29

29

29

29

29

29

29

29

29

29

29

29

29

29

29

29

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151
Price: Printed Copy \$5.45 Microfiche \$1.45

NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Atomic Energy Commission, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

SHIPPING CASK FOR FAST REACTOR FUEL ELEMENTS

by

Horace E. Noyes

ABSTRACT

A well-shielded shipping container weighing approximately 12 500 lb has been designed to accommodate irradiated fuel pins up to 40 in. in length in support of the Liquid Metal Fast Breeder Reactor Program. Having attained a burnup of 10 at.%, with increased irradiation exposure and corresponding increase in temperature, it is important that some fuel elements be shipped in a vertical position. In compliance with existing regulatory requirements, the background material and approvals are given in appendixes.

IRRADIATED FUEL PIN SHIPPING CASK

As one of the sites having hot cell facilities, the Los Alamos Scientific Laboratory was selected to examine several thousand irradiated fuel pins to provide information in support of the Liquid Metal Fast Breeder Reactor Program. Because an insufficient number of casks were available to satisfy the anticipated heavy shipping schedules, two casks to meet the Laboratory shipping requirements were fabricated based on a cask cavity of 42 in. in height and 6 in. in diameter, with a shielding capacity for up to 19 pins (EBR-II type), each of which had attained a burnup of 10 at.%. Versatility of the cask was increased by providing a bottom drain to permit loading under water, and the fabricating of a variety of 6-in.-diam inserts (equivalent to Specification DOT-2R containers) with holes to accommodate fuel pins of different sizes.

With the increasing radiation exposure of the fuel pins, and with a corresponding increase in temperature of the pins, it is important that the sodium-bonded fuel pins having temperatures near or above the melting point of sodium be shipped in the vertical attitude to prevent the loss of certain experimental objectives and information. Most of the other DOT approved casks are designed for shipment in the horizontal position. The casks have been modified to be compatible with the loading ports at the HFEF-North and South facilities at NRTS and the Wing 9 hot cell facility at the Los Alamos Scientific Laboratory.

RADIOLOGICAL SAFETY

No exception is made to applicable external radiation levels as prescribed by the Regulatory Agencies, and loadings will be confined to those limits. The insert and packaging tubes used to hold the irradiated pins are loaded in such a manner as to provide essentially contamination-free surfaces. This in turn assures that the inner and exterior surfaces of the cask are also essentially contamination-free.

The recipient of a cask is provided with the following information prior to or at the time of shipping.

- Appropriate sketches showing the containers used in packaging, and identification and location within the containers of their contents.
- An assembly drawing of the shipping cask. A photograph may also be supplied if required.
- Technical details regarding the encapsulated samples, such as the contamination level of the inner containers, beta-gamma activity levels of the samples, and physical condition of the samples are discussed with the recipient prior to shipment.

DESIGN CRITERIA

The packaging will consist of a right cylindrical weldment, which is a steel encased depleted uranium shielded

MASTER

cask weighing approximately 12 500 lb. A copper barrier is provided between the steel and uranium to preclude eutectic formation. The uranium is 6.5 in. thick, and the outer steel jacket is 3/8 in. thick. Allowable loadings are specified which will provide compliance with Fissile Class 1 criteria, with a 1000-W heat rating. A fusible drain plug is provided.

The cylinder is approximately 2 ft in diameter and 5 ft high with a containment cavity along its central axis of approximately 6 in. in diameter by 42 in. in length. The uranium shielding consists of a stack of six large machined castings. Five of these are penetrated by the sample receiver and the sixth forms the bottom shield. The containment cavity is capped at its upper end by a seventh uranium piece which is enclosed in a stainless steel jacket formed into a bolted lid arrangement weighing approximately 400 lb.

The exterior surface formed by the stainless steel jacket is fitted with a horizontal mating flange for joining to a removable shipping and handling pedestal. This pedestal is 4-ft square, fitted with two channels for fork lift handling, and is fabricated from structural grade carbon steel.

EXTERNAL SURFACE TEMPERATURES

Because the shipping cask is designed to accommodate a 1000-W loading, it is not anticipated that the external surface temperature will ever exceed 25°C. Experimental loading of the insert with 15 pins with 10 at.% burnup averaged 86 R/h at 1 m. From this, only 31.1°C was viewed internally, and 25°C on the external surface. These pins were of considerably higher R value than normal shipments; therefore, although a personnel heat shield is provided to conform to 49 CFR 173.393(c)(2), there is no indication that its use will be required.

NUCLEAR CRITICALITY SAFETY ANALYSIS

Nuclear criticality safety analysis is attached as Appendix A.

STRUCTURAL ANALYSIS

The structural analysis of the shipping cask for activated metal samples is attached as Appendix Z. The analysis is in compliance with Part II, "Packaging Standards," of AEC Manual Chapter 0529, "Safety Standards for the Packing of Radioactive and Fissile Materials," and with Title 10, Code of Federal Regulations, Part 71. The paragraphs of the analysis are numbered to correspond to Part II of AEC Manual Chapter 0529.

THERMAL ANALYSIS

Assuming an ambient temperature of 130°F, the temperature profile of the package when exposed in still air is shown on page 11a of Appendix B. There will be no effect on the package, its contents, or the containment seals, nor will an ambient temperature of -40°F have any effect on the usefulness and integrity of the package.

QUALITY ASSURANCE

Quality assurance specifications, including welding specifications, are attached as Appendix C.

U S. ATOMIC ENERGY COMMISSION APPROVAL

Certification of Approval issued by the Operational Safety Division, Albuquerque Operations Office, USAEC, identified as AEC-AL-USA/5885/BLF, is attached as Appendix D.

CONTAINER DRAWING

Los Alamos Scientific Laboratory Drawings ENG-E-112,D-1 through D-6 are attached as Appendix E.

APPENDIX A: NUCLEAR CRITICALITY SAFETY ANALYSIS

Allowable Fissile Material Loading SP 5885

The experimental fast reactor fuel pins for which this shipping container was designed may contain carbides, oxides, nitrides, or perhaps other compounds of uranium and plutonium. While the fast reactors being developed are expected to be fueled with a mixture of depleted uranium and high burnup plutonium, developmental fuel pins may consist of highly enriched uranium and plutonium with approximately 5% plutonium 240.

To evaluate allowable loadings for criticality control, it is assumed that a fuel pin consists of one part plutonium 239 and three parts uranium enriched to 93% in the 235 isotope. The form assumed is a mixed mono-carbide, but a density of 15.6 g/cc (substantially above theoretical density) provides a generous margin of conservatism to compensate for any other compound which might need to be shipped. A somewhat simplified geometry is used. The fissile material has an outer radius of 0.3175 cm and is contained in 88% iron - 12% nickel to a radius of 0.394 cm. This fissile material radius corresponds to that found in fuel pins, and the wall thickness and material is typical of that used, but the outside radius is reduced from the actual 3/16" OR to provide a compact cell. This has the effect of reducing the quantity of jacket material which is somewhat absorbent for neutrons, and is another

increment of conservatism in the calculations. The 12% nickel fraction represents the lowest level of nickel in any of the common jacket materials; and while the calculations will be relatively insensitive to this, higher alloys will absorb a few more neutrons. The active length of a typical fuel pin is 15", but calculations were performed assuming unlimited fuel length.

The maximum planned loading of the cask would consist of 19 fuel pins with a total fissile material content of about 3.5 kg, however our conservative assumption provides for about 2.5 kg plutonium and 7.5 kg enriched uranium. This would be diluted with about 2.5 kg of jacket material.

The bare critical mass of 25% plutonium - 75% uranium metal is about 25 kg, from transport calculations, so the above 10 kg would be subcritical in a reflector, and substantially subcritical when diluted with the jacket material. Thus no criticality control problem will arise in the absence of moderating materials.

Evaluation of a flooded cask assumes that the fuel pins are evenly spaced in the cask cavity. The spacing can be varied in the calculations to search for an optimum moderation. As the first step, cell calculations were performed with the fuel pin surrounded by a water annulus and with a reflecting outer boundary to simulate an infinite lattice of pins spaced in water. Using the LARCA⁽¹⁾ code, k_{∞} values and flux-weighted cross sections were generated for

this infinite lattice. These weighted cross sections were then used to evaluate the flooded cask. For the cask calculation, the axial region was taken to be moderated fuel characterized by the weighted cross-sections, with an area adjusted so that the cask would be critical. The region between the fuel and the inner wall of the cask was filled with water. The outer surface of the cask was specified to be a reflecting boundary, so that results obtained apply to an infinite array of these casks.

The following table summarizes the results of these calculations.

<u>cell radius</u>	<u>k_{∞}</u>	<u>critical fuel radius</u>	<u>critical no. of pins</u>
0.9 cm	1.843	5.66 cm	39.5
1.0	1.820	6.02	36.2
1.1	1.791	6.39	33.7
1.2	1.755	6.83	32.3
1.3	1.715	7.37	32.1

The number of pins is obtained by squaring the ratio of the fuel radius to the cell radius. This demonstrates that criticality cannot be achieved with the 19 fuel pins the cask was designed to contain, and in fact a loading of 25 pins would provide an acceptable margin of safety for any degree of moderation

These calculations used the Hansen-Roach 16 group cross section sets with DTF IV in the S4 angular approximation.

On the basis of these calculations, it is recommended that the fissile loading of this package be restricted to 10 kg, of which not more than 2.5 kg may be plutonium or uranium 233. The material may be present as oxide, carbide, or other non-hydrogenous compounds. The material shall be encapsulated to comply with "special form" criteria, in a stainless steel, Hastalloy X, or Incalloy cladding with a minimum clad thickness of .030 in (0.0762 cm). The minimum capsule o.d. should be 0.375 in (0.9525 cm). The maximum number of fuel pins or capsules should be nineteen.

These restrictions will provide compliance with the "Fissile Class I" criteria of the AEC and DOT regulations.

(1) R. C. Anderson, "LARCA: A Fortran IV CDC 6600 Program for Calculating Flux-Weighted Cross Sections", Los Alamos Scientific Laboratory Report LA-3873-MS, March 1968.

APPENDIX B: STRUCTURAL ANALYSIS OF SHIPPING CASK FOR FAST REACTOR FUEL ELEMENTS

-i-

SHIPPING CASK FOR FAST REACTOR FUEL ELEMENTS

(Number reference AECM Chap. 0529)

- II.A.1. The packaging components, being primarily depleted uranium shielding in a stainless steel jacket, are completely compatible with one another and with the package contents. The radioactive material is in special form. A copper barrier is provided at the steel uranium interface to preclude eutectic formation at elevated temperatures. There will be no significant chemical, galvanic or other reaction among these materials.
- II.A.2. Inadvertent opening of the package is prevented by use of redundant positive closure devices consisting of:
 - a. A gasketed plate covering the access end of the package secured by multiple bolts with a safety wire seal.
 - b. The containment access lid is covered by (a.) above and secured by multiple bolts and a safety wire seal.
 - c. The lid weight of almost 400 lbs. aids in preventing inadvertent opening.
- II.A.3.a. There exist two sets of lifting devices which are structural parts of the package. Each is capable of supporting more than the minimum requirement of three times the package weight without exceeding the yield strength of the materials. (Appendix, page 3).
- II.A.3.b. The containment access lid is lifted by an eyebolt which is capable of supporting more than the minimum requirement of three times the weight of the lid without exceeding the yield strength of the materials. (Appendix, page 7).
- II.A.3.c. There exists no structural part of the package with which it could be lifted which does not comply with II.A.3.a. above except the tapped hole for the lid lift eyebolt which will be filled with a plug and seal wired to the lid attach bolts. A warning against improper use of this tapped hole shall be stenciled in its immediate vicinity.
- II.A.3.d. Failure of any lifting device under excessive load would not impair the containment or shielding properties of the package.
- II.A.4.a. There are no tie-down devices on this package. Its stability has been investigated. (Appendix, page 8).

- II.A.4.b. No structural portion of the package could reasonably be employed as a tie-down device.
- II.B.1. Load resistance is more than adequate when the package is regarded as an end supported simple beam with five times the package weight uniformly distributed along its length. No stress is produced in the material greater than its yield strength. (Appendix, page 9).
- II.B.2. The package is adequate to withstand an external pressure of 25 p.s.i.g. with no loss of contents. (Appendix, page 10).
- II.C. Criticality Standards (See Criticality Analysis)
- II.D.1. Single package evaluation is based upon calculations subjecting the package to the normal conditions of transport (annex 1) and to the hypothetical accident conditions (annex 2).
- II.D.2. No controls by the shipper are anticipated and the shipment is therefore evaluated without the transporting vehicle.
- II.D.3. No deviations are anticipated from normal conditions of transport (annex 1) and hypothetical accident conditions (annex 2) for package evaluation.
- II.E.1. The package is so designed, constructed and its contents limited such that subjected to the normal conditions of transport specified in annex 1:
 - a. There will be no release of radioactive material from the containment vessel.
 - b. Effectiveness of the package will not be substantially reduced.
 - c. No mixture of gases or vapors will occur in the package which through explosion or increase of pressure could reduce the effectiveness of the package.
- II.E.2. The package is so designed, constructed, and its contents limited such that subjected to the normal conditions of transport, specified in annex 1, considered individually:
 - a. The package will be subcritical. (See Criticality Analysis)
 - b. The geometric form of the contents will not be significantly altered.
 - c. There will be no leakage of water into the container as specified under this test requirement.
 - d. There will be no substantial reduction in the effectiveness of the material packaging. External volume and spacing changes will be less than 5% and no aperturing of the outer surface will occur.

- II.E.3. The containment vessel will not be vented directly to the atmosphere following the tests regarded under this section. (Appendix, page 11, for specific findings and discussion)
- II.F.1. The package is so designed, constructed and its contents limited such that subjected to the hypothetical accident conditions, in the sequence listed, as specified in annex 2:
 - a. No shielding reduction would occur yielding an external radiation dose rate in excess of 1000 milliroentgens per hour at one meter from the package's surface.
 - b. No radioactive material would be released from the package. (Appendix, page 23, for specific findings and discussion)
- II.F.2. (See Criticality Analysis)

APPENDIX 1

Structural and Thermal Compliance Calculations
for
Shipping Cask for Fast Reactor Fuel Elements
(LASL Drawing No. ENG-E-112)

Prepared By

J. W. McMullen
7-7-73

Approved By

Bob J. Donham

MATERIAL PROPERTIES:

DEPLETED URANIUM:

TENSILE STRENGTH (PSI)	60,500 ± 13,700
YIELD STRENGTH (.2%) (PSI)	30,000 ± 13,100
ELONGATION (%)	6.2 ± 5.7
POISSON'S RATIO	0.23
YOUNG'S MODULUS	27.9 × 10 ⁶ PSI
DENSITY	18.94 g/cc
MELTING POINT	1133°C ± 1°C

(FROM OAK RIDGE Y-12 PLANT DATASHEET Number 2.1.1)

TYPE 304 STAINLESS STEEL (ANNEALED)

TENSILE STRENGTH (PSI)	82,000
YIELD STRENGTH (.2%) (PSI)	35,000
ELONGATION	55
POISSON'S RATIO	.27
YOUNG'S MODULUS	28 × 10 ⁶ PSI
DENSITY	.28 lb/in. ³
MAX REC. SERV. TEMP	1600°F

ASTM A-36 LOW CARBON STEEL

TENSILE STRENGTH (PSI)	58,000
YIELD STRENGTH (.2%) (PSI)	36,000
ELONGATION (%)	20
POISSON'S RATIO	.27
YOUNG'S MODULUS	29 × 10 ⁶ PSI
DENSITY	.283 lb/in. ³

ASTM A-307 (SAE Grade 1) Bolt MATL

TENSILE STRENGTH (PSI)	60,000
PROOF LOAD (PSI)	33,000

LIFTING DEVICES:

The package has two distinct sets of lifting devices: The three inch and one-quarter eyebolt receivers on its upper surface and the fork lift channels which are built into its base.

EACH SET MUST BE SHOWN CAPABLE OF supporting at least three times the package weight without exceeding the yield strength of the material.

EYEBOLTS:

Three 1/4-7 NC thd. Forged steel shoulder eyebolts lift the package:

Allowable load, 1/4-7 Eyebolt:

Safe working loads:

Machinery's Handbook	15,000 lb
AISC Manual	17,180 lb
Crosby Laughlin (Typ Mfg)	15,200 lb

LOAD which will yield bolt = $(T_y)(A_{net})$

$$= (.969)(33 \text{ ksi})$$

$$= 31.977 \text{ kips}$$

$$\text{FACTOR OF SAFETY (yield)} = \frac{31.977 \times 3}{12.5}$$

$$= 7.67$$

WELL ABOVE THE NECESSARY
FACTOR OF 3.

The strength of the tapped receivers for the eyebolts and the eyebolts are checked for thread shear:

The MALE THREADS would fail at $75\% (P - P_A)$ of the area computed at the female threads minor DIA:

$$P_{allow} = (.75) \left(\frac{F_y P}{2} \right) A_s = (.75) \left(\frac{33,000}{2} \right) \pi (1.095)(1.29) \\ = 54.916 \text{ kips}$$

The Female Threads would fail at $87\frac{1}{2}\% (P - P_A)$ of the area computed at the male threads major dia.

$$P_{allow} = (.875) \left(\frac{F_y P}{2} \right) A_s = (.875) \left(\frac{35,000}{2} \right) \pi (1.223)(1.29) \\ = 75.89 \text{ kips}$$

Thread strip out is no problem on the lifting eyes.

FORK LIFT CHANNELS (BASE)

A VERY CONSERVATIVE ANALYSIS MAY BE PERFORMED ON THE BASE BY SIMPLIFYING IT INTO A SIMPLE BOX STRUCTURE.

$$MOM_{max} = \frac{W}{4}(L_1 - L_2/2) = \frac{W}{4}(48 - 17) = 7.75W$$

$$I_{xx} = \frac{2 \times .375 (16.88)^3}{12} + 12(.5)(8.44)^2 = 728 \text{ in}^4$$

BENDING STRESS THE SECTION WILL SEE:

$$\overline{Y}_B = \frac{M_c}{I} = \frac{(7.75)(12.5)(8.44)}{728} = 1.12 \text{ KSI}$$

$$\text{FACTOR OF SAFETY} = \frac{36 \text{ KSI}}{1.12 \text{ KSI}} = 32$$

WELL ABOVE THE REQUIRED FACTOR OF 3

DETERMINE A CALCULATED WEIGHT OF THE LID ASSEMBLY:

DEPLETED URANIUM SHIELDING:

$$WT = .2618 h (D_1^2 + D_1 D_2 + D_2^2) \rho$$

$$= .2618 (7.62) (9.33^2 + 9.33(8.40) + 8.40^2) 18.99 (.03613)$$

$$WT_1 = 322 \text{ lbs}$$

TOP STEEL PLATE:

$$WT = \frac{\pi}{4} (14.5)^2 (.88) (.28)$$

$$WT_2 = 41 \text{ lbs}$$

BOTTOM STEEL PLATE:

$$WT_3 = \frac{\pi}{4} (8.49)^2 (.25) (.28)$$

$$WT_3 = 4 \text{ lbs}$$

Side Plate, steel:

$$WT = \pi \left(\frac{8.4 + 9.3}{2} \right) (8) (.25) (.28)$$

$$WT_4 = 16 \text{ lbs}$$

$$\text{TOTAL Lid weight} = 322 + 41 + 16 + 4 = 383 \text{ lb}$$

USE 400 lbs FOR CALCULATIONAL PURPOSES.

LID LIFTING DEVICE:

THE PACKAGE'S LID IS LIFTED BY A SINGLE
1/2-13 UNC THD EYEBOLT, .75 LONG.

ALLOWABLE LOAD, 1/2-13 EYEBOLT:

SAFE WORKING LOADS:

MACHINERY'S HANDBOOK	2600 lbs
CROSBY LAUGHLIN	2200 lbs

$$\begin{aligned}\text{LOAD WHICH WILL YIELD BOLT} &= (T_y)(A_{\text{net}}) \\ &= (33 \text{ ksi})(.1919 \text{ in}^2) \\ &= 4.683 \text{ kips}\end{aligned}$$

$$\text{FACTOR OF SAFETY (yield)} = \frac{4.683}{.400} = 11.7$$

WELL ABOVE THE NECESSARY FACTOR
OF 3.

THREAD SHEAR IS CHECKED:

MALE THREAD FAILURE:

$$\begin{aligned}P_{\text{max}} &= (.75) \left(\frac{33,000}{2} \right) \pi (.75) (.417) \\ &= 12.16 \text{ kips}\end{aligned}$$

Female Thread Failure:

$$\begin{aligned}P_{\text{max}} &= (.875) \left(\frac{33,000}{2} \right) (\pi) (.75) (.482) \\ &= 16.4 \text{ kips}\end{aligned}$$

THREAD STRIP OUT IS NO PROBLEM.

NOTE: THIS LID LIFTING DEVICE COULD BE
IMPROPERLY EMPLOYED TO LIFT THE ENTIRE
PACKAGE. ITS USE IN THIS MANNER MUST BE
AVOIDED. A PLUG FOR THE TAPPED HOLE SHALL
BE PROVIDED WHICH IS SEAL WIRE TO THE LID
FASTENING BOLTS DURING TRANSPORTATION.
APPROPRIATE WARNING AGAINST MISUSE OF THE
EYEBOLT SHALL BE IMPRINTED NEAR THE TAPPED HOLE.

PACKAGE STABILITY:

AS THE PACKAGE HAS NO TIE-DOWN PROVISIONS ITS BASE STABILITY IS INVESTIGATED.

For g load upset:

$$g \geq \frac{24}{27}$$

$$\geq .89$$

(NO SLIP CONDITION)

ϕ = UPSET ANGLE

$$\phi = \tan^{-1} \left(\frac{24}{27} \right)$$

$$\phi = 41.6^\circ$$

THE PACKAGE HAS A BASICALLY STABLE GEOMETRY. UPSET IS NOT ANTICIPATED DURING NORMAL TRANSPORT CONDITIONS.

SIMPLE BEAM LOAD RESISTANCE:

CONSIDER THE OUTER STAINLESS STEEL JACKET OF THE PACKAGE ONLY (VERY CONSERVATIVE) AS AN END SUPPORTED SIMPLE BEAM. LOAD CAPABILITY MUST BE GREATER THAN FIVE TIMES THE PACKAGE WEIGHT.

$$\begin{aligned}
 W &= wL \\
 M_{max} &= \frac{wL^2}{8} = \frac{WL}{8} \\
 I &= \frac{\pi}{64} (D_0^4 - D_i^4) \\
 Y_b &= \frac{M_c}{M_D} = \frac{I}{2I}
 \end{aligned}$$

DETERMINE W SUCH THAT THE STRESS INDUCED EQUALS THE YIELD STRENGTH OF THE MATERIAL.

$$\frac{\Delta_b}{L} = \frac{WL D_0}{16 I} \quad \text{or} \quad W = \frac{16 \Delta_b I}{L D_0}$$

For $\Delta_b = 35 \text{ ksi}$, yield strength of jacket:

$$W = \frac{16 (35 \text{ ksi}) \pi (20.5^4 - 19.75^4)}{64 (61) (20.5)}$$

$$W = 537.7 \text{ kips}$$

$W = 43$ times the package weight, much greater than the 5 times required.

EXTERNAL PRESSURE RESISTANCE:

THE PACKAGE MUST WITHSTAND AN EXTERNAL PRESSURE OF 25 psig WITH NO LOSS OF CONTENTS.

THIS TEST REPRESENTS A TRIVIAL LOADING CONDITION TO THIS PACKAGE, A THICK WALL CYLINDRICAL STRUCTURE.

THE STEEL SHELL ONLY (A THIN WALL STRUCTURE) IS ANALYZED TO ESTABLISH WORST CONDITION (INTERNAL PRESSURE) STRESSES INDUCED.

AT $P = 25 \text{ psig}$:

$$\tau = \frac{PR}{2t} \pm \frac{PR}{t} = \frac{25(10.25)}{2(.375)} \pm \frac{25(10.25)}{.375}$$

$$\tau = \sqrt{(391.7)^2 + (683.3)^2} = \underline{764 \text{ psi}}$$

A very small value even in this very conservative thin wall investigation.

For comparative purposes the collapse pressure of the thin wall geometry is found:

$$P' = \frac{t}{R} \left(\frac{S_y}{1 + 4.5 \frac{t}{R} \left(\frac{R}{t} \right)^2} \right) = \frac{.375}{10.25} \left(\frac{35,000}{1 + 4 \left(\frac{35}{28000} \right) \left(\frac{10.25}{.375} \right)^2} \right)$$

$$P' = 270 \text{ psi}$$

PACKAGE WILL NOT BE INFLUENCED BY REASONABLE EXTERNAL PRESSURES, AND THE CONTAINMENT CAVITY WILL REMAIN SEALED WITH THE O-RING AT THE LID AND THE PLASTIC PIPE PLUG ON THE DRAIN PIPE REMAINING EFFECTIVE.

Exposure of package to "Normal Conditions of Transport"

per annex 1 of AEC Manual, Chap. 0529

- Heat:** The temperature profile of the package when exposed to an ambient temperature of 130°F in still air is shown on page 11a. There will be no effect on the package, its contents, or the containment seals.
- Cold:** An ambient temperature of -40°F will have no effect on the usefulness and integrity of the package. The neoprene o-ring utilized at the lid interface is rated for service to a temperature of -65°F. The fusible plastic pipe plug stays effective to this temperature as it is above the brittle point of most thermoset materials.
- Pressure:** Differential pressure of one-half atmosphere will cause no change in the package effectiveness. No exchange of atmosphere occurs between the containment cavity and the surrounding ambient environment. External pressure comments, page 10, apply here, as a one-half atmosphere differential pressure (either internal or external raised) is an even more trivial case than that investigated.
- Vibration:** Normal transport vibrations are not anticipated to effect this package in the least. No unexpected heat production, material fatigue failures, objectionable noise production, or critical (non-damped) system responses are anticipated. Safety wiring and adequate wrench tightening will assure that the fastener effectiveness is not diminished.
- Water spray:** The sealed package will experience no change when subjected to a thirty minute water spray on all exposed surfaces.
- Free drop:** A drop through a Free Fall Distance of three feet striking the package surface in a position for which maximum damage is expected is investigated on page 12. The package effectiveness will not be substantially reduced and the containment vessel will remain sealed. Volume and spacing changes are less than 5% and no rupturing of the outer skin occurs.
- Corner drop:** Not Required
- Penetration:** The requirement of a 13⁵/₈" steel cylinder of 1¹/₂" diameter to be dropped from a height of 40" is a trivial loading condition for a container made of steel and uranium.
- Compression:** Not Required

THERMAL MODEL

THERMAL RESPONSE

11a

Normal Conditions of Transport:

FREE DROP:

Utilizing the analysis philosophy expressed for the free drop, hypothetical accident conditions, the maximum credible damage to the package is postulated for the three foot drop condition.

$$\begin{aligned}\text{Energy to be dissipated} &= (\text{weight}) \times (\text{height}) \\ &= 12.5 \text{ kips} \times 36 \text{ in} \\ &= 450 \text{ in-kips}\end{aligned}$$

Because of the relatively small deformations involved in the system absorbing this amount of energy, the yield strength value of the material is used as the deformation stress. This produces maximum credible deformed volumes, shielding reduction, and largest possible reduction in package effectiveness.

The lid end drop geometry produces .018 inches of plastic deformation in the package. The compression mode of the impact should insure continued effectiveness of the package and non-venting of the containment cavity to the atmosphere.

The angle drop analyses yield deformed areas and g load values also indicative of continued package effectiveness and containment cavity seal integrity.

The side drop geometry produces negligible deformations and high radial g loads. Once again, the package effectiveness should not be diminished.

All drop analyses conservatively assume that 100% of the drop energy is dissipated in the zone which initially contacts the drop surface.

End drop Geometry:

δ = deformation measured normal to the drop surface

γ = strength of material at which deformation occurs.

Energy Absorbed = Energy stored elastically,
+ Energy dissipated plastically
= $E_1 + E_2$

E_1 = Energy of elastic deformation

$$\delta_1 = \frac{PL}{AE} = \frac{30K \times 58}{28 \times 10^6} = .062"$$

$$E_1 = (.5)(.062)(30K) = .93 \text{ in-kip/in}^2$$

$$E_1 = .93 \text{ in-kip} (\pi(10.25^2 - 3^2)) = 281 \text{ in-kips}$$

$$E_2 = E_{\text{reqd}} - E_1 = 450 - 281 = 169 \text{ in-kips}$$

$$\delta_2 = \frac{E_2}{\gamma \times A} = \frac{169}{30 \times 302 \text{ in}^2} = .018 \text{ in plastic deformation}$$

$$g's = \frac{30 \text{ Ksi} \times 302 \text{ in}^2}{12.5K} = 725$$

THE LID IS IN THE ZONE OF DEFORMATION. THE THREE-QUARTER INCH FLANGE THICKNESS TO THE SEAL INTERFACE SHOULD INSURE CONTINUED EFFECTIVENESS AND NON-VENTING OF THE CONTAINMENT CAVITY TO THE ATMOSPHERE. THE COMPRESSION LOAD EXPERIENCED BY THE LID PROHIBITS ITS MOVEMENT DESPITE THE HIGH g FORCES EXERTED.

ANGLE DROP GEOMETRY:

θ = Drop angle

δ = Long DEFORMATION

c = RADIAL DEFORMATION

ϕ = DEFORMATION ANGLE

PLASTIC DEFORMATION, UTILIZING YIELD STRENGTH VALUES FOR THE DEPLETED URANIUM, WAS CALCULATED FOR VARIOUS DROP ANGLES. THE RESULTS OF THESE CALCULATIONS ARE SHOWN ON THE FOLLOWING PAGES.

AS SEEN IN THE PRECEEDING END DROP ANALYSIS THE PACKAGE IS CAPABLE OF ABSORBING ABOUT TWO-THIRDS THE IMPACT ENERGY ELASTICALLY. THESE RESULTS, BEING WHOLLY PLASTIC ENERGY ABSORPTION, ARE CONSERVATIVE.

THE LID EXISTS IN THE ZONE OF DEFORMATION ONLY WHEN THE RADIAL DEFORMATION EXCEEDS 3.25 inches. EVEN WHEN IN THE DEFORMATION AREA THE LID FLANGE THICKNESS PROTECTS THE SEALING INTERFACE.

THE MAGNITUDE OF THE g FORCES IS LOW ENOUGH SUCH THAT NO FAILURE MODE OF THE LID IS POSSIBLE. (See page 30 FOR ALLOWABLE LID LOAD ANALYSIS).

36 IN DROP HEIGHT

[illegible]

DROP ANGLE IS 55 DEGREES				DROP ANGLE IS 75 DEGREES				DROP ANGLE IS 60 DEGREES				DROP ANGLE IS 45 DEGREES			
RADIAL DEPM	DEPM ANGLE	LONG DEPM	ENERGY ABS	RADIAL DEPM	DEPM ANGLE	LONG DEPM	ENERGY ABS	RADIAL DEPM	DEPM ANGLE	LONG DEPM	ENERGY ABS	RADIAL DEPM	DEPM ANGLE	LONG DEPM	ENERGY ABS
1.17733	7.73299	1	53131	1.03573	16.30162	1	1340599	1.81542	22.1431	1	1340599	1.03382	16.28346	1	1340599
2.441545	25.04126	2	3309643	2.37351	23.0713	2	7632286	2.334534	22.0681	2	7632286	2.334534	22.0681	2	7632286
3.656318	35.72547	3	636531	3.125026	28.28108	3	2079702	3.061273	26.39728	3	2079702	3.061273	26.39728	3	2079702
4.883391	35.51334	4	936531	4.141101	32.68434	4	4313843	4.092556	32.33768	4	4313843	4.092556	32.33768	4	4313843
5.133643	39.74534	5	2502016	5.176377	36.57316	5	5176377	5.176377	36.57316	5	5176377	5.176377	36.57316	5	5176377
7.324506	43.58314	7	4713325	7.6211652	40.33833	7	6146595	7.6211652	40.33833	7	6146595	7.6211652	40.33833	7	6146595
8.545499	47.12328	8	631351	8.7846927	43.34852	8	8882203	8.7846927	43.34852	8	8882203	8.7846927	43.34852	8	8882203
9.542822	50.42864	9	139393	9.9317478	46.38166	9	107338	9.9317478	46.38166	9	107338	9.9317478	46.38166	9	107338
1.32773	53.49757	1	1631045	1.332875	51.94666	1	133003	1.332875	51.94666	1	133003	1.332875	51.94666	1	133003
1.53164	59.31604	1.1	2131028	1.538275	54.55987	1.1	1438003	1.538275	54.55987	1.1	1438003	1.538275	54.55987	1.1	1438003
1.634927	63.81922	1.2	2645749	1.6415584	57.15049	1.2	124333	1.6415584	57.15049	1.2	124333	1.6415584	57.15049	1.2	124333
1.73724	68.61948	1.3	3227542	1.73724	68.61948	1.3	3227542	1.73724	68.61948	1.3	3227542	1.73724	68.61948	1.3	3227542
1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328
1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474
1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168
2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824
3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876
4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016
5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016
6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546
7.825592	49.33312	7	101998	7.825592	49.33312	7	101998	7.825592	49.33312	7	101998	7.825592	49.33312	7	101998
9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316
1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889
1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297
1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593
1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176
1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795
1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271
1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271
1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328
1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474
1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168
2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824
3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876
4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016
5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016
6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546
7.825592	49.33312	7	101998	7.825592	49.33312	7	101998	7.825592	49.33312	7	101998	7.825592	49.33312	7	101998
9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316
1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889
1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297
1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593
1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176
1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795
1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271
1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271
1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328
1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474
1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168	1.1154692	74.1816	1	5672168
2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824	2.350358	27.3797	2	8059824
3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876	3.653397	34.53135	3	1651876
4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016	4.91876	38.6417	4	2502016
5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016	5.773495	48.37425	5	4052016
6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546	6.72191	45.81958	6	7307546
7.825592	49.33312	7	101998	7.825592	49.33312	7	101998	7.825592	49.33312	7	101998	7.825592	49.33312	7	101998
9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316	9.237591	54.0475	9	1366316
1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889	1.039823	54.61652	1	1775889
1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297	1.154599	57.6535	1.1	2250297
1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593	1.271159	61.87632	1.2	2794593
1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176	1.385539	65.76994	1.3	3489176
1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795	1.531159	68.63544	1.4	439795
1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271	1.616578	67.59259	1.5	4863271
1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271	1.732343	70.59259	1.5	4863271
1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328	1.83882	73.7356	1.4	3679328
1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474	1.93159	69.55944	1.5	4693474
1.1154692	74.1816	1	5672168	1.1154692	74.1816	1</									

SIDE DROP GEOMETRY:

Energy dissipated =
Volume deformed $\times$
deformation stress

PLASTIC DEFORMATION ANALYSIS UTILIZING YIELD
STRENGTH VALUE OF THE DEPLETED URANIUM.

ϕ	d	V_d	Energy Dissipated	g's
4	.0063	.19	5.7	72
8	.024	1.45	43.5	171
12	.056	4.79	143.7	251
16	.100	11.40	342.3	361
17	.113	13.68	410	417
18	.126	16.20	486	468

THE CONTAINER'S LID IS LOADED IN SHEAR
IN THIS DROP GEOMETRY AND THIS LOAD
TRANSFERRED DIRECTLY TO THE LID RECIEVER.

The possibility of the container yielding
by going oval is investigated:

PLASTIC HINGES DEVELOPE
AT THE FOUR AXES
INTERCEPTS AT THE
CONDITION OF FLATTENING.

$$\text{LET } F = g \frac{W}{4}$$

THE SUMMATION OF MOMENTS YIELDS:

$$H = .707 F$$

SUMMATION OF MOMENTS YIELDS:

$$F = \frac{2 M_P}{R} \quad \text{OR} \quad g = \frac{8 M_P}{W R}$$

DETERMINE M_P :

STRESS DIAGRAM:

$$F_T = F_C = 35(1) \frac{6.5}{2} = 113.75 \text{ KIPS/in}$$

$$M_P = (113.75) \left(\frac{6.5}{2} \right) = 369.69 \frac{\text{IN-KIP}}{\text{IN}}$$

WEIGHT, W , OF URANIUM CYLINDER:

$$W = \pi (9.5^2 - 6^2) (1) (.486 \frac{\text{lb}}{\text{in}^3}) = 175.1 \text{ lb/in}$$

Solving for the g loading required for the container to yield by ovality.

$$g = \frac{8M_p}{WR} = \frac{8(369.69 \frac{\text{in} \cdot \text{KIP}}{\text{in}})}{(.1751 \text{ KIP/in})(6.25 \text{ in})}$$

$$\underline{g = 2702}$$

THIS VALUE IS WELL ABOVE THE 468 g's to which the package is subjected in this drop geometry. Not a failure mode.

SHIELDING REDUCTION:

THE CHART BELOW SHOWS THE EFFECT OF THE 3 FOOT DROP ON THE PACKAGE SHIELDING THICKNESS. ONLY WHEN DROPPED ON OR NEARLY ON ITS SIDE IS THE SHIELDING THICKNESS REDUCED.

$$\text{FRACTION OF MIN WALL} = \frac{\text{SHIELDING REMAINING}}{6.5" \text{ MIN DESIGN U THICKNESS}}$$

DROP ANGLE DEGREES	DEFORMATION INCHES	SHIELDING REMAINING	FRACTION OF MIN. WALL
0	.08	7.42	1.141538
5	.5	7.537974	1.159688
10	.75	7.764773	1.194581
15	.92	8.00677	1.231811
20	1.1	8.170829	1.257051
25	1.2	8.34433	1.283743
30	1.3	8.445193	1.29926
35	1.4	8.471889	1.303367
40	1.45	8.473453	1.303608
45	1.5	8.399494	1.29223
55	1.5	8.126306	1.250201
60	1.48	7.899157	1.215255
65	1.4	7.660627	1.178558
70	1.31	7.363139	1.132791
75	1.2	7.019644	1.079945
80	1.03	6.673591	1.026706
85	.8	6.32891	.9736784
90	.126	6.374	.9806154

VOLUME AND SPACING REDUCTIONS

THE MAXIMUM CREDIBLE VOLUME REDUCTION MAY BE CONSIDERED AS SIMPLY THE REMOVAL OF THE DEFORMED MATERIAL FROM THE ORIGINAL CYLINDER. AS THE SHIPPING PEDESTAL IS NOT CONSIDERED, THIS REDUCTION IS VERY CONSERVATIVE:

$$\begin{aligned} \text{VOLUME REDUCTION (\%)} &= \frac{\text{VOLUME DEFORMED}}{\text{ORIGINAL VOLUME}} \times 100 \\ &= \frac{\text{ENERGY ABS./DEFORMATION STRESS}}{\text{ORIGINAL VOLUME}} \\ &= \frac{450 \text{ IN-KIPS/IN}^2}{\frac{\pi}{4} (20.5)^2 \times 61} \end{aligned}$$

$$\underline{\underline{\text{VOLUME REDUCTION} = .07\%}}$$

THE MAXIMUM CREDIBLE SPACING CHANGE, THE SHIPPING PEDESTAL NOT CONSIDERED:

$$\text{SPACING CHANGE (\%)} = \frac{\text{DEFORMED DEPTH}}{\text{ORIGINAL DIMENSION}} \times 100$$

END DRUP:

$$\begin{aligned} \text{SPACING CHANGE \%} &= \frac{.016}{61} \times 100 \\ &= \underline{\underline{.03\%}} \end{aligned}$$

SIDE DRUP:

$$\begin{aligned} \text{SPACING CHANGE \%} &= \frac{.136}{20.5} \times 100 \\ &= \underline{\underline{.6\%}} \end{aligned}$$

HYPOTHETICAL ACCIDENT CONDITIONS

1. Free Drop-- A free drop through a distance of thirty feet onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected.

ANALYSIS PHILOSOPHY:

An energy absorption (deformed volume) method of analysis is employed to calculate the maximum credible damage to the container when subjected to the hypothetical accident condition of a thirty-foot free drop.

An available energy (potential energy) is determined. This energy is assumed to be dissipated in deforming the package's component materials. For purposes of ease of calculation and to gain additional conservatism the presence of the stainless steel jacket is neglected and the energy considered to be directly dissipated by the depleted uranium which forms the major portion of the package. A rather low value for the ultimate strength of uranium is used since this yields the most conservative estimate of deformed volumes and the largest credible shielding reduction leading to reduction in packaging effectiveness.

Determination of the drop geometry for which maximum damage is expected is accomplished by ascertaining trends in deformation patterns as the drop angle is varied from end on to side on. The base, being purposefully designed to react "softly" in these energy absorption modes, is conservatively considered to be absent for calculational purposes.

Shielding reduction is calculated based upon the decreased thickness of the depleted uranium. To determine this decreased thickness, the volume into which the energy is dissipated is considered to have vanished entirely.

The post drop structural integrity of the package which provides containment of radioactive material is investigated by close scrutiny of lid behavior, jacket effectiveness as a continuing restraint on the uranium pieces, and postulated behavior of the special form material.

END DROP GEOMETRY

$$\begin{aligned} \text{VOLUME DEFORMED} &= \frac{\text{ENERGY DISSIPATED}}{\text{MTL DEFORMATION STRESS}} \\ &= \frac{12.5 \times 30 \times 12 \text{ IN-KIPS}}{46.6 \text{ KIPS/IN}^2} \\ &= 96.15 \text{ IN}^3 \end{aligned}$$

$$d = \text{DEFORMATION} = \frac{96.15 \text{ IN}^3}{\pi (10.25^2 - 3^2)} = .318 \text{ IN}$$

$$S = \frac{4500 \text{ IN-KIPS}}{(.318 \text{ IN})(12.5 \text{ KIPS})} = 1132$$

THE LID IS FULLY SUPPORTED THROUGHOUT THIS DEFORMATION PROCESS AND THE ONLY CONCEIVABLE FAILURE MODE WOULD BE EXCESSIVE STRAIN IN THE OUTER JACKET OR CLOSURE WELD WHICH WOULD RELEASE THE RESTRAINT ON THE DEPLETED URANIUM SHIELDING PIECES.

ASSUME TOTAL DEFORMATION OCCURS IN FIRST 10% OF PACKING LENGTH
10% OF 60.5 = 6.05

$$\begin{aligned} \text{NEW VOL} &= \text{ORIG VOL} = 1826 \text{ IN}^3 \\ \text{NEW DIA} &= 21.01 \end{aligned}$$

$$\text{ELONGATION} = \frac{21.01 - 20.5}{20.5} \times 100 = 2.5\%$$

<< ALLOWABLE ELONGATION OF 304 JACKET (~50%) OR CONTAINER CLOSURE WELD

THE LID REMAINS INTEGRAL TO THE PACKAGE AND THE JACKET REMAINS EFFECTIVE IN RESTRAINING THE URANIUM SHIELDING.

ANGLE DROP Geometry

θ = drop angle
 δ = long deformation
 c = radial deformation
 ϕ = deformation angle

The zones of deformation for the various possible drop angles are calculated and shown on the following pages.

One hundred per cent of the available energy is assumed to be dissipated in all cases, yielding maximum damage. This is not a realistic condition, although it is conservative, for those angles (θ) greater than approximately 20° (c.g. above the corner) where the dissipated energies would decrease and the problem become a "first-bounce" investigation.

The allowable g loading for an unsupported lid assembly loaded along the axis of the cavity is determined and those drop angles which produce g loadings high enough to cause lid failure (>151) find the lid entering the zone of deformation and being supported by the drop surface prior to the attainment of these high g values.

30 FT. DROP HEIGHT

[illegible]

PROP. ANGLE IS 50 DEGREES				PROP. ANGLE IS 70 DEGREES				PROP. ANGLE IS 75 DEGREES				PROP. ANGLE IS 80 DEGREES				PROP. ANGLE IS 85 DEGREES			
PROF. DEPTH	DEPT. ANGLE	LONG. DEPTH	ENERGY ABS.	PROF. DEPTH	DEPT. ANGLE	LONG. DEPTH	ENERGY ABS.	PROF. DEPTH	DEPT. ANGLE	LONG. DEPTH	ENERGY ABS.	PROF. DEPTH	DEPT. ANGLE	LONG. DEPTH	ENERGY ABS.	PROF. DEPTH	DEPT. ANGLE	LONG. DEPTH	ENERGY ABS.
0.05	50.0000	0.05	3.1044	0.05	70.0000	0.05	11.104	0.05	75.0000	0.05	14.104	0.05	80.0000	0.05	17.104	0.05	85.0000	0.05	20.104
0.10	50.0000	0.10	4.1044	0.10	70.0000	0.10	12.104	0.10	75.0000	0.10	15.104	0.10	80.0000	0.10	18.104	0.10	85.0000	0.10	21.104
0.15	50.0000	0.15	4.6044	0.15	70.0000	0.15	12.604	0.15	75.0000	0.15	15.604	0.15	80.0000	0.15	18.604	0.15	85.0000	0.15	21.604
0.20	50.0000	0.20	4.8044	0.20	70.0000	0.20	12.804	0.20	75.0000	0.20	15.804	0.20	80.0000	0.20	18.804	0.20	85.0000	0.20	21.804
0.25	50.0000	0.25	4.9044	0.25	70.0000	0.25	12.904	0.25	75.0000	0.25	15.904	0.25	80.0000	0.25	18.904	0.25	85.0000	0.25	21.904
0.30	50.0000	0.30	4.9544	0.30	70.0000	0.30	12.954	0.30	75.0000	0.30	15.954	0.30	80.0000	0.30	18.954	0.30	85.0000	0.30	21.954
0.35	50.0000	0.35	4.9844	0.35	70.0000	0.35	12.984	0.35	75.0000	0.35	15.984	0.35	80.0000	0.35	18.984	0.35	85.0000	0.35	21.984
0.40	50.0000	0.40	5.0044	0.40	70.0000	0.40	13.004	0.40	75.0000	0.40	16.004	0.40	80.0000	0.40	19.004	0.40	85.0000	0.40	22.004
0.45	50.0000	0.45	5.0144	0.45	70.0000	0.45	13.014	0.45	75.0000	0.45	16.014	0.45	80.0000	0.45	19.014	0.45	85.0000	0.45	22.014
0.50	50.0000	0.50	5.0244	0.50	70.0000	0.50	13.024	0.50	75.0000	0.50	16.024	0.50	80.0000	0.50	19.024	0.50	85.0000	0.50	22.024
0.55	50.0000	0.55	5.0344	0.55	70.0000	0.55	13.034	0.55	75.0000	0.55	16.034	0.55	80.0000	0.55	19.034	0.55	85.0000	0.55	22.034
0.60	50.0000	0.60	5.0444	0.60	70.0000	0.60	13.044	0.60	75.0000	0.60	16.044	0.60	80.0000	0.60	19.044	0.60	85.0000	0.60	22.044
0.65	50.0000	0.65	5.0544	0.65	70.0000	0.65	13.054	0.65	75.0000	0.65	16.054	0.65	80.0000	0.65	19.054	0.65	85.0000	0.65	22.054
0.70	50.0000	0.70	5.0644	0.70	70.0000	0.70	13.064	0.70	75.0000	0.70	16.064	0.70	80.0000	0.70	19.064	0.70	85.0000	0.70	22.064
0.75	50.0000	0.75	5.0744	0.75	70.0000	0.75	13.074	0.75	75.0000	0.75	16.074	0.75	80.0000	0.75	19.074	0.75	85.0000	0.75	22.074
0.80	50.0000	0.80	5.0844	0.80	70.0000	0.80	13.084	0.80	75.0000	0.80	16.084	0.80	80.0000	0.80	19.084	0.80	85.0000	0.80	22.084
0.85	50.0000	0.85	5.0944	0.85	70.0000	0.85	13.094	0.85	75.0000	0.85	16.094	0.85	80.0000	0.85	19.094	0.85	85.0000	0.85	22.094
0.90	50.0000	0.90	5.1044	0.90	70.0000	0.90	13.104	0.90	75.0000	0.90	16.104	0.90	80.0000	0.90	19.104	0.90	85.0000	0.90	22.104
0.95	50.0000	0.95	5.1144	0.95	70.0000	0.95	13.114	0.95	75.0000	0.95	16.114	0.95	80.0000	0.95	19.114	0.95	85.0000	0.95	22.114
1.00	50.0000	1.00	5.1244	1.00	70.0000	1.00	13.124	1.00	75.0000	1.00	16.124	1.00	80.0000	1.00	19.124	1.00	85.0000	1.00	22.124
1.05	50.0000	1.05	5.1344	1.05	70.0000	1.05	13.134	1.05	75.0000	1.05	16.134	1.05	80.0000	1.05	19.134	1.05	85.0000	1.05	22.134
1.10	50.0000	1.10	5.1444	1.10	70.0000	1.10	13.144	1.10	75.0000	1.10	16.144	1.10	80.0000	1.10	19.144	1.10	85.0000	1.10	22.144
1.15	50.0000	1.15	5.1544	1.15	70.0000	1.15	13.154	1.15	75.0000	1.15	16.154	1.15	80.0000	1.15	19.154	1.15	85.0000	1.15	22.154
1.20	50.0000	1.20	5.1644	1.20	70.0000	1.20	13.164	1.20	75.0000	1.20	16.164	1.20	80.0000	1.20	19.164	1.20	85.0000	1.20	22.164
1.25	50.0000	1.25	5.1744	1.25	70.0000	1.25	13.174	1.25	75.0000	1.25	16.174	1.25	80.0000	1.25	19.174	1.25	85.0000	1.25	22.174
1.30	50.0000	1.30	5.1844	1.30	70.0000	1.30	13.184	1.30	75.0000	1.30	16.184	1.30	80.0000	1.30	19.184	1.30	85.0000	1.30	22.184
1.35	50.0000	1.35	5.1944	1.35	70.0000	1.35	13.194	1.35	75.0000	1.35	16.194	1.35	80.0000	1.35	19.194	1.35	85.0000	1.35	22.194
1.40	50.0000	1.40	5.2044	1.40	70.0000	1.40	13.204	1.40	75.0000	1.40	16.204	1.40	80.0000	1.40	19.204	1.40	85.0000	1.40	22.204
1.45	50.0000	1.45	5.2144	1.45	70.0000	1.45	13.214	1.45	75.0000	1.45	16.214	1.45	80.0000	1.45	19.214	1.45	85.0000	1.45	22.214
1.50	50.0000	1.50	5.2244	1.50	70.0000	1.50	13.224	1.50	75.0000	1.50	16.224	1.50	80.0000	1.50	19.224	1.50	85.0000	1.50	22.224
1.55	50.0000	1.55	5.2344	1.55	70.0000	1.55	13.234	1.55	75.0000	1.55	16.234	1.55	80.0000	1.55	19.234	1.55	85.0000	1.55	22.234
1.60	50.0000	1.60	5.2444	1.60	70.0000	1.60	13.244	1.60	75.0000	1.60	16.244	1.60	80.0000	1.60	19.244	1.60	85.0000	1.60	22.244
1.65	50.0000	1.65	5.2544	1.65	70.0000	1.65	13.254	1.65	75.0000	1.65	16.254	1.65	80.0000	1.65	19.254	1.65	85.0000	1.65	22.254
1.70	50.0000	1.70	5.2644	1.70	70.0000	1.70	13.264	1.70	75.0000	1.70	16.264	1.70	80.0000	1.70	19.264	1.70	85.0000	1.70	22.264
1.75	50.0000	1.75	5.2744	1.75	70.0000	1.75	13.274	1.75	75.0000	1.75	16.274	1.75	80.0000	1.75	19.274	1.75	85.0000	1.75	22.274
1.80	50.0000	1.80	5.2844	1.80	70.0000	1.80	13.284	1.80	75.0000	1.80	16.284	1.80	80.0000	1.80	19.284	1.80	85.0000	1.80	22.284
1.85	50.0000	1.85	5.2944	1.85	70.0000	1.85	13.294	1.85	75.0000	1.85	16.294	1.85	80.0000	1.85	19.294	1.85	85.0000	1.85	22.294
1.90	50.0000	1.90	5.3044	1.90	70.0000	1.90	13.304	1.90	75.0000	1.90	16.304	1.90	80.0000	1.90	19.304	1.90	85.0000	1.90	22.304
1.95	50.0000	1.95	5.3144	1.95	70.0000	1.95	13.314	1.95	75.0000	1.95	16.314	1.95	80.0000	1.95	19.314	1.95	85.0000	1.95	22.314
2.00	50.0000	2.00	5.3244	2.00	70.0000	2.00	13.324	2.00	75.0000	2.00	16.324	2.00	80.0000	2.00	19.324	2.00	85.0000	2.00	22.324
2.05	50.0000	2.05	5.3344	2.05	70.0000	2.05	13.334	2.05	75.0000	2.05	16.334	2.05	80.0000	2.05	19.334	2.05	85.0000	2.05	22.334
2.10	50.0000	2.10	5.3444	2.10	70.0000	2.10	13.344	2.10	75.0000	2.10	16.344	2.10	80.0000	2.10	19.344	2.10	85.0000	2.10	22.344
2.15	50.0000	2.15	5.3544	2.15	70.0000	2.15	13.354	2.15	75.0000	2.15	16.354	2.15	80.0000	2.15	19.354	2.15	85.0000	2.15	22.354
2.20	50.0000	2.20	5.3644	2.20	70.0000	2.20	13.364	2.20	75.0000	2.20	16.364	2.20	80.0000	2.20	19.364	2.20	85.0000	2.20	22.364
2.25	50.0000	2.25	5.3744	2.25	70.0000	2.25	13.374	2.25	75.0000	2.25	16.374	2.25	80.0000	2.25	19.374	2.25	85.0000	2.25	22.374
2.30	50.0000	2.30	5.3844	2.30	70.0000	2.30	13.384	2.30	75.0000	2.30	16.384	2.30	80.0000	2.30	19.384	2.30	85.0000	2.30	22.384
2.35	50.0000	2.35	5.3944	2.35	70.0000	2.35	13.394	2.35	75.0000	2.35	16.394	2.35	80.0000	2.35	19.394	2.35	85.0000	2.35	22.394
2.40	50.0000	2.40	5.4044	2.40	70.0000	2.40	13.404	2.40	75.0000	2.40	16.404	2.40	80.0000	2.40	19.404	2.40	85.0000	2.40	22.404
2.45	50.0000	2.45	5.4144	2.45	70.0000	2.45	13.414	2.45	75.0000	2.45	16.414	2.45	80.0000	2.45	19.414	2.45	85.0000	2.45	22.414
2.50	50.0000	2.50	5.4244	2.50	70.0000	2.50	13.424	2.50	75.0000	2.50	16.424	2.50	80.0000	2.50	19.424	2.50	85.0000	2.50	22.424
2.55	50.0000	2.55	5.4344	2.55	70.0000	2.55	13.434	2.55	75.0000	2.55	16.434	2.55	80.0000	2.55	19.434	2.55	85.0000	2.55	22.434
2.60	50.0000	2.60	5.4444	2.60	70.0000	2.60	13.444	2.60	75.0000	2.60	16.444	2.60	80.0000	2.60	19.444	2.60	85.0000	2.60	22.444
2.65	50.0000	2.65	5.4544	2.65	70.0000	2.65	13.454	2.65	75.0000	2.65	16.454	2.65	80.0000	2.65	19.454	2.65	85.0000	2.65	22.454
2.70	50.0000	2.70	5.4644	2.70	70.0000	2.70	13.464	2.70	75.0000	2.70	16.464	2.70	80.0000	2.70	19.464	2.70	85.0000	2.70	22.464
2.75	50.0000	2.75	5.4744	2.75	70.0000	2.75	13.474	2.75	75.0000	2.75	16.474	2.75	80.0000	2.75	19.474	2.75	85.0000	2.75	22.474
2.80	50.0000	2.80	5.4844	2.80	70.0000	2.80	13.484	2.80	75.0000	2.80	16.484	2.80	80.0000	2.80	19.484	2.80	85.0000	2.80	22.484
2.85	50.0000	2.85	5.4944	2.85	70.0000	2.85	13.494	2.85	75.0000	2.85									

ALLOWABLE LID LOAD

POSSIBLE MODES OF LID FAILURE

1. MATERIAL YIELDING: WOULD ALLOW CONTAINMENT CAVITY TO VENT DIRECTLY TO ATMOSPHERE

A. YIELDING OF LID FLANGE

B. YIELDING OF SECURING FASTENERS

C. YIELDING OF TAPPED RECEIVER

2. MATERIAL ULTIMATE STRENGTHS EXCEEDED. LID NO LONGER EFFECTIVE SHIELDING FOR PACKAGE

A. EXCEED ULTIMATE STRENGTH OF LID FLANGE

B. EXCEED ULTIMATE STRENGTH OF SECURING FASTENERS

C. CAUSE FAILURE OF THE TAPPED RECEIVER

LID FLANGE:

$$S_{MAX} = \frac{3W}{2\pi t^2} \left[1 - \frac{r_o^2}{2A^2} \right]$$

$$= \frac{3W}{2\pi (1.75)^2} \left[1 - \frac{4.70^2}{2 \times 65^2} \right]$$

$$= .627 W$$

FOR $T_y = 35K$, $W = 55.83K$, $g = 139.59$

$T_u = 82K$, $W = 130.81$, $g = 327$

SECURING FASTENERS(8) $\frac{1}{2}$ - 13 FASTENERS, SAE GRADE 5TENSILE YIELD = 12.1 K (EACH) $W = 96.8K$ $g = 242$ TENSILE ULT. = 17 K (EACH) $W = 136K$ $g = 340$

MALE THREAD SHEAR

$$P = (.75) \left(\frac{85,000}{2} \right) \pi (8) (.417) (.5) = 167 K, g = 417$$

TAPPED RECEIVER:(8) $\frac{1}{2}$ - 13 TAPPED HOLES .50 DEEP, 304 STL.

FEMALE THREAD SHEAR:

$$P = (.875) \left(\frac{35,000}{2} \right) \pi (8) (.5) (.482) = 92.75K, g = 232$$

MATERIAL YIELDING, (CAUSING CONTAINMENT CAVITY TO VENT DIRECTLY TO THE ATMOSPHERE WILL OCCUR WHEN

$$g \geq 140 \text{ ALONG AXIS OF PACKAGE}$$

(NOTE THAT PACKAGE CONTENTS WOULD NOT BE LOST).

MATERIAL FAILURE, ALLOWING THE LID TO SEPARATE FROM THE PACKAGE AND CONTENTS TO COME OUT OF CAVITY WILL OCCUR WHEN:

$$g \geq 232 \text{ ALONG AXIS OF PACKAGE}$$

THE ABOVE NUMBERS DO NOT REFLECT THE WEIGHT OF THE PACKAGE CONTENTS LOADING THE LID. IF THE CONTENTS HAVE AN AVERAGE SPECIFIC GRAVITY OF 5.0 (215 lb load). ACCEPTABLE g LOADS BECOME:

YIELDING OCCURS AT $g \geq 91$ FAILURE OCCURS AT $g \geq 151$

SIDE DROP GEOMETRY

ϕ	d	VOL	ENERGY DISSIPATED	g 's
5°	.0097	3.78	17.7 in.-kips	146
10°	.039	2.77	129 "	306
15°	.087	2.39	439 "	517
20°	.156	22.19	1038 "	694
25°	.243	43.24	2024 "	907
30°	.349	74.38	3481 "	1100
33°	.422	98.72	4670 "	1248

THE g COMPONENT TENDING TO OPEN THE LID INTERFACE IS 0, ($\cos 90^\circ$) IN THIS GEOMETRY. THE LIDS DESIGN IS SUCH THAT THE HIGH APPLIED SHEAR LOAD IS TAKEN UP IN THE RECEIVER.

THE OUTER SHELL AND THE INTERNAL STAINLESS STEEL RECEIVER REMAIN EFFECTIVE IN RESTRAINING THE URANIUM SHIELDING PIECES.

THERE IS NO POSSIBILITY OF THE PACKAGE FAILING BY COLLAPSE AS THE 1248 g MAX DECELERATION IT EXPERIENCES IS CONSIDERABLY LESS THAN THE 2702 g 's REQUIRED FOR THIS FAILURE MODE (SEE PAGE 20)

NO MODE OF FAILURE FOR THIS DROP GEOMETRY IS FORESEEN.

Shielding reduction based upon the decreased thickness of the uranium after exposure to the 30 foot free drop analysis may be computed from the chart below.

$$\text{FRACTION OF MIN WALL} = \frac{\text{SHIELDING REMAINING}}{6.5" \text{ MIN. DESIGN U THICKNESS}}$$

DROP ANGLE DEGREES	DEFORMATION INCHES	SHIELDING REMAINING	FRACTION OF MIN. WALL
0	.318	7.182	1.104923
5	1.15	6.887974	1.059688
10	1.62	6.894773	1.060734
15	2	6.92677	1.065657
20	2.3	6.970829	1.072435
25	2.6	6.94433	1.068358
30	2.8	6.945193	1.068491
35	3	6.871889	1.057214
40	3.12	6.803453	1.046685
45	3.18	6.719494	1.033768
50	3.2	6.600193	1.015414
55	3.22	6.406306	.9855856
60	3.12	6.259157	.9629473
65	3	6.060627	.9324041
70	2.75	5.923139	.9112522
75	2.5	5.719644	.8792452
80	2.2	5.503591	.8467064
85	1.7	5.42891	.8352169
90	.422	6.078	.9350769

2. Puncture-- A free drop through a distance of forty inches striking, in a position for which maximum damage is expected, the top end of a vertical cylindrical mild steel bar mounted on an essentially unyielding horizontal surface. The bar shall be six inches in diameter, with the top horizontal and its edge rounded to a radius of not more than one-quarter inch, and of such a length as to cause maximum damage to the package, but not less than eight inches long. The long axis of the bar shall be normal to the package surface.

PUNCTURE EFFECTS:

Subjecting the package to this test releases no radioactive material from the containment cavity (cavity is unaffected), and produces approximately .59 in reduction in shielding thickness (leaving 90.9% of minimum design wall thickness).

PUNCTURE TEST:

35

AREA OF 6" DIA SPIKE
= 28.27

ENERGY TO DISSIPATE
= 90 IN (12.5 KIIPS)
= 500 IN-KIPS

SHEAR AREA IN THE URANIUM = $\pi (6) (12.5)$
= 122.5 IN²

IF PUNCTURE TEST ENERGY IS ABSORBED PLASTICALLY
BY THE URANIUM:

$$F = (28.27 \text{ IN}^2) (30 \text{ KSI})$$

$$F = 848.1 \text{ KIIPS}$$

(URANIUM YIELD STRENGTH
USED BECAUSE OF EXPECTED
SMALL PLASTIC
DEFORMATION)

SHEAR STRENGTH REQUIRED:

$$T = \frac{848.1}{122.5} = 6.92 \text{ KSI}$$

SHEAR STRENGTH PRESENT:

$$\frac{1}{2} \text{ TENSILE YIELD OF URANIUM} = \frac{30 \text{ KSI}}{2} = 15 \text{ KSI}$$

THE SPIKE DOES NOT CAUSE PUNCTURE TO TAKE

URANIUM DOES
NOT FAIL IN
SHEAR

PENETRATION DEPTH

NEGLECTING THE ENERGY DISSIPATION
PRIOR TO FLATTENING THE WALL:

$$\delta_{\text{MAX}} = \frac{E}{\text{AREA}} = \frac{\text{ENERGY}}{\text{STRESS AREA}}$$

$$= \frac{500}{30 \times 28.27} = 1.59 \text{ IN}$$

$$\frac{1}{2} \text{ LOAD ON PACKAGE} = \frac{848.1}{12.5} = 68$$

NO FAILURE AT
COLLAPSE - SEE
PAGE 26

CHECK BENDING CAUSED BY PUNCTURE DROP:

EFFECTIVENESS OF THE STEEL JACKET IN ~~CONTAINING~~ CONTINUING TO RESTRAIN THE URANIUM SHIELDING PIECES (CAN BE FOUND BY CHECKING THE BENDING STRESS INDUCED. (INNER CAVITY LINER NEGLECTED))

$$I = \frac{\pi}{64} (D_o^4 - D_i^4) = \frac{\pi}{64} (20.5^4 - 19.75^4)$$

$$I = 1200.74 \text{ in}^4$$

$$M = \frac{FL^2}{8} = 6360.75 \text{ in-kips}$$

$$\sigma_b = \frac{Mc}{I} = \frac{848.1k \times 60 \times 10.25}{8 \times 1200.74 \text{ in}^4}$$

$$\sigma_b = 54.3 \text{ ksi} \text{ ABOVE THE ALLOWABLE}$$

YIELD STRENGTH (35 ksi) OF THE JACKET MATERIAL, FURTHER INVESTIGATION REQUIRED. THE FOLLOWING WILL EVALUATE THE EXTENT OF PLASTIC ACTION

USING PLASTIC ANALYSIS THEORY:

$$\text{IF } F_t = F_c$$

$$\text{AND IF } T_c = T_t \text{ THEN}$$

$$\text{AREA}_{(\text{COMPRESSION})} = \text{AREA}_{(\text{TENSION})}$$

AND THE NEUTRAL AXIS WILL LIE ON THE LINE DIVIDING THESE EQUAL AREAS.

Locate the neutral axis $x-x$ for the new geometry by equating the areas of the cylindrical segment above it to the area of the circular segment below it.

Cyl. segment: $A = \left(\frac{2\pi - \phi}{2\pi}\right) \pi (r_o^2 - r_i^2)$

$$A = \left(\frac{2\pi - \phi}{2}\right) (r_o^2 - r_i^2)$$

Circular segment: $A = \frac{1}{2} r_o^2 (\phi - \sin \phi)$

equating the two:

$$\frac{2\pi - \phi}{\phi - \sin \phi} = \frac{r_o^2}{r_o^2 - r_i^2} = 13.92$$

- OR -

$$\phi = .93 \sin \phi + .421$$

$$\phi = 1.32 \text{ radian } (75.74^\circ)$$

ϕ	$.93 \sin \phi + .421$
1.0	1.203
1.2	1.28
1.3	1.31
1.32	1.32

$$\begin{aligned} \text{Area of each segment} &= \frac{2\pi - 1.32}{2} (10.25^2 - 9.875^2) \\ &= \underline{\underline{18.73 \text{ in}^2}} \end{aligned}$$

Locate centroids for each segment:

cyl. seg:

$$\begin{aligned} \bar{y}_c &= R \left(\frac{\sin \alpha}{\alpha} - \cos \alpha \right) \\ &= 10.25 (.2477 + .789) \end{aligned}$$

$$\bar{y}_c = 10.626$$

CIRC. SEG:

$$\bar{y}_c = R \left(\frac{4 \sin^3 \theta}{6 \theta - 3 \sin 2\theta} - \cos \theta \right)$$

$$= 10.25 \left(\frac{.925}{1.05} - .789 \right)$$

$$\bar{y}_c = .92$$

IF THE SECTION BEHAVES
IN A PLASTIC MODE THE
STRESS DIAGRAM WILL
APPEAR AS:

$$F = \sigma A$$

$$= 35 \text{ ksi} (18.73 \text{ in}^2)$$

$$F = 655.55 \text{ Kips}$$

Moment to which the section
will be subjected:

$$M = FL = (655.55)(11.55)$$

$$M = 7572 \text{ in-kips (larger than the 6361 in-kips the section is subjected to.)}$$

$$g = \frac{BM}{WL} = \frac{8(7572)}{12.5 \times 60} = 81$$

Inelastic bending will occur but the amount will be small as the material in contact with the spike will start to deform before the full plastic bending capacity of the package is reached. The deformation at the spike is therefore less than the .59 inches calculated.

3. Thermal-- Exposure for thirty minutes within a source of radiant heat having a temperature of 1475°F and an emissivity coefficient of 0.9, or equivalent. For calculational purposes, it shall be assumed that the package has an absorption coefficient of 0.8. The package shall not be cooled artificially until after the thirty minute test period has expired and the temperature at the center of the package has begun to fall.

THERMAL ANALYSIS:

A computer program, TRUMP, for transient and steady-state temperature distributions in multidimensional systems was utilized to obtain thermal response data for the package.

TRUMP solves a general nonlinear parabolic partial differential equation describing flow in various kinds of potential fields, such as temperature. Steady-state and transient flow in one, two, or three dimensions are considered in geometrical configurations having simple or complex shapes and structures. Initial conditions may vary with spatial position. Material properties, source and sink strengths, boundary conditions, and other problem parameters may vary with spatial position, time, or the primary dependent variable-temperature. External sources or sinks, coupled to the system by means of specified boundary conditions, may vary with time.

Based upon the containment cavity's large length to radius ratio (42/3) a one dimensional analysis was employed. The cross-sectional geometry is shown. The following figure presents a steady-state temperature profile through the package and the thermal response curve for exposure of the package to the required thermal test.

No material failures are anticipated in the package as a result of the thermal test exposure. The containment cavity of the package is vented directly to the ambient atmosphere through the loss of the o-ring lid seal and the fusible plug on the drain pipe. There is, however, no release of radioactive material from the package as the fuel pins it contains constitute a special form material package.

THERMAL MODEL

IMPOSED FIRE CONDITION
FOLLOWED BY
130°F AMBIENT AIR

TEMPERATURE RESPONSE

4. Water Immersion-- Immersion in water for twenty-four hours to a depth of at least three feet.

IMMERSION EFFECTS:

Twenty-four hours of water immersion at a depth of at least three feet after the package has been subjected to the foregoing free drop, puncture, and thermal exposure sections of the hypothetical accident conditions will produce the following effects:

- a. Water may enter the containment cavity of the package through the deformed lid interface where the o-ring seal is no longer effective and through the open drain pipe which would no longer be capped with the fusible plug. Because of the special form material contained, this would cause no release of radioactive material. No chemical, galvanic, or other significant reaction would occur due to the addition of the water in this location.
- b. Water could enter the interface spaces between the depleted uranium shielding material and the stainless steel jacket. No reaction, chemical, galvanic, or other would occur due to this water entrance.

APPENDIX C: QUALITY ASSURANCE

LASL QUALITY ASSURANCE PROGRAM MANUAL LA-UR-73-603, SUPPL. 19

QUALITY ASSURANCE PROGRAM PLAN FOR SHIPPING CASK FOR FAST REACTOR FUEL ELEMENTS LAB-JOB 3856-0

1. SCOPE

This document sets forth the elements of a program for quality assurance and methods of quality control and verification which will be used during the design, procurement, fabrication, operation, maintenance, and modification phases of the Shipping Cask for Fast Reactor Fuel Elements, hereafter called the Container. The quality assurance program presented in this document is based on meeting the requirements of the LASL Quality Assurance Program Manual for Engineering and Construction Projects.

The Container is intended for the shipment of fissile material and large quantity amounts of radioactive material. The operating organization for the Container will be CMB-14.

2. QUALITY PROGRAM ELEMENTS AND ACTIONS

The Quality Assurance Program for the Container will be in accordance with the "LASL Quality Assurance Program for Engineering and Construction Projects", including the Quality Assurance manuals, design, documentation, procedures, inspection, and other activities pertaining to quality assurance of all organizations performing quality assurance functions for the project.

The consequence of failure for the Container has been established as Type I (failure could cause an incident affecting public health and safety) and its component complexity category is L (simple parts). The Component Quality Assurance Level Classification for the Container is therefore C. Table 1 lists the Quality Assurance activities required for the Container.

3. ORGANIZATION

The requirements of this document will be imposed on all organizations performing work on the Container. Services of other groups will be required to carry out project functions including, but not limited to, those listed below:

<u>Function</u>	<u>Organizations or Individuals</u>
Design	LASL Engineering Department CMB-14 QA Review Board
Stress Analysis	LASL Engineering Department
Failure Studies	LASL Engineering Department
Purchasing	LASL Supply & Property Department
Supplier Qualifications	LASL Supply & Property Department LASL Engineering Department
Source Inspection	LASL Engineering Department LASL Shop Department
Receiving	LASL Supply & Property Department
Receiving Inspection	LASL Supply & Property Department LASL Engineering Department LASL Shop Department
Warehousing & Material Protection & Control	LASL Supply & Property Department
Fabrication	LASL Shop Department Contractor
Chemical, Physical & Spectographic Analyses	LASL CMB-Division
Nondestructive Testing	LASL M-1 Group Contractor
Inspection of Fabrication	LASL Engineering Department LASL Shop Department LASL Supply & Property Department Contractor
Third Party Inspection for Compliance	As required
Fabrication Administration	LASL Engineering Department

<u>Function</u>	<u>Organizations or Individuals</u>
Acceptance Test Procedures	LASL Engineering Department CMB-14
Acceptance Test Performance	LASL Engineering Department CMB-14 Contractor
Welding Qualification	Contractor
Auditing	LASL Quality Assurance Head
Quality Assurance Review	
Board Members	See LASL Internal Supplemental Information Bulletin
Quality Assurance Waiver	
Board Members	See LASL Internal Supplemental Information Bulletin
Operation Administration	CMB-14

4. DOCUMENTATION

A. Records Accumulation and Retention

All quality assurance documentation shall be retained in the "Quality Assurance Binder" of the LAB JOB 3856-0 Folder. The LAB JOB is an internal Engineering Department numbering system that allows documentation for any given project to be filed and retrieved. Upon completion of fabrication a copy of the QA Binder will reside with the LASL Supply and Property Department.

MANAGEMENT

Quality Assurance Planning
Quality Assurance Personnel Organization,
Retention, and Distribution

DESIGN

Design Document Release and Change Controls
Design Criteria
Fabrication Drawings and Specifications
Procurement Drawings and Specifications
Special or Industrial Standards
Design Review
Failure Study
Operability and Maintainability Study

PROCUREMENT

Q.A. Review of Procurement Document and Changes
Purchase Order to Include Necessary Standards
Qualified Suppliers
Qualified LASL Inspectors and NDT Personnel
Control of Received Items
Controls on Handling, Packaging, etc.
Source Inspection
Control of Nonconforming Items
Corrective Action
Warehouse Control

MANUFACTURING

Qualified Workers and Procedures
Qualified NDT Personnel and Procedures
Certified Materials
Acceptance Testing
Certified Inspection
Control on Nonconforming Items
Corrective Action
Control of Measuring and Test Equipment
Cleaning and Clearances Control
Handling, Packaging, and Shipping Controls
Working of Shop

OPERATION AND MAINTENANCE

Document Control
Operator Training and Qualification
Controlled Operating Procedures
Controlled Maintenance Procedures
In-Service Inspection Program
Failure and Incident Report
Corrective Action

TABLE 1
QUALITY ASSURANCE ACTIVITIES
REQUIRED FOR COMBAT

LOS ALAMOS SCIENTIFIC LABORATORY
ENGINEERING DEPARTMENT

WELDING SPECIFICATION ENG-6 Sp-8

1.0 PURPOSE

- 1.1 The purpose of this specification is to govern the welding of corrosion resistant steels, aluminum alloys, and carbon and low alloy steels.

2.0 SCOPE

- 2.1 This specification covers the requirements for process control, inspection, and acceptance of welds of corrosion-resistant steels, aluminum alloys, and carbon and low alloy steels. Use of manual, semiautomatic, and automatic techniques are within the scope of this specification.
- 2.2 Drawing references to particular welds and callout of particular processes will be in addition to the requirements of these specifications.

3.0 APPLICABLE DOCUMENTS

- 3.1 MIL-STD-410, "Certification of Penetrant Inspection Personnel".
- 3.2 MIL-I-6866, "Inspection, Penetrant Method of."
- 3.3 MIL-I-6868, "Inspection Process, Magnetic Particle".
- 3.4 MIL-C-7701, "Certification of Magnetic Particle Inspection Personnel".
- 3.5 American Society of Mechanical Engineers, Boiler and Pressure Vessel Code, Sections VIII and IX.
- 3.6 AWS Welding Handbook (Welding Symbol Interpretations).

4.0 REQUIREMENTS

4.1 Qualification and Certification of Welders.

- 4.1.1 Welders and welding operators using manual, semiautomatic, and automatic equipment shall pass qualification tests and be certified per the ASME Boiler and Pressure Vessel Code, Section IX, for the applicable material thickness, alloy, and process.
- 4.1.2 The supplier shall furnish evidence of such qualification to the buyer.

4.1.3 The welding procedure to be used by the supplier shall be submitted to the buyer for approval. In addition to standard items, this procedure shall specify a list showing which filler materials will be used on each alloy, or combination of alloys as called out on the drawings of parts to be welded. Also included shall be a detailed description of the cleaning procedure to be used before welding.

4.1.4 The welding equipment used shall be capable of consistently producing satisfactory welds, when used by a competent operator.

4.2 Weld Preparation

4.2.1 All scale, slag, grease, oil, rust and other foreign matter shall be removed from the area within four inches on both sides of the welding zone before welding is started.

5.0 QUALITY ASSURANCE PROVISIONS

5.1 All flux, slag, and spatter shall be thoroughly removed from the weldment before final inspection.

5.2 Weldments shall be inspected after any heat treatment and prior to machining or surface finishing operations which might obscure defects.

5.3 Evidence of lack of control over the welding process, poor workmanship, or poor appearance shall be cause for rejection by the buyer's inspector.

5.4 Inspection - Class I

5.4.1 Unless otherwise specified on the product drawing, the inspection requirements for Class I welds shall be (1) 100 percent visual, (2) 100 percent magnetic particle or penetrant, and (3) 100 percent radiographic inspection of each weldment. Limits of imperfections in acceptable welds are shown in Table I. Magnetic particle and penetrant inspection shall be in accordance with MIL-I-6866 and MIL-I-6866, respectively. Magnetic particle and penetrant inspection personnel shall be certified in accordance with MIL-C-7701 or MIL-STD-410, as applicable. Radiographic inspection shall be in accordance with Para. UW-51, Section VIII of ASME Pressure Vessel Code.

5.5 Inspection - Class II

5.5.1 Unless otherwise specified on the product drawing, the inspection requirements for Class II welds shall be 100 percent visual. Limits of imperfections in acceptable welds are shown in Table II. Magnetic

- 5.5.1 particle and penetrant inspection, if required, shall be in accordance with MIL-I-6868 and MIL-I-6866, respectively. Magnetic particle and penetrant inspection personnel shall be certified in accordance with MIL-C-7701 or MIL-STD-410, as applicable.

5.6 Repair of Defects

- 5.6.1 Repair of defects is permissible if the repaired weldment, the repair weld itself, and the adjacent parent metal meet the requirements of the original weldment. A repaired weldment shall be re-inspected in the same manner as the original weldment.

6.0 CARBON AND LOW ALLOY STEEL

6.1 Method

- 6.1.1 Welding shall be done by any of the arc welding processes or by the oxyacetylene process where applicable.
- 6.1.2 Beveling and weld preparation may be done by any conventional means including oxyacetylene cutting, provided precautions are taken to prevent cracking.
- 6.1.3 All low alloy steels having a carbon content greater than 0.25 percent and carbon steels having a carbon content greater than 0.35 percent shall be preheated to, and maintained at, a minimum temperature of 350°F during welding.
- 6.1.4 Welds shall be cooled no more severely than by still air at room temperature.

6.2 Repair of Defects in Heat Treated Parts

- 6.2.1 Weldments that are heat treated after welding may be repair-welded only after reduction to a strength level lower than 125,000 psi tensile ultimate and provided that heat treatment follows repairing.

7.0 CORROSION RESISTANT STEELS

7.1 Method

- 7.1.1 Welding shall be done by any of the arc welding processes.

7.2 Repair of Defects in Heat Treated Parts

- 7.2.1 Weldments that are heat treated after welding may be repair-welded only after reduction to a strength level lower than 125,000 psi tensile ultimate and provided that heat treatment follows repairing.

8.0 ALUMINUM

8.1 Method

- 8.1.1 Welding shall be done by the inert-gas-shielded metal arc process using a consumable electrode, or the inert-gas-shielded tungsten arc process.

CLASS I WELDS
TABLE I
LIMITS OF IMPERFECTIONS IN ACCEPTABLE WELDS

Imperfection	Limit	
Cracks in weld bead	Unacceptable	
Cracks in parent metal	Unacceptable	
Crater cracks	Unacceptable	
Incomplete fusion	Unacceptable	
Inadequate joint penetration	Unacceptable	
Porosity	Porosity may be scattered, aligned, or a combination of both. The maximum size and population of porosity as seen on the radiographic film shall be in accordance with Appendix IV of Section VIII of the ASME Pressure Vessel Code.	
Inclusions	Inclusions shall be evaluated as porosity.	
Undercut	Unacceptable	
Overlap	Unacceptable	
Convexity of butt welds either side (reinforcement height maximum)	<u>Weld Size</u> Up to 0.125 0.125 to 0.500 0.500 and over	<u>Convexity</u> 0.050 inch 25% of weld size 0.125 inch
Concavity	Unacceptable in butt welds. In fillet welds, actual throat shall be not less than theoretical throat for specified weld size.	
Fillet weld size limits	Specified weld size (leg) $+50\%$, -0% .	

CLASS II WELDS
TABLE 2
LIMITS OF IMPERFECTIONS IN ACCEPTABLE WELDS

Imperfection	Limit	
Cracks in weld bead	Unacceptable	
Cracks in parent metal	Unacceptable	
Crater cracks	Unacceptable (See Note 1)	
Incomplete fusion or Inadequate joint penetration	Added together. Unacceptable if greatest summation exceeds a length of $1 \frac{1}{2}T$ in a weld length of $6T$ or a single defect exceeds $1/2T$ (See Note 2). If the weld length is less than $6T$, the greatest summation shall not exceed $1/4$ the length of the weld or a single defect exceed $1/12$ the length.	
Porosity	Internal spherical porosity is not a factor in the acceptability.	
Undercut	Unacceptable (See Note 3)	
Overlap	Unacceptable (See Note 3)	
Convexity of butt welds, either side (reinforcement height)	<u>Weld Size</u>	<u>Convexity (Max)</u>
	Up to 0.125	0.050 inch
	0.125 to 0.500	25% of weld size
	0.500 and over	0.125 inch
Concavity	Unacceptable in butt welds. In fillet welds, actual throat shall be not less than theoretical throat for specified weld size.	
Fillet weld size limits	Specified weld size (leg) +50%, -0%	

NOTES:

1. Infrequent star or single crater cracks that do not extend beyond the crater itself may be acceptable, as judged by an approved inspector from LASL.

CLASS II WELDS

TABLE 2

NOTES: (Continued)

2. (T) is the specified weld size.
3. Infrequent undercut and overlap may be acceptable, as judged by an approved inspector from LASL.

APPENDIX D: U. S. ATOMIC ENERGY COMMISSION APPROVAL

Form AEC-618
(9-72)
AECM 5201

**U.S. ATOMIC ENERGY COMMISSION
CERTIFICATE OF COMPLIANCE
For Radioactive Materials Packages**

1a. Number AEC - AL USA/5885/ULF	1b. Revision No. ORIGINAL	1c. Page No. 1	1d. Total No. Pages 2
--	-------------------------------------	--------------------------	---------------------------------

2. Authority

This certificate is issued pursuant to Sections 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations as amended (49 CFR 170-189 and 14 CFR 103), and AEC Manual Chapters 5201 and 0529.

3. CONDITIONS

3a. This certificate is issued on the basis of SAFETY ANALYSIS REPORT FOR PACKAGING (SARP)

(1) Prepared by

Los Alamos Scientific Laboratory
University of California
Los Alamos, N.M. 87544

(2) Number

LA-5526

(3) Date Published

MARCH 1974

3b. The packaging described in the SARP and further described in item 4 below, when constructed and assembled as prescribed in the SARP, with the contents as authorized herein, meets the standards prescribed in DOT regulations.

3c. The outside of each package must be plainly and durably marked with the letters and number shown in item 1a, on this form in accordance with the standards for markings in paragraph 173.24(b) of 49 CFR 173.

3d. This certificate does not relieve the consignor from compliance with any requirements of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies.

3e. Each user of packages approved under this certificate shall register his name and address with the issuing office.

4. Description of Packaging and Authorized Contents, Restrictions, and References:

(a) Description

Container is a steel-jacketed cylindrical depleted uranium cask weighing approximately 12,500 lbs. A copper barrier is provided between the steel and uranium to preclude eutectic formation. The uranium is 6.5-inches thick and the outer jacket is 3/8" steel. A removable base is provided for ease of handling. Cask dimensions are 61" high and 20.5" diameter with a cavity 44" in length and 6.12" diameter.

(b) Authorized Contents

Fissile or other radioactive materials will be contained in fuel pins or capsules which conform to special form criteria.

TO BE COMPLETED BY AEC

5a. Address (of AEC Approving Official) Albuquerque Operations Office P. O. Box 3400 Albuquerque, New Mexico 87115	5b. Signature (of AEC Approving Official)
	5c. Name and Title (of AEC Approving Official) Jack R. Roeder, Director Operational Safety Division	
	6. Expiration Date (If appropriate) --	7. Date April 17, 1974

- 2 - AEC-AL USA/5885/BLF
April 17, 1974

(c) Restrictions

The cask as prepared for shipment may contain fissile material and large quantities of radioactive material. Fissile material may include uranium 233, uranium 235, and plutonium. The linear density of uranium 233 times 0.004 plus the linear density of plutonium times 0.004 plus the linear density of uranium 235 times 0.00133 will not exceed 1 gram per centimeter. The cask will be shipped as Fissile Class I.

These drawings are available from the
National Technical Information Service,
U. S. Department of Commerce, 5285 Port
Royal Road, Springfield, VA 22151.