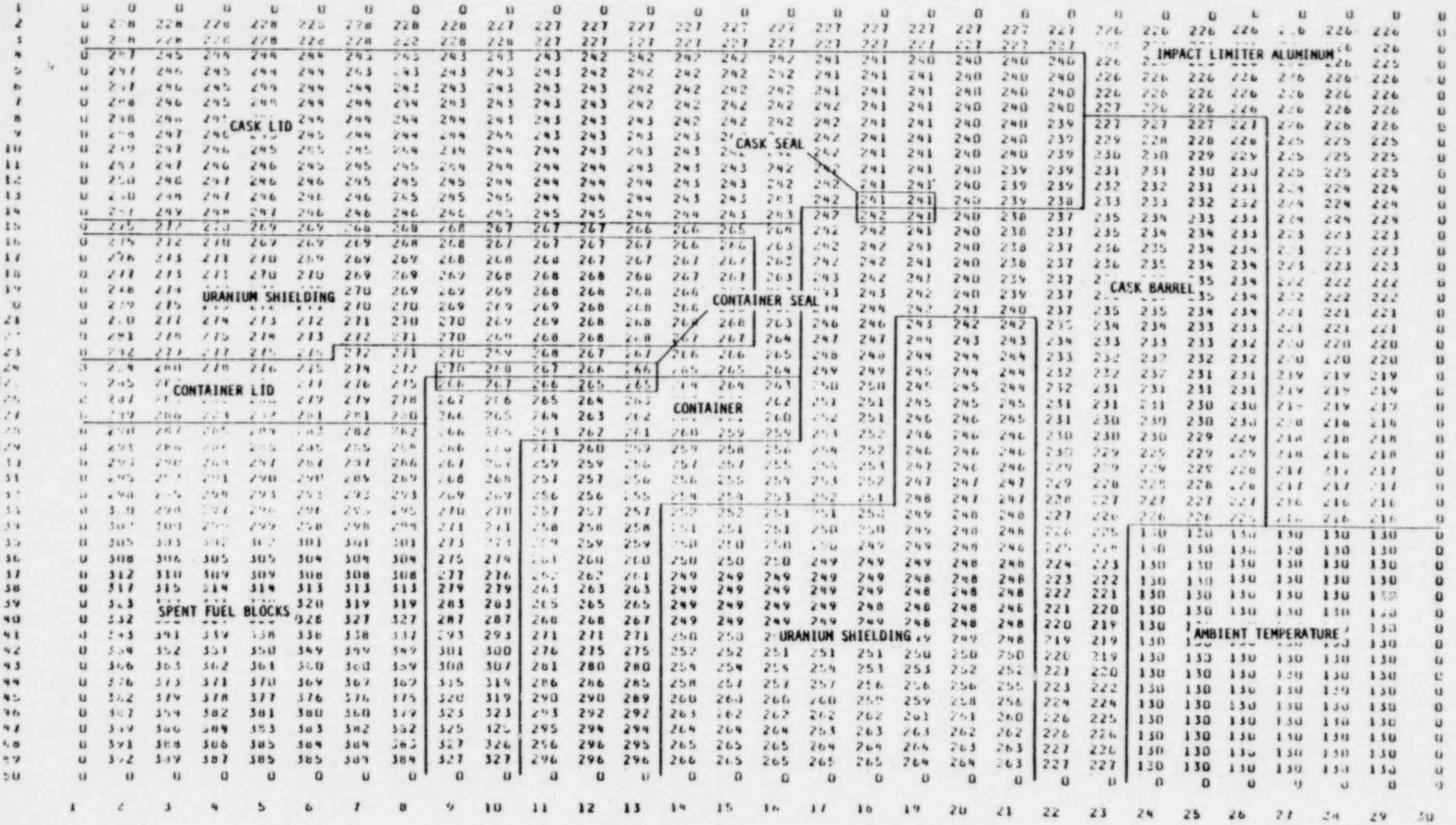
Figure VIII-4b
Fire Accident (Mixed Gaps)

Figu[illegible] II-5

Fuel Shipping Cask Temperature Map for Steady State Condition 1A (Maximum Temperature Day) - Minimum Gap Configuration, 100 Day Fuel

TEMPERATURES (F)

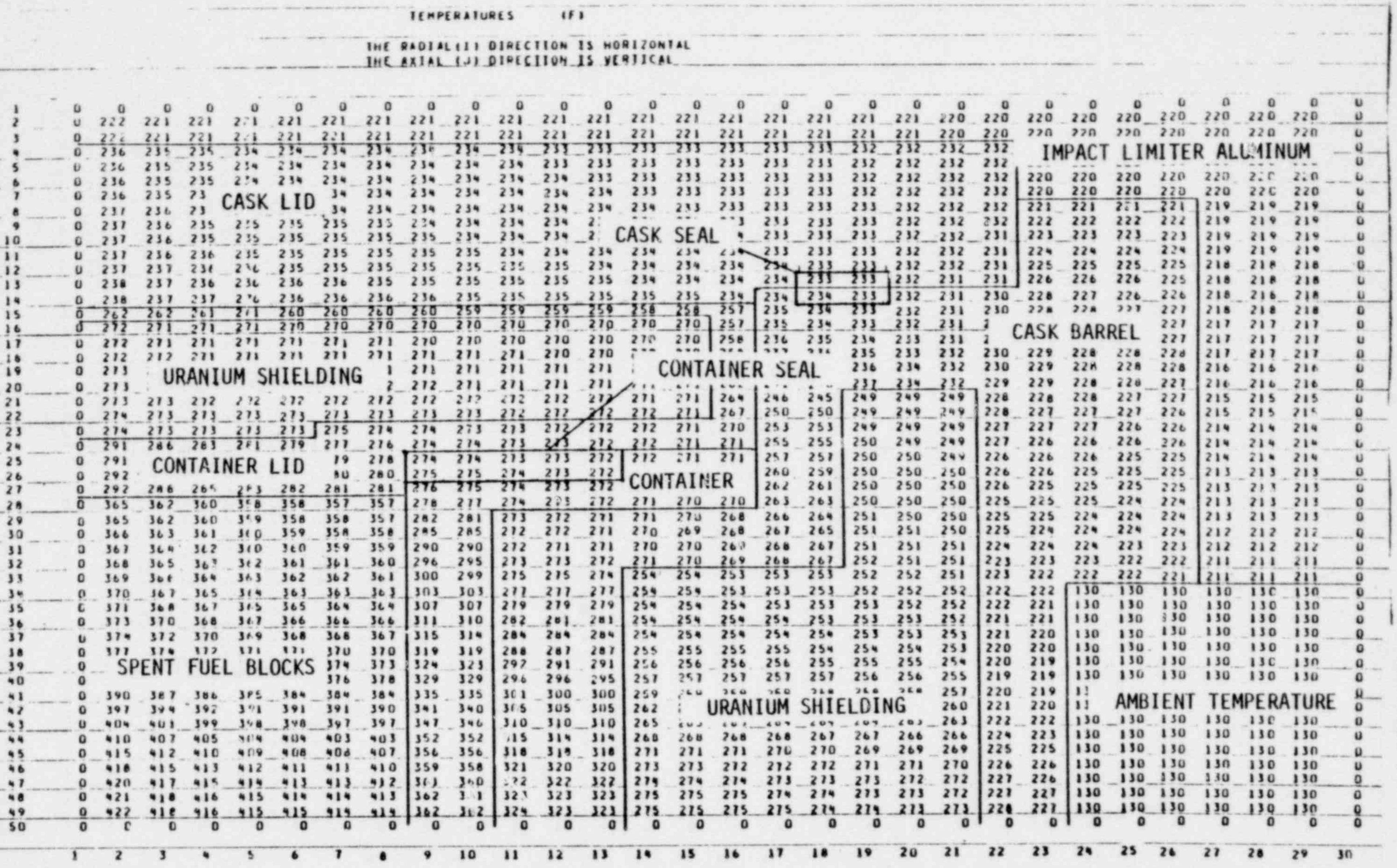
THE RADIAL(I) DIRECTION IS HORIZONTAL
THE AXIAL (J) DIRECTION IS VERTICAL



1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	228	228	228	228	228	228	228	228	227	227	227	227	227	227	227	227	227	227	227	227	227	226	226	226	226	226	226	226	0
3	0	228	228	228	228	228	228	228	228	228	227	227	227	227	227	227	227	227	227	227	227	227	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	226	226	0
4	0	247	245	244	244	244	243	243	243	243	243	242	242	242	242	242	241	241	240	240	240	240	226	[illegible]	[illegible]	[illegible]	[illegible]	226	225	0
5	0	247	246	245	244	244	243	243	243	243	243	242	242	242	242	242	241	241	241	240	240	240	226	226	226	226	226	226	226	0
6	0	247	246	245	244	244	244	243	243	243	243	243	242	242	242	242	241	241	241	240	240	240	226	226	226	226	226	226	226	0
7	0	248	246	245	244	244	244	244	243	243	243	243	242	242	242	242	242	241	241	240	240	240	227	226	226	226	226	226	226	0
8	0	248	246	[illegible]	[illegible]	244	244	244	244	243	243	243	243	242	242	242	242	241	241	240	240	239	227	227	227	227	226	226	226	0
9	0	249	247	246	[illegible]	245	244	244	244	244	243	243	243	243	[illegible]	[illegible]	242	241	241	240	240	239	229	228	228	228	225	225	225	0
10	0	249	247	246	245	245	245	244	244	244	244	243	243	243	[illegible]	[illegible]	242	241	241	240	240	239	230	230	229	229	225	225	225	0
11	0	[illegible]	247	246	246	245	245	245	244	244	244	244	243	243	243	242	242	241	241	240	239	239	231	231	230	230	225	225	225	0
12	0	250	248	247	246	246	245	245	245	244	244	244	244	243	243	242	242	241	241	240	239	239	232	232	231	231	224	224	224	0
13	0	250	249	247	246	246	246	245	245	245	244	244	244	243	243	243	242	241	241	240	239	238	233	233	232	232	224	224	224	0
14	0	251	249	248	247	246	246	246	246	245	245	245	244	244	243	243	242	242	241	240	238	237	235	234	233	233	224	224	224	0
15	0	275	272	270	269	269	268	268	268	267	267	267	266	266	265	264	242	242	241	240	238	237	235	234	234	233	223	223	223	0
16	0	275	272	270	269	269	269	268	268	267	267	267	267	266	266	263	242	242	241	240	238	237	236	235	234	234	223	223	223	0
17	0	276	273	271	270	269	269	269	268	268	268	267	267	267	267	262	242	242	241	240	238	237	236	235	234	234	223	223	223	0
18	0	277	275	271	270	270	269	269	269	268	268	268	268	267	267	263	243	242	241	240	239	237	[illegible]	[illegible]	235	234	222	222	222	0
19	0	278	274	[illegible]	[illegible]	[illegible]	270	269	269	269	268	268	268	266	[illegible]	[illegible]	243	243	242	240	239	237	[illegible]	[illegible]	235	234	222	222	222	0
20	0	279	275	[illegible]	[illegible]	[illegible]	270	270	269	269	269	268	268	266	[illegible]	[illegible]	244	244	242	241	240	237	235	235	234	234	221	221	221	0
21	0	280	277	274	273	272	271	270	270	269	269	268	268	[illegible]	268	263	246	246	243	242	242	235	234	234	233	233	221	221	221	0
22	0	281	278	275	274	273	272	271	270	269	268	268	268	267	267	264	247	247	244	243	243	234	233	233	233	232	220	220	220	0
23	0	282	[illegible]	277	275	275	272	271	270	269	268	267	267	266	266	265	248	248	244	244	244	233	232	232	232	232	220	220	220	0
24	0	284	280	278	276	275	274	272	270	268	267	266	266	265	265	264	249	249	245	244	244	232	232	232	231	231	219	219	219	0
25	0	285	[illegible]	[illegible]	[illegible]	277	276	275	266	267	266	265	265	264	264	263	250	250	245	245	244	232	231	231	231	231	219	219	219	0
26	0	287	[illegible]	[illegible]	[illegible]	279	279	278	267	266	265	264	263	[illegible]	[illegible]	262	251	251	245	245	245	231	231	231	230	230	219	219	219	0
27	0	289	286	283	[illegible]	281	281	280	266	265	264	263	262	[illegible]	[illegible]	260	252	251	246	246	245	231	230	230	230	230	218	218	218	0
28	0	290	287	[illegible]	284	283	282	282	266	265	263	262	261	260	259	259	253	252	246	246	246	230	230	230	229	229	218	218	218	0
29	0	293	286	[illegible]	285	285	285	[illegible]	266	[illegible]	261	260	259	259	258	256	254	252	246	246	246	230	229	229	229	229	218	218	218	0
30	0	[illegible]	290	[illegible]	287	287	287	286	267	[illegible]	259	259	256	257	257	255	254	253	247	246	246	229	229	229	229	228	217	217	217	0
31	0	295	[illegible]	291	290	290	289	289	268	268	257	257	256	256	255	254	253	252	247	247	247	229	228	228	228	228	217	217	217	0
32	0	298	[illegible]	294	293	293	293	293	269	269	256	256	255	254	254	253	252	251	248	247	247	228	227	227	227	227	216	216	216	0
33	0	300	298	297	[illegible]	296	[illegible]	295	270	270	257	257	257	252	252	251	251	250	249	248	248	227	226	226	226	225	216	216	216	0
34	0	[illegible]	303	[illegible]	299	298	298	298	271	271	258	258	258	251	251	251	250	250	249	248	248	226	225	130	130	130	130	130	130	0
35	0	305	303	302	302	301	301	301	273	273	259	259	259	250	250	250	250	249	249	248	248	225	224	130	130	130	130	130	130	0
36	0	308	306	305	305	304	304	304	275	274	261	260	260	250	250	250	249	249	249	248	248	224	223	130	130	130	130	130	130	0
37	0	312	310	309	309	308	308	308	277	276	262	262	261	249	249	249	249	249	248	248	248	223	222	130	130	130	130	130	130	0
38	0	317	315	314	314	313	313	313	279	279	263	263	263	249	249	249	249	249	248	248	248	222	221	130	130	130	130	130	130	0
39	0	323	[illegible]	[illegible]	[illegible]	320	319	319	283	283	265	265	265	249	249	249	249	248	248	248	248	221	220	130	130	130	130	130	130	0
40	0	332	[illegible]	[illegible]	[illegible]	328	327	327	287	287	268	268	267	249	249	249	249	249	248	248	248	220	219	130	[illegible]	[illegible]	[illegible]	[illegible]	130	0
41	0	343	341	339	338	338	338	337	293	293	271	271	271	250	250	[illegible]	[illegible]	[illegible]	249	249	248	219	219	130	[illegible]	[illegible]	[illegible]	[illegible]	130	0
42	0	354	352	351	350	349	349	349	301	300	276	275	275	252	252	251	251	251	250	250	250	220	219	130	130	130	130	130	130	0
43	0	366	363	362	361	360	360	359	308	307	281	280	280	254	254	254	254	253	253	252	252	221	220	130	130	130	130	130	130	0
44	0	376	373	371	370	369	367	367	315	314	286	286	285	258	257	257	257	256	256	256	255	223	222	130	130	130	130	130	130	0
45	0	382	379	378	377	376	376	375	320	319	290	290	289	260	260	260	260	259	259	258	256	224	224	130	130	130	130	130	130	0
46	0	387	384	382	381	380	380	379	323	323	293	292	292	263	262	262	262	262	261	261	260	226	225	130	130	130	130	130	130	0
47	0	389	386	384	383	383	382	382	325	325	295	294	294	264	264	264	263	263	263	262	262	226	226	130	130	130	130	130	130	0
48	0	391	388	386	385	384	384	383	327	326	296	296	295	265	265	265	264	264	264	263	263	227	226	130	130	130	130	130	130	0
49	0	392	389	387	385	385	384	384	327	327	296	296	296	266	265	265	265	265	264	264	263	227	227	130	130	130	130	130	130	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

Figure III-6

Fuel Shipping Cask Temperature Map for Steady State Condition 1A (Maximum Temperature Day) - Maximum Gap Configuration, 100 Day Fuel



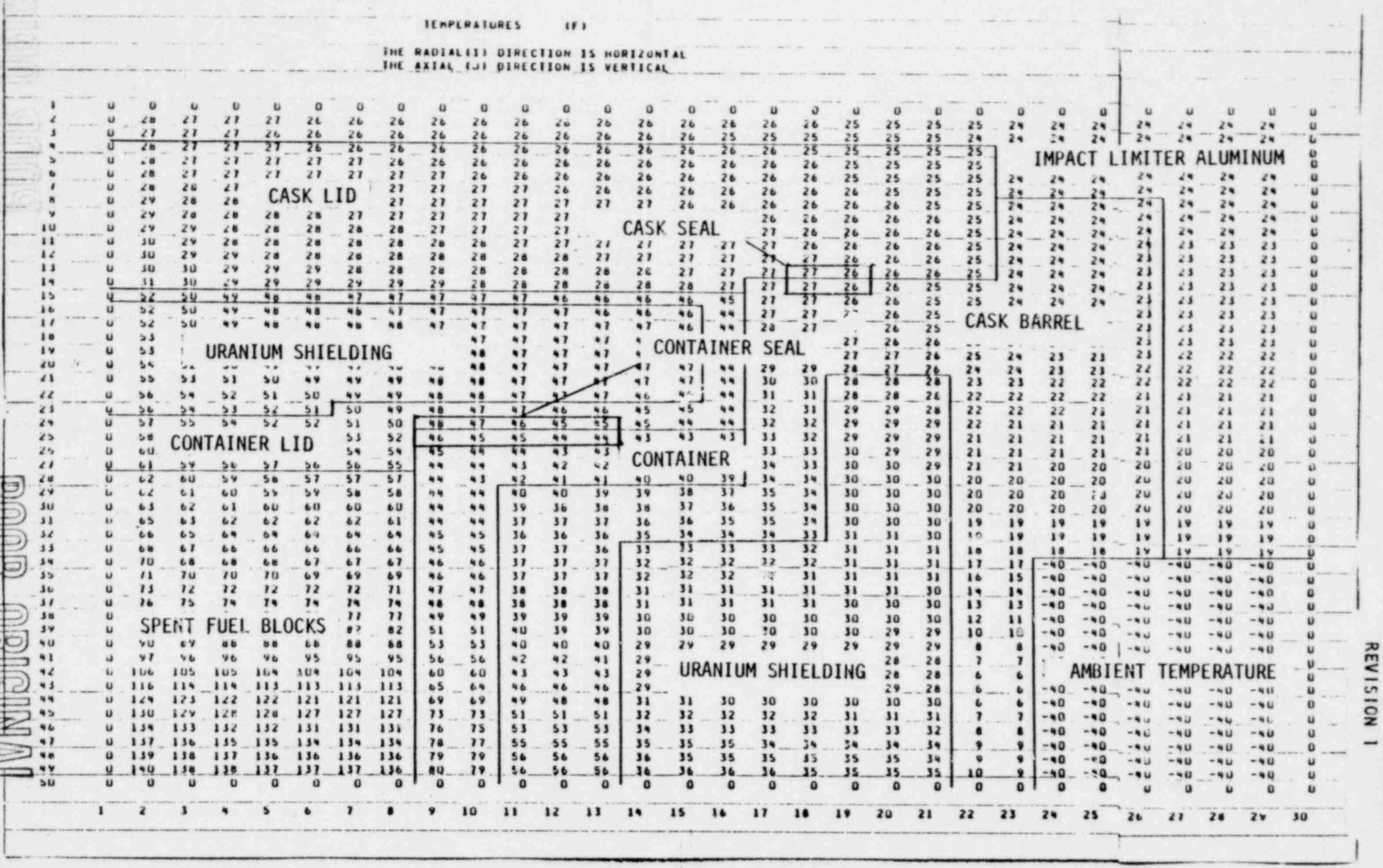
TEMPERATURES (F)

THE RADIAL(I) DIRECTION IS HORIZONTAL
THE AXIAL (J) DIRECTION IS VERTICAL

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	222	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	220	220	220	220	220	220	220	220	220	0
3	0	222	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	221	220	220	220	220	220	220	220	220	220	0
4	0	236	235	235	234	234	234	234	234	234	234	233	233	233	233	233	233	233	232	232	232	232	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
5	0	236	235	235	234	234	234	234	234	234	234	233	233	233	233	233	233	233	232	232	232	232	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
6	0	236	235	235	234	234	234	234	234	234	234	234	233	233	233	233	233	233	232	232	232	232	220	220	220	220	220	220	220	0
7	0	236	235	[illegible]	[illegible]	[illegible]	[illegible]	234	234	234	234	234	234	233	233	233	233	233	232	232	232	232	220	220	220	220	220	220	220	0
8	0	237	236	[illegible]	[illegible]	[illegible]	[illegible]	234	234	234	234	234	234	234	233	233	233	233	233	232	232	232	221	221	221	221	219	219	219	0
9	0	237	236	235	235	235	235	235	234	234	234	234	[illegible]	[illegible]	[illegible]	[illegible]	233	233	233	232	232	232	222	222	222	222	219	219	219	0
10	0	237	236	235	235	235	235	235	235	234	234	234	[illegible]	[illegible]	[illegible]	[illegible]	233	233	233	232	232	231	223	223	223	223	219	219	219	0
11	0	237	236	236	235	235	235	235	235	235	234	234	234	234	234	234	233	233	233	232	232	231	224	224	224	224	219	219	219	0
12	0	237	237	236	236	235	235	235	235	235	235	235	234	234	234	234	234	233	233	232	232	231	225	225	225	225	218	218	218	0
13	0	238	237	236	236	236	236	235	235	235	235	235	235	234	234	234	234	233	233	232	231	231	226	226	226	225	218	218	218	0
14	0	238	237	237	236	236	236	236	236	235	235	235	235	235	235	234	234	234	233	232	231	230	228	227	226	226	218	216	218	0
15	0	262	262	261	261	260	260	260	260	259	259	259	259	258	258	257	235	234	233	232	231	230	228	228	227	227	218	218	218	0
16	0	272	271	271	271	270	270	270	270	270	270	270	270	270	270	257	235	234	233	232	231	[illegible]	[illegible]	[illegible]	[illegible]	227	217	217	217	0
17	0	272	271	271	271	271	271	271	270	270	270	270	270	270	270	258	236	235	234	233	231	[illegible]	[illegible]	[illegible]	[illegible]	227	217	217	217	0
18	0	272	272	271	271	271	271	271	271	271	271	270	270	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	235	233	232	230	229	228	228	228	217	217	217	0
19	0	273	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	271	271	271	271	271	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	236	234	232	230	229	228	228	228	216	216	216	0
20	0	273	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	272	271	271	271	271	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	237	234	232	229	229	228	228	227	216	216	216	0
21	0	273	273	272	272	272	272	272	272	272	272	272	272	271	271	264	246	245	249	249	249	228	228	228	227	227	215	215	215	0
22	0	274	273	273	273	273	273	273	273	273	272	272	272	272	271	267	250	250	249	249	249	228	227	227	227	226	215	215	215	0
23	0	274	273	273	273	273	275	274	274	273	273	272	272	272	271	270	253	253	249	249	249	227	227	227	226	226	214	214	214	0
24	0	291	286	283	281	279	277	276	274	274	273	273	272	272	271	271	255	255	250	249	249	227	226	226	226	226	214	214	214	0
25	0	291	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	278	274	274	273	273	272	272	271	271	257	257	250	250	249	226	226	226	225	225	214	214	214	0
26	0	292	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	280	275	275	274	273	272	[illegible]	[illegible]	[illegible]	260	259	250	250	250	226	226	225	225	225	213	213	213	0
27	0	292	286	285	283	282	281	281	276	275	274	273	272	[illegible]	[illegible]	[illegible]	262	261	250	250	250	226	225	225	225	225	213	213	213	0
28	0	365	362	360	358	358	357	357	278	277	274	273	272	271	270	270	263	263	250	250	250	225	225	225	224	224	213	213	213	0
29	0	365	362	360	359	358	358	357	282	281	273	272	271	271	270	268	266	264	251	250	250	225	225	224	224	224	213	213	213	0
30	0	366	363	361	360	359	358	358	285	285	272	272	271	270	269	268	267	265	251	251	250	225	224	224	224	224	212	212	212	0
31	0	367	364	362	360	360	359	359	290	290	272	271	271	270	270	269	268	267	251	251	251	224	224	224	223	223	212	212	212	0
32	0	368	365	363	362	361	361	360	296	295	273	273	272	271	270	269	268	267	252	251	251	223	223	223	222	222	211	211	211	0
33	0	369	366	364	363	362	362	361	300	299	275	275	274	254	254	253	253	253	252	252	251	223	222	222	222	221	211	211	211	0
34	0	370	367	365	364	363	363	363	303	303	277	277	277	254	254	253	253	253	252	252	252	222	222	130	130	130	130	130	130	0
35	0	371	368	367	365	365	364	364	307	307	279	279	279	254	254	254	253	253	253	252	252	222	221	130	130	130	130	130	130	0
36	0	373	370	368	367	366	366	366	311	310	282	281	281	254	254	254	254	253	253	253	252	221	221	130	130	130	130	130	130	0
37	0	374	372	370	369	368	368	367	315	314	284	284	284	254	254	254	254	254	253	253	253	221	220	130	130	130	130	130	130	0
38	0	377	374	372	371	371	370	370	319	319	288	287	287	255	255	255	255	254	254	254	253	220	220	130	130	130	130	130	130	0
39	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	374	373	324	323	297	291	291	256	256	256	256	255	255	255	254	220	219	130	130	130	130	130	130	0
40	0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	376	378	329	329	296	296	295	257	257	257	257	257	256	256	255	219	219	130	130	130	130	130	130	0
41	0	390	387	386	385	384	384	384	335	335	301	300	300	259	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	257	220	219	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
42	0	397	394	392	391	391	391	390	341	340	305	305	305	262	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	260	221	220	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0
43	0	404	401	399	398	398	397	397	347	346	310	310	310	265	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	263	222	222	130	130	130	130	130	130	0
44	0	410	407	405	404	404	403	403	352	352	315	314	314	268	268	268	268	267	267	266	266	224	223	130	130	130	130	130	130	0
45	0	415	412	410	409	408	408	407	356	356	318	318	318	271	271	271	270	270	269	269	269	225	225	130	130	130	130	130	130	0
46	0	418	415	413	412	411	411	410	359	358	321	320	320	273	273	272	272	272	271	271	270	226	226	130	130	130	130	130	130	0
47	0	420	417	415	414	413	413	412	363	360	322	322	322	274	274	274	273	273	273	272	272	227	226	130	130	130	130	130	130	0
48	0	421	418	416	415	414	414	413	362	361	323	323	323	275	275	275	274	274	273	273	272	227	227	130	130	130	130	130	130	0
49	0	422	418	416	415	415	415	415	362	362	324	323	323	275	275	275	275	274	274	273	273	228	227	130	130	130	130	130	130	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figu III-7

Fuel Shipping Cask Temperature Map for Steady State Condition 2 (Minimum Temperature Day) - Minimum Gap Configuration, 200 Day Fuel



```
                                   TEMPERATURES      (F)

                              THE RADIAL(I) DIRECTION IS HORIZONTAL
                              THE AXIAL (J) DIRECTION IS VERTICAL

  1    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0
  2    0   28   27   27   27   26   26   26   26   26   26   26   26   26   26   26   26   26   25   25   25   25   24   24   24   24   24   24   24    0
  3    0   27   27   27   26   26   26   26   26   26   26   26   26   26   26   25   25   25   25   25   25   24   24   24   24   24   24   24   24    0
  4    0   26   27   27   27   26   26   26   26   26   26   26   26   26   26   26   26   25   25   25   25   25                                        0
  5    0   28   27   27   27   27   27   26   26   26   26   26   26   26   26   26   26   26   25   25   25   25                                        0
  6    0   28   27   27   27   27   27   27   27   26   26   26   26   26   26   26   26   26   25   25   25   25   24   24   24   24   24   24   24    0
  7    0   28   26   27                  27   27   27   27   26   26   26   26   26   26   26   26   25   25   25   24   24   24   24   24   24   24    0
  8    0   29   28   28                  27   27   27   27   27   27   27   26   26   26   26   26   26   25   25   24   24   24   24   24   24   24    0
  9    0   29   28   28   28   28   27   27   27   27   27   27                       26   26   26   26   26   25   24   24   24   24   24   24   24    0
 10    0   29   29   28   28   28   28   28   27   27   27   27                       27   26   26   26   26   25   24   24   24   24   24   24   24    0
 11    0   30   29   28   28   28   28   28   26   26   27   27   27   27   27   27   27   26   26   26   26   25   24   24   24   24   23   23   23    0
 12    0   30   29   29   28   28   28   28   28   28   28   28   27   27   27   27   27   27   26   26   26   25   24   24   24   23   23   23   23    0
 13    0   30   30   29   29   29   28   28   28   28   28   28   28   28   27   27   27   27   26   26   26   25   24   24   24   23   23   23   23    0
 14    0   31   30   29   29   29   29   29   29   28   28   28   28   28   28   27   27   27   26   26   25   25   24   24   24   23   23   23   23    0
 15    0   52   50   49   48   48   47   47   47   47   47   46   46   46   46   45   27   27   26   26   25   25   24   24   24   23   23   23   23    0
 16    0   52   50   49   48   48   46   47   47   47   47   47   46   46   46   44   27   27 [illegible] 26   25                     23   23   23   23    0
 17    0   52   50   49   48   48   46   48   47   47   47   47   47   47   46   44   28   27        26   25                     23   23   23   23    0
 18    0   53                                     47   47   47   47    4                       27   26   26                     23   23   23   23    0
 19    0   53                                     48   47   47   47    4                       27   27   26   25   24   23   23   23   22   22   22    0
 20    0   54 [illegible] [illegible] [illegible] [illegible] [illegible] [illegible] [illegible]   48   47   47   47   47   47   44   29   29   28   27   26   24   24   23   23   22   22   22   22    0
 21    0   55   53   51   50   49   49   49   48   48   47   47   47   47   47   44   30   30   28   28   28   23   23   22   22   22   22   22   22    0
 22    0   56   54   52   51   50   49   49   48   48   47   47   47   46 [illegible] 44   31   31   28   28   26   22   22   22   22   21   21   21   21    0
 23    0   56   54   53   52   51   50   49   48   47   47   46   46   45   45   44   32   31   29   29   28   22   22   22   21   21   21   21   21    0
 24    0   57   55   54   52   52   51   50   48   47   46   45   45   45   44   44   32   32   29   29   29   22   21   21   21   21   21   21   21    0
 25    0   58                       53   52   46   45   45   44   44   43   43   43   33   32   29   29   29   21   21   21   21   21   21   21   21    0
 26    0   60                       54   54   45   44   44   43   43                  33   33   30   29   29   21   21   21   21   21   20   20   20    0
 27    0   61   59   56   57   56   56   55   44   44   43   42   42                  34   33   30   30   29   21   21   20   20   20   20   20   20    0
 28    0   62   60   59   56   57   57   57   44   43   42   41   41   40   40   39   34   34   30   30   30   20   20   20   20   20   20   20   20    0
 29    0   62   61   60   55   59   58   58   44   44   40   40   39   39   38   37   35   34   30   30   30   20   20   20   20   20   20   20   20    0
 30    0   63   62   61   60   60   60   60   44   44   39   36   38   38   37   36   35   34   30   30   30   20   20   20   20   20   20   20   20    0
 31    0   65   63   62   62   62   62   61   44   44   37   37   37   36   36   35   35   34   30   30   30   19   19   19   19   19   19   19   19    0
 32    0   66   65   64   64   64   64   64   45   45   36   36   36   35   34   34   34   33   31   31   30   19   19   19   19   19   19   19   19    0
 33    0   68   67   66   66   66   66   66   45   45   37   37   36   33   33   33   33   32   31   31   31   18   18   18   18   19   19   19   19    0
 34    0   70   68   68   68   67   67   67   46   46   37   37   37   32   32   32   32   32   31   31   31   17   17  -40  -40  -40  -40  -40  -40    0
 35    0   71   70   70   70   69   69   69   46   46   37   37   37   32   32   32 [illegible] 31   31   31   31   16   15  -40  -40  -40  -40  -40  -40    0
 36    0   73   72   72   72   72   72   71   47   47   38   38   38   31   31   31   31   31   31   31   30   14   14  -40  -40  -40  -40  -40  -40    0
 37    0   76   75   74   74   74   74   74   48   48   38   38   38   31   31   31   31   31   30   30   30   13   13  -40  -40  -40  -40  -40  -40    0
 38    0                            77   77   49   49   39   39   39   30   30   30   30   30   30   30   30   12   11  -40  -40  -40  -40  -40  -40    0
 39    0                            82   82   51   51   40   39   39   30   30   30   30   30   30   29   29   10   10  -40  -40  -40  -40  -40  -40    0
 40    0   90   89   88   88   88   88   88   53   53   40   40   40   29   29   29   29   29   29   29   29    8    8  -40  -40  -40  -40  -40  -40    0
 41    0   97   96   96   96   95   95   95   56   56   42   42   41   29                            28   28    7    7                                0
 42    0  106  105  105  104  104  104  104   60   60   43   43   43   29                            28   28    6    6                                0
 43    0  116  114  114  113  113  113  113   65   64   46   46   46   29                            29   28    6    6  -40  -40  -40  -40  -40  -40    0
 44    0  124  123  122  122  121  121  121   69   69   49   48   48   31   31   30   30   30   30   30   30    6    6  -40  -40  -40  -40  -40  -40    0
 45    0  130  129  128  128  127  127  127   73   73   51   51   51   32   32   32   32   32   31   31   31    7    7  -40  -40  -40  -40  -40  -40    0
 46    0  134  133  132  132  131  131  131   76   75   53   53   53   34   33   33   33   33   33   33   32    8    8  -40  -40  -40  -40  -40  -40    0
 47    0  137  136  135  135  134  134  134   78   77   55   55   55   35   35   35   34   34   34   34   34    9    9  -40  -40  -40  -40  -40  -40    0
 48    0  139  138  137  136  136  136  136   79   79   56   56   56   36   35   35   35   35   35   35   34    9    9  -40  -40  -40  -40  -40  -40    0
 49    0  140  138  138  137  137  137  136   80   79   56   56   56   36   36   36   36   35   35   35   35   10    9  -40  -40  -40  -40  -40  -40    0
 50    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0    0

       1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20   21   22   23   24   25   26   27   28   29   30
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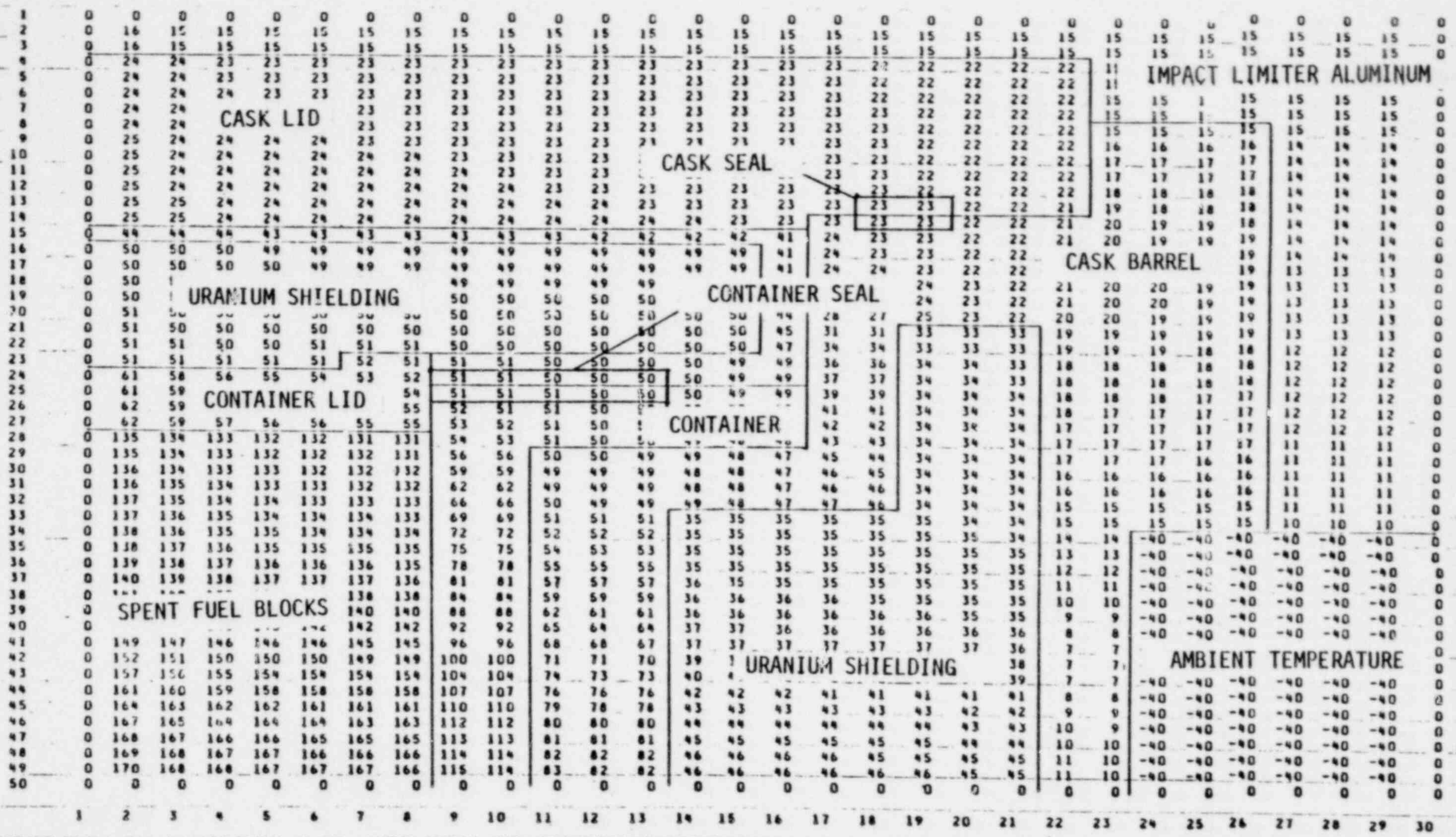
Figure III-8

Fuel Shipping Cask Temperature Map for Steady State Condition 2 (Minimum Temperature Day) - Maximum Gap Configuration, 200 Day Fuel



TEMPERATURES (F)

THE RADIAL(I) DIRECTION IS HORIZONTAL
THE AXIAL (J) DIRECTION IS VERTICAL

1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	0
3	0	16	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	0
4	0	24	24	23	23	23	23	23	23	23	23	23	23	23	23	23	23	22	22	22	22	22	11							
5	0	24	24	23	23	23	23	23	23	23	23	23	23	23	23	23	23	22	22	22	22	22	11							
6	0	24	24	24	23	23	23	23	23	23	23	23	23	23	23	23	23	22	22	22	22	22	15	15	1	15	15	15	15	0
7	0	24	24				23	23	23	23	23	23	23	23	23	23	23	23	22	22	22	22	15	15	1	15	15	15	15	0
8	0	24	24				23	23	23	23	23	23	23	23	23	23	23	23	22	22	22	22	15	15	15	15	15	16	15	0
9	0	25	24	24	24	24	23	23	23	23	23	23	23	23	23	23	23	23	22	22	22	22	16	16	16	16	14	14	14	0
10	0	25	24	24	24	24	24	24	23	23	23	23					23	23	22	22	22	22	17	17	17	17	14	14	14	0
11	0	25	24	24	24	24	24	24	24	23	23	23					23	23	22	22	22	22	17	17	17	17	14	14	14	0
12	0	25	24	24	24	24	24	24	24	24	23	23	23	23	23	23	23	23	22	22	22	22	18	18	18	18	14	14	14	0
13	0	25	25	24	24	24	24	24	24	24	24	24	23	23	23	23	23	23	23	22	22	21	19	18	18	18	14	14	14	0
14	0	25	25	24	24	24	24	24	24	24	24	24	24	24	23	23	23	23	23	22	22	21	20	19	19	18	14	14	14	0
15	0	44	44	44	43	43	43	43	43	43	43	42	42	42	42	41	24	23	23	22	22	21	20	19	19	19	14	14	14	0
16	0	50	50	50	49	49	49	49	49	49	49	49	49	49	49	41	24	23	23	22	22					19	14	14	14	0
17	0	50	50	50	50	49	49	49	49	49	49	49	49	49	49	41	24	24	23	22	22					19	13	13	13	0
18	0	50							49	49	49	49	49						24	23	22	21	20	20	19	19	13	13	13	0
19	0	50							50	50	50	50	50						24	23	22	21	20	20	19	19	13	13	13	0
20	0	51	50	50	50	50	50	50	50	50	50	50	50	50	50	44	28	27	25	23	22	20	20	19	19	19	13	13	13	0
21	0	51	50	50	50	50	50	50	50	50	50	50	50	50	50	45	31	31	33	33	33	19	19	19	19	19	13	13	13	0
22	0	51	51	50	50	51	51	51	50	50	50	50	50	50	50	47	34	34	33	33	33	19	19	19	18	18	12	12	12	0
23	0	51	51	51	51	51	52	51	51	51	50	50	50	50	49	49	36	36	34	34	33	18	18	18	18	18	12	12	12	0
24	0	61	58	56	55	54	53	52	51	51	50	50	50	50	49	49	37	37	34	34	33	18	18	18	18	18	12	12	12	0
25	0	61	59					54	51	51	51	50	50	50	49	49	39	39	34	34	34	18	18	18	17	17	12	12	12	0
26	0	62	59					55	52	51	51	50					41	41	34	34	34	18	17	17	17	17	12	12	12	0
27	0	62	59	57	56	56	55	55	53	52	51	50					42	42	34	34	34	17	17	17	17	17	12	12	12	0
28	0	135	134	133	132	132	131	131	54	53	51	50	50	[illegible]	[illegible]	[illegible]	43	43	34	34	34	17	17	17	17	17	11	11	11	0
29	0	135	134	133	132	132	132	131	56	56	50	50	49	49	48	47	45	44	34	34	34	17	17	17	16	16	11	11	11	0
30	0	136	134	133	133	132	132	132	59	59	49	49	49	48	48	47	46	45	34	34	34	16	16	16	16	16	11	11	11	0
31	0	136	135	134	133	133	132	132	62	62	49	49	49	48	48	47	46	46	34	34	34	16	16	16	16	16	11	11	11	0
32	0	137	135	134	134	133	133	133	66	66	50	49	49	49	48	47	47	46	34	34	34	15	15	15	15	15	11	11	11	0
33	0	137	136	135	134	134	134	133	69	69	51	51	51	35	35	35	35	35	35	34	34	15	15	15	15	15	10	10	10	0
34	0	138	136	135	135	134	134	134	72	72	52	52	52	35	35	35	35	35	35	35	34	14	14	-40	-40	-40	-40	-40	-40	0
35	0	138	137	136	135	135	135	135	75	75	54	53	53	35	35	35	35	35	35	35	35	13	13	-40	-40	-40	-40	-40	-40	0
36	0	139	138	137	136	136	136	135	78	78	55	55	55	35	35	35	35	35	35	35	35	12	12	-40	-40	-40	-40	-40	-40	0
37	0	140	139	138	137	137	137	136	81	81	57	57	57	36	35	35	35	35	35	35	35	11	11	-40	-40	-40	-40	-40	-40	0
38	0						138	138	84	84	59	59	59	36	36	36	36	35	35	35	35	10	10	-40	-40	-40	-40	-40	-40	0
39	0						140	140	88	88	62	61	61	36	36	36	36	36	36	35	35	9	9	-40	-40	-40	-40	-40	-40	0
40	0						142	142	92	92	65	64	64	37	37	36	36	36	36	36	36	8	8	-40	-40	-40	-40	-40	-40	0
41	0	149	147	146	146	146	145	145	96	96	68	68	67	37	37	37	37	37	37	37	36	7	7							0
42	0	152	151	150	150	150	149	149	100	100	71	71	70	39							38	7	7							0
43	0	157	156	155	154	154	154	154	104	104	74	73	73	40							39	7	7	-40	-40	-40	-40	-40	-40	0
44	0	161	160	159	158	158	158	158	107	107	76	76	76	42	42	42	41	41	41	41	41	8	8	-40	-40	-40	-40	-40	-40	0
45	0	164	163	162	162	161	161	161	110	110	79	78	78	43	43	43	43	43	43	42	42	9	9	-40	-40	-40	-40	-40	-40	0
46	0	167	165	164	164	164	163	163	112	112	80	80	80	44	44	44	44	44	44	43	43	10	9	-40	-40	-40	-40	-40	-40	0
47	0	168	167	166	166	165	165	165	113	113	81	81	81	45	45	45	45	45	45	44	44	10	10	-40	-40	-40	-40	-40	-40	0
48	0	169	168	167	167	166	166	166	114	114	82	82	82	46	46	46	46	45	45	45	45	11	10	-40	-40	-40	-40	-40	-40	0
49	0	170	168	168	167	167	167	166	115	114	83	82	82	46	46	46	46	46	46	45	45	11	10	-40	-40	-40	-40	-40	-40	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

SECTION IX

CRITICALITY ANALYSIS

No changes made for alternate closure system.

SECTION X

MANUFACTURING AND QUALITY CONTROL PROCEDURES AND FABRICATION PLAN

A. QUALITY ASSURANCE PROGRAM

The Quality Assurance requirements for the design and manufacture of the alternate closure system for the FSV-1 cask will be complied with by suitable application of General Atomic Company Topical Report GA-A13010A (GA-LTR-11), "General Atomic Co. Q.A. Program," which is accepted by the NRC for activities required to meet 10CFR50 Appendix B.

As part of the Q.A. program the following requirements will apply to the design and manufacture of the alternate closure system.

All steel materials will be purchased to the requirements of the ASME Code, 1974 Edition through Summer 1976 Addenda, Section III, Div. 1, Class 2. Chemical and/or physical test reports will be provided for all materials. Welding will be performed by welders qualified to Section IX, ASME Code. Welding procedures will also be qualified in accordance with Section IX of the Code.

Detailed manufacturing procedures will be prepared outlining step by step sequences for all fabrication, machining, assembly operations, and quality control. Inspection system will be in accordance with Section III of the ASME Code. Mandatory hold and inspection points will be incorporated into the Manufacturing/QC Procedures in order that GAC Engineering and the Authorized Code Inspector may witness tests and inspections being performed in accordance with ASME Code requirements.

Nondestructive testing techniques and acceptance standards will be in accordance with ASME Code Section III and will be performed by personnel qualified to the ASME Code. Welds will be inspected in accordance with the ASME Code.

The depleted uranium will be volumetrically inspected by using gamma scanning, radiography or a combination of the gamma scan and radiography method.

SECTION XI

PRELIMINARY LOW TEMPERATURE URANIUM DROP TESTS

No changes made for the alternate closure system.