APPLICATION

for

NRC CERTIFICATE OF COMPLIANCE

authorizing

SHIPMENT OF REACTOR FUEL ELEMENTS IN

WESTINGHOUSE MODEL MO-1 PACKAGING

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WESTINGHOUSE ELECTRIC CORPORATION

Pittsburgh, PA

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APPLICATION

FOR

NRC CERTIFICATE OF COMPLIANCE

AUTHORIZING

SHIPMENT OF MIXED OXIDE FUEL ASSEMBLIES

IN

WESTINGHOUSE NUCLEAR FUEL ASSEMBLY PACKAGING MODEL MO-1

0.0 GENERAL INFORMATION

0.1 Introduction

This application seeks authorization to deliver reactor fuel assemblies in the Model MO-1 Packaging to carriers for transport. When the reactor fuel contains mixed oxides (i.e., UO_2 -PuO_2) exclusive use vehicles will be used. The maximum number of such packages per shipment under Class II conditions is thirty one (31) or a Transport Index of 1.6. Under Class III conditions the maximum number of packages is sixty two (62). Authorization is sought for shipment by cargo vessel, motor vehicle, and rail.

The Model MO-1 Packaging uses an adjustable fuel element internal clamping assembly identical with that employed in the Model RCC-1 Fuel Assembly Shipping Container as approved under

NRC Certificate No. 5450, Docket 71-5450. (See Appendix 1.10.1) A new outer container employs design features assuring that the packaging meets the requirements of 10 CFR 71.

0.2 Package Description

0.2.1 Packaging

0.2.1.1 General Description

The Model MO-1 Packaging consists of a reusable insulated and shock absorbing shipping packaging designed to protect reactor fuel element assemblies from normal conditions of transport and hypothetical accident conditions.

0.2.1.2 Materials of Construction, Dimensions, & Fabricating Methods

General Arrangement drawings of the Model MO-1 Packaging are included in Appendix 1.10.2. They show overall dimensions of the overpack with its outer and inner steel shells. The shells are fabricated of ductile low carbon steel which allows them to undergo large deformation without fracturing. All joints are arc welded with full penetration welds to assure structural integrity.

The volume between the inner and outer shell is filled with a shock-and-thermal-insulating material consisting of rigid polyurethane foam having a density of approximately five pounds per cubic foot. The insulating material is poured into the cavity between the two shells and allowed to expand completely filling the void. Here it bonds to the shells creating a unitized construction for the packaging. Mechanical properties of these materials are further described in Section 1.0, below.

Once assembled, the overpack takes the shape of a rectangular box with a central separation plane. In use, the lower unit comprises the body or base of the container while the upper unit serves as the lid. The stepped joint between the two halves is sealed with a neoprene gasket. Heavy gauge rectangular tubing is used to form a rigid structural interface and support frame for the internal shock mount system.

The upper and lower sections of the overpack, called the lid and body respectively, are pulled together and secured by 12 ratchet binders (primary attachment). As a redundant or secondary method, twelve high strength latch pins, 5/8 inches in diameter are then inserted through the lid into the body. This will insure that the overpack halves will remain together even if the ratchet binders are destroyed. Each latch pin is attached adjacent to a steel guide assembly which protects it from inadvertent abuse. From the general arrangement drawing, it can be seen that all pins are loaded in double shear.

0.2.1.3 Containment Vessel

The overpack is not intended to be the containment vessel. Its prime function is to reduce the severity of the hypothetical accident conditions such that the reactor fuel elements (rods) can serve as the containment vessel. Fuel may be shipped in pressurized or unpressurized rods. These rods may in turn be fabricated into fuel assemblies or be packed as loose rods in fuel rod boxes. The assemblies or boxes would then be secured to the strongback assembly for transport. The strong-back assembly and shock mount system are identical to those currently used in the RCC-1 container. In all cases the individual rod will be considered the containment vessel.

0.2.1.4 Neutron Absorbers

The strongback assembly must contain neutron absorbers positioned between pairs of fuel assemblies. The Model MO-1 Packaging provides for two 0.188 inch thick, full length, borated stainless steel poison plates or their equivalents.

0.2.1.5 Package Weight

Gross weight of the package is approximately 8600 pounds.

0.2.1.6 Support System

The internal shock mounted support mechanism is identical to that used in the existing RCC-1 Package. This support mechanism is suspended within the container shell by means of 18 rubber shock mounts. These provide shock and vibration isolation and permit movement of the internals within the shell.

0.2.1.7 Sampling Port

There are no sampling ports.

0.2.1.8 Tiedowns

Tiedowns are a structural part of the package. From the attached general arrangement drawing it can be seen that four reinforced tiedown locations are provided. Refer to Section 1.4.4 for a detailed analysis of their structural integrity.

0.2.1.9 Lifting Devices

Lifting devices are a structural part of the package. From the general arrangement drawing it can be seen that four reinforced lifting locations are provided. Refer to Section 1.4.3 for a detailed analysis of their structural integrity.

0.2.1.10 Pressure Relief System

There are two valves involved; one used for pressurizing (with dry air or nitrogen) the inner cavity prior to shipping or storage, and one for relieving the inner cavity pressure prior to removing the lid. As such, both valves are grouped at one end of the overpack and protected from unnecessary exposure or damage during shipping and handling.

0.2.1.11 Heat Dissipation

There are no special devices used for the transfer or dissipation of heat. The package maximum design capacity is 400 watts. However, this value may be exceeded if it can be demonstrated that actual equilibrium temperatures with the higher heat load are still within allowable limits.

0.2.1.12 Coolants

There are no coolants involved.

0.2.1.13 Protrusions

There are no outer or inner protrusions except the external ratchet binders described in 0.2.1.2, above and the internal shock mounted support mechanism described in 0.2.1.6, above.

0.2.1.14 Shielding

The contents will be limited such that no radiological shielding will be needed to assure compliance with DOT regulatory requirements.

0.2.2. Operational Features

Refer to the schematic diagram of the packaging. There are no complex operational requirements connected with the Model MO-1 Packaging and none that have any transport significance.

0.2.3 Contents of Packaging

Contents will be those shown in Table 1 of Appendix 5.6.1.

1.0 STRUCTURAL EVALUATION

This Section identifies and describes the principal structural engineering design of the packaging, components, and systems important to safety and to compliance with the performance requirements of 10 CFR 71.

1.1 Structural Design

1.1.1 Discussion

The principal structural members and systems in the Model MO-1 Packaging are: (1) the primary containment vessel as described in Section 0.2.1 above; (2) the internal shock mounted support mechanism supporting and protecting the fuel rod assemblies; and (3) the insulated shipping container or overpack with its ratchet binder closure devices. The above components are identified on the drawing as noted in Appendix 1.10.2. They work together to satisfy the standards set forth in subpart C of 10 CFR 71. A detailed discussion of the structural design and performance of these components will be provided below.

1.1.2 Design Criteria

The overpack and shock mounted internal support mechanism are designed to work in combination to protect the fuel rods from normal transport conditions as well as the hypothetical accident conditions. Significant areas of concern are the transport environment, 30 foot drop test, the 40 inch puncture test, the 1475° F thermal exposure and the transfer or dissipation of any internally generated heat.

To eliminate any problems associated with shock and vibration loads during transport it was decided that the new package would incorporate the identical shock isolation system used in the standard RCC-1 Package. This system incorporates a strongback frame which is used to support two fuel assemblies over their entire length. A number of clamping frames clamp the fuel assemblies rigidly to the strongback. The entire system is then supported from the interior surface of the overpack by means of rubber shock absorbers. Proven performance over the years substantiates the adequacy of this concept.

It should be noted that both the unprotected pressurized and unpressurized fuel rods are capable of meeting all the requirements set forth for special form material with one exception. It has been determined through testing that the pressurized rod configuration when heated to temperatures exceeding 1100° F may be stressed beyond their yield point. (Ref. Appendix 1.10.3). This would result in a gross violation of rod clad integrity and the leakage of the helium and air mixture surrounding the pellets. Therefore, the prime function of the proposed overpack is to thermally insulate the pressurized rods from the 1475° F fire. For design purposes, it was determined that a conservative safety factor on temperature would be used to establish the maximum allowable rod temperature. Using this criteria, the maximum allowable temperature to be experienced by any rod must not exceed 600°F.

The nonpressurized rods do meet the special form requirement for 1475°F exposure and therefore the insulation requirement is even more conservative.

Since the fuel rods can sustain a 30 foot free fall unprotected, it is conservative to conclude that the environment experienced within an energy absorbing overpack and rubber mounted shock isolation system will be much less severe.

Damage to the overpack resulting from the 30 foot drop test and the 40 inch puncture test will be assessed in the following sections. The results of the thermal exposure will also be analyzed. The design criteria for measuring the effect of these tests is to prevent release of fuel assembly materials by mechanical and temperature control measures.

To expand the utility of the package, it was assumed that at some time it may be desirable to ship mixed oxide fuels that have heat generating capabilities. Therefore, it was assumed that a load of such rods may be represented by a maximum heat source of 400 watts and the packaging was designed accordingly.

1.2 Weights and Center of Gravity

The weight of the internal support mechanism containing the two fully loaded fuel assemblies will not exceed 4800 pounds. The overpack weight is approximately 3800 pounds making a maximum total gross weight for the Model MO-1 package of 8600 pounds. The center of graivyt for the assembled package is located at the approximate geometric center of gravity. A reference point for locating the center of gravity is shown on drawing 1581F50. (See Appendix 1.10.2)

1.3 Mechanical Properties of Materials

The Model MO-1 packaging uses an outer and inner shell fabricated of various thicknesses of low carbon hot rolled steel. Material properties of the steel are as follows:

Per Mil HDBK-V

F_{tu} = 55,000 psi

F_{ty} = 36,000 psi

F_{su} = 35,000 psi

F_{bry} = 90,000 psi

Rigid polyurethane foam fills the cavity between the steel shells. This material will have a density of approximately 5 pcf and be of a self-extinguishing variety. Minimum mechanical properties are as follows:

Compression Strength	=	100 psi
Thermal Conductivity K	=	.20 Btu in/hr-ft^2-^{o}F

1.4 General Standards for All Packages

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

1.4.1 Chemical and Galvanic Reactions

The materials from which the packaging is fabricated (steel, rubber shock mounts, and polyurethane foam) along with the contents of the package (zircaloy or stainless steel clad fuel rods and internal support mechanism hardware) will not cause significant chemical, galvanic, or other reaction in air, nitrogen, or water atmospheres.

1.4.2 Positive Closure

The positive closure system has been previously described in Section 0.2.1. In addition, each package will be sealed with an approved tamper indicating seal and suitable locks to prevent inadvertent and undetected opening.

1.4.3 Lifting Devices

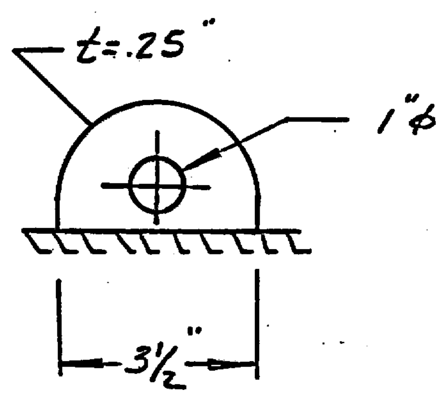
Four lifting locations are provided. The total load to be carried at each location can be calculated as follows:

P = (Pkg Wt) (3 g's)/No. of Lugs

= (8600 lbs) (3 g's) / (4)

= 6450 lbs/lug

The capacity of each lug can be determined from the following:



F_{su} = 35,000 psi (Min Per MIL HDB

Using the standard 40° shearout equation:

$P = F_{su}\, 2\, t \left[E.M. - d/2 \cos 40^{\circ}\right]$

= 35,000 psi) (2) (.25) (1.25-.50 cos 40°)

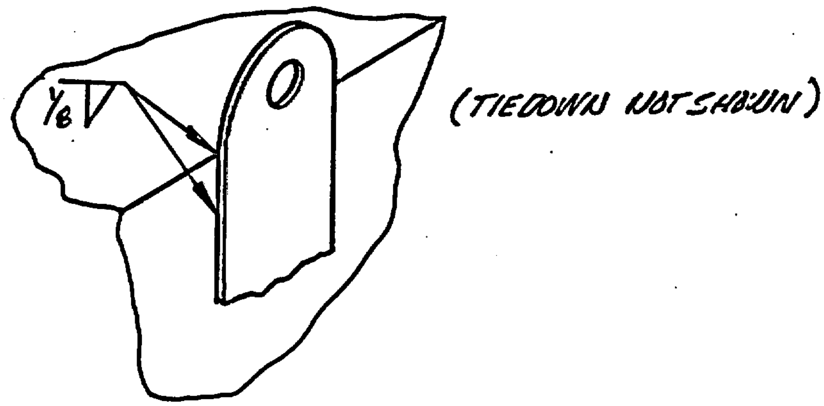
= 15,172lbs

Margin of Safety is:

MS = 15,172 /6450 - 1

MS = + Large

Stress along the welded lug base to skin is calculated as follows:



$F = P/A$

Where

$P = 6450$ lbs.

$A = (8 \text{ in}) (.125) (\text{Sin } 45^{\circ})$

$= .707 \text{ in}^2$

$F_t = 6450 \text{ lbs}/.707 \text{ in}^2$

$= 9123$ psi

Margin of Safety:

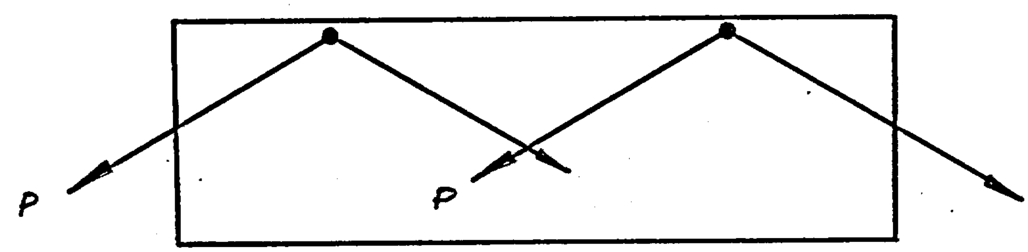
$MS = 35000/9123 - 1$

$MS = +$ LARGE

Therefore, it can be concluded that the lifting points are more than capable of reacting a load equal to three times the package weight. Should the lugs experience a load greater than 15172 pounds they will shear out locally. This will have no detrimental effects on the package's ability to meet other requirements of the subpart. The lugs will be covered during transport.

1.4.4 Tiedowns

Four tiedowns are provided. The total load carried by each can be calculated as follows:

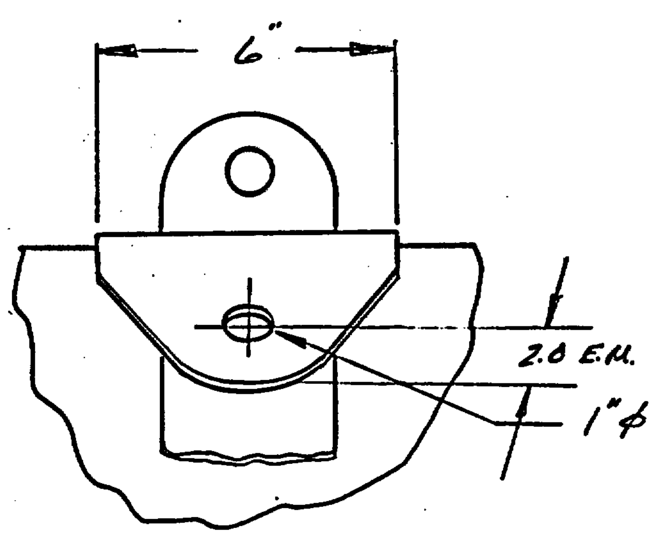


$$P = \text{(Pkg Wt) (10 g's) / (4 lugs) (Tiedown Angle, } \cos 30^{\circ})$$

$$= (8600)\ (10)\ /\ (4)\ (\cos 30^{\circ})$$

$$= 24826 \text{ lbs/lug}$$

The capacity of each lug can be determined from the following:



The capacity of the tiedown lug can be calculated as follows:

a) Using standard 40° shear out equation:

$$P = F_{su} 2\ t \left[E.M. - d/2 \cos 40^{\circ}\right]$$

$$= (35000)\ (2)\ (.375) \left[2.00 - 1/2 \cos 40^{\circ}\right]$$

$$= 42446 \text{ lbs.}$$

Margin of Safety:

$$MS = 42446/24826 - 1$$

$$MS = + .71$$

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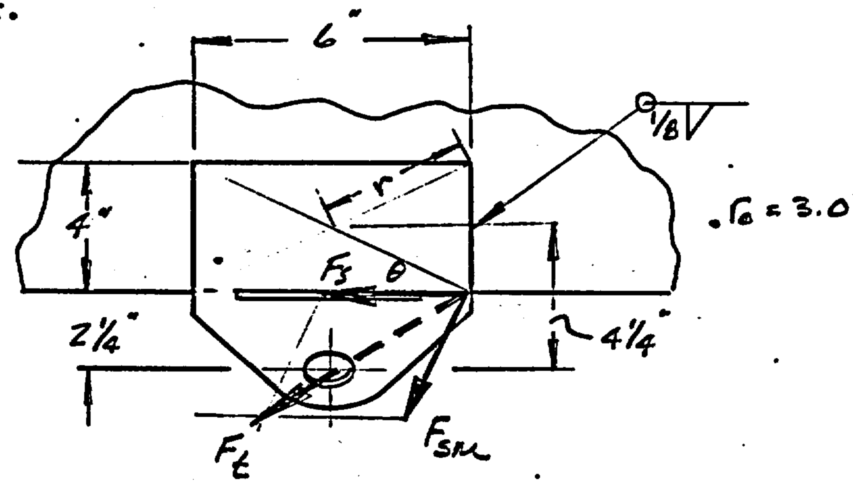
b) Lug to container shell welds:

Conservatively assume full load to be reacted parallel to container.



Direct shear stress is calculated as follows:

$$F_s = P/A$$

Where

$$P = 24826 \text{ lbs}$$

$$A = (20 \text{ in})\ (.125 \text{ in})\ (.707)$$

$$F_s = 14045 \text{ psi}$$

Secondly stress resulting from the moment is calculated as follows:

$$F_{sm} = Mr/J$$

Where

$$M = (24826 \text{ lbs})\ (4.25 \text{ in})$$

$$= 105510 \text{ in-lbs}$$

$$r = 3.60$$

$$J = A(L2/12 + ro)$$

$$= (20\ in)\ (1/8)\ (.707)\ (400/12 + 3)$$

$$= 64.23$$

$$F_{sm} = (105510)\ (3.6)\ /64.23$$

$$F_{sm} = 5914$$

Combining these stresses vectorily the total is given by:

$$F_t = F_s + F_{sm} \sin \theta$$

Where

F_s = 14045 psi

F_{sm} = 5914 psi

θ = 33.7°

$\sin \theta$ = .555

$$F_t = 14045 + (5914)\ (.555)$$

$$F_t = 17327 \text{ psi}$$

Margin of Safety:

$$M.S. = 36000/17327 - 1$$

$$M.S. = +1.07$$

Therefore, it can be concluded that the tiedowns are able to react loads greater than 10 g's. Should they experience loads greater than 42,446 lbs, (17 g's) the lug hole will locally shear out. This will not impair the overpack's ability to meet other requirements of this subsection.

Impact loads resulting from 30 foot drops will locally flatten both lugs (lifting and tiedown). Edge compression through the lifting lug will result in localized buckle of the tension strap portion. Therefore, the ratchet assemblies will not experience detrimental compression loads.

1.5 Standards for Type "B" and Large Quantity Packaging

This section demonstrates that the standards for Type "B" and large quantity packaging are met.

1.5.1 Load Resistance

The Model MO-1 Packaging was analyzed according to the requirements of 10 CFR 71.32, to demonstrate that it could satisfactorily withstand the specified loading. In performing the necessary calculations, the outer shell was analyzed as a simple beam without consideration being given to any reinforcing members. Assuming a package 206 inches long with a gross weight of 8600 pounds, the maximum unit load will be:

stress:

$$f = MC/I$$
$$= (1{,}108{,}640)(23.5)/9196$$
$$= 2833 \text{ psi}$$

where:

$$w = (5)(8600\text{lbs})/206 = 209 \text{ lb/in}$$
$$M = wL^2/8 = (209)(206)^2/8 = 1{,}108{,}640 \text{ in-lb}$$
$$I = (h_o^4 - h_i^4)/12 = (47^4 - 46.732^4)/12 = 9196 \text{ in}^4$$
$$C = 23.5 \text{ in}$$

Therefore, it can be safely concluded that the stress generated in the packaging due to this type of loading is considerably less than the yield stress. This is extremely conservative since the design of the package precludes its ability to be stacked in a manner that would produce this type of loading. All stacking loads are in direct foam and steel compression onto the ends of the overpack. This eliminates all bending loads.

1.5.2 External Pressure

The containment vessel, which is the individual fuel rod, is designed to operate at internal reactor pressures far greater than the 25 psig imposed by this condition. It is therefore safe to conclude that the containment vessel will suffer no loss of contents if subjected to an external pressure of 25 psig.

1.6 Normal Conditions of Transport

The Model MO-1 Packaging has been designed and constructed, and the contents are so limited (as described in Section 0.2.3 above) that the performance requirements specified in 10 CFR 71.35 will be met when the package is subjected to the normal conditions of transport specified in Appendix A of 10 CFR 71. The ability of the Model MO-1 Packaging to satisfactorily withstand the normal conditions of transport has been assessed as described below:

1.6.1 Heat

A detailed thermal analysis can be found in Section 1.7.3 wherein the package was exposed to direct sunlight and 130°F still air. The steady state analysis conservatively assumed a 24 hour day at maximum solar heat load. An internal heat load of 400 watts was used.

The maximum fuel rod temperature was found to be 232°F. External package temperature was less than 173°F. These temperatures will have no detrimental effects on the package.

1.6.2 Cold

The materials of construction for the packaging, including the overpack and the fuel rods themselves, are not significantly effected by an ambient temperature of -40°F. The package contains no fluids which could freeze and expand such as water.

1.6.3 Pressure

The package is not designed to be pressure tight. Seals located along the package lid to body interface are designed to minimize the entrance of external environmental elements such as rain, dust, etc. Should the package prove to hold pressure under a .5 atmospheric condition, it is equipped with a back up pressure relief valve. Any pressure rise in the container above 7.5 psig plus or minus 1 psi will be released by this release valve. It is designed to close at 5 psig plus or minus 1 psi gauge. It should be noted that this is the identical valve currently used on the RCC series of packages. Therefore, .5 time atmospheric pressure will not have a detrimental effect on the package.

1.6.4 Vibration

Shock and vibration normally incident to transport are considered to have negligible effects on the Model MO-1 Packaging. Rubber shock mounts previously described in Section 0.2.1 above are designed to limit the shock load at any position on the fuel assemblies to acceptable values under severe handling conditions. Conversely, the inertial loads imposed on the overpack by the strongback assembly are significantly attenuated.

1.6.5 Water Spray

Since the package exterior is constructed of steel, this test is not required.

1.6.6 Free Drop

This requirement is not applicable in light of the more stringent 30 foot drop requirement of Appendix B of 10 CFR 71.

Refer to Section 1.7, below.

1.6.7 Corner Drop

This requirement is not applicable since the Model MO-1 Packaging is fabricated of steel.

1.6.8 Penetration

From previous container tests as well as engineering judgement, it can be concluded that the 13 pound rod would have a negligible effect on a heavy 10 gauge steel shell.

1.6.9 Compression

It was demonstrated, in Section 1.5.1, above, that the Model MO-1 Packaging will support a uniformly distributed load equal to five times it fully loaded weight without generating stress in any packaging material in excess of its yield strength. Secondly, the entire external shell is backed with rigid polyurethane foam that has a compressive strength in excess of 100 psi. Therefore, the package can safely support compressive loads greater than 2 psi.

1.6.10 Conclusion

As the result of the above assessment, it is concluded that under normal conditions of transport:

1) There will be no release of radioactive material from the containment vessel;
2) The effectiveness of the packaging will not be substantially reduced;
3) There will be no mixture of gases or vapors in the package which could, through any credible increase in pressure or an explosion, significantly reduce the effectiveness of the package;
4) N/A (No coolants involved)
5) N/A (No coolants involved)

Also, as a result of the assessment described above, it is concluded that under normal conditions of transport:

1) The package will be subcritical (See Section 5.0 below for nuclear criticality safety assumptions, methods of analysis, and results);
2) The geometric form of the package contents will not be substantially altered;
3) The leakage of water into the package is of no significance since complete light water moderation and full light water reflection are assumed in all nuclear criticality safety calculations involved in the application;
4) There will be no substantial reduction in the effectiveness of the packaging, i.e.:
   i) The effective volume of the packaging on which nuclear criticality safety is assessed will not

be reduced by more than 5 %;

ii) The effective spacing on which nuclear criticality safety is assessed, between the center of the containment vessel and the outer surface of the packaging will not be reduced by more than 5%;

iii) An aperture cannot occur through the outer surface of the packaging.

1.7 Hypothetical Accident Conditions

The Model MO-1 Package has been designed and its contents are so limited that the performance requirements specified in 10 CFR 71.36 will be met if the package is subjected to the hypothetical accident conditions specified in Appendix B of 10 CFR 71.

To demonstrate the structural integrity of the package and its ability to withstand the hypothetical accident conditions, a detailed computerized analysis was conducted. It is important to note that the techniques, analysis methods, assumptions, and routines employed follow closely those used for other petitions such as:

1) DOT 6400 Super Tiger
2) DOT 6553 Paducah Tiger
3) DOT 6272 Poly Panther
4) DOT 6679 Half Super Tiger
5) DOT 6744 Poly Tiger
6) AECB - Resin Flask

These are proven techniques that agree closely with full scale tests as well as other publicized standards such as ORNL-NSIC-68. In all cases the analysis has been proven to be conservative when compared with full scale testing.

1.7.1 Free Drop

The performance and structural integrity of the Model MO-1 Package was evaluated for the drop orientation that casued the most severe damage as described below. The assessment of the package was made by analysis and details are provided below to show that the results have been verified.

1.7.1.1 Free Drop Impact Analysis

1.7.1.1.1 General Program Description

Introduction:

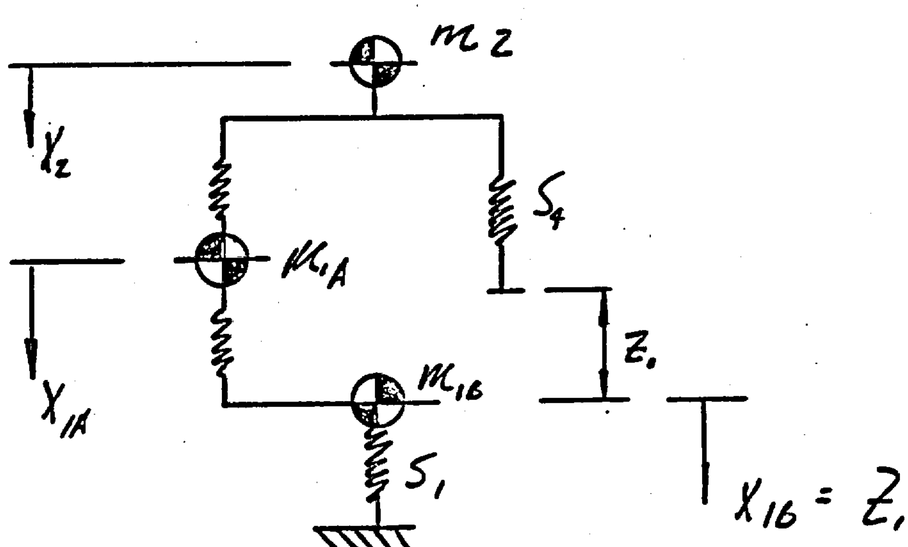
This program treats the impact of a shipping container as a three degree of freedom non-linear dynamics model. One degree of freedom depicts the response of the container, whereas, the second degree of freedom depicts the response of the payload. The non-linear springs, or load resisting elements, are represented with maximum generality and may be characterized by: linear coefficients, non-linear force-deflection tabular data, built-in functions (corner, edge, flat sides) or user defined subroutines. These non-linear springs may be tension-compression, compression only, or compression-memory and may, in certain instances, possess clearance gaps.

Additional provisions recognize (approximately) the change of mass as a body is incrementally crushed and comes to rest. Provisions are incorporated to select automatically appropriate computing and print intervals during the impact-time history. The solution terminates when the kinetic energy of the three body model falls below a pre-selected threshold value signifying "at rest" upon the unyielding surface.

Solution is achieved by an efficient variable step Runge-Kutta-Merson integration algorithm used extensively for highly non-linear dynamic analyses.

Derivation of Equations of Motion:

The math model schematic is as follows:



Where: m_{1A} = container mass - midbody (variable)

m_{1B} = container mass - impact zone (variable)

m_2 = payload mass (fixed)

S_i = Non-Linear Spring (whose Force = F_i)

g_o = Initial Clearance Gap for Spring S_4

Initial Conditions @ t = 0:

$$X_{1A} = X_{1B} = X_2 = 0$$

$$\dot{X}_1 = \dot{X}_{1B} = \dot{X}_2 = \sqrt{2gh} \qquad \text{(h = Drop height)}$$

The Differential Equations of Motion are:

$$\ddot{X}_{1A} = \frac{1}{m_{1A}} \left[F_3 - F_2\right] + g$$

$$\ddot{X}_{1B} = \frac{1}{m_{1B}} \left[F_2 + F_4 - F_1\right] + g$$

$$X_2 = \frac{1}{m_2} \left[-F_3 - F_4\right] + g$$

Mass terms are determined from the impact weights of the container, Wc, and the payload, Wp. The container mass is subdivided into a midbody mass, m_{1A}, and an impact zone mass, m_{1B}. The midbody mass equals 75% of the moving mass while the impact zone mass equals 25% of the moving mass plus the arrested mass. Specifically:

$$m_{1A} = 3/4\ (Wc - Wa)/g$$

$$m_{1B} = \left[1/4\ (Wc - Wa) + Wa\right] /g$$

$$m_2 = Wp/g.$$

Where:

Wa = $\phi_A(g_1)$, Arrested Weight (a function of g_1)

g = Gravitational Constant

Auxilliary Relations:

The force, F_i, in each spring, S_i, is directly related to the relative deflection, z_i, of each spring. These relative deflections are as follows:

Spring S_1

$$z = X_{1B}$$

Springs S_2 and S_3

$$z_2 = X_{1A} - z_1$$
$$z_3 = X_2 - X_1$$

Spring S_4

$$z_4 = (X_2 - z_1 - z_o); \quad (X_2 - z_1 - z_o) > 0$$
$$= 0 \quad ; \quad (X_2 - z_1 - z_o) \not\leq 0$$

Force Deflection Relations:

Each of the springs may be defined by tabular data (depicts linear and non-linear behavior) built-in subroutines and user defined "drop-in" subroutines. Correction for the arrested fraction of container mass follows the general approach used for springs.

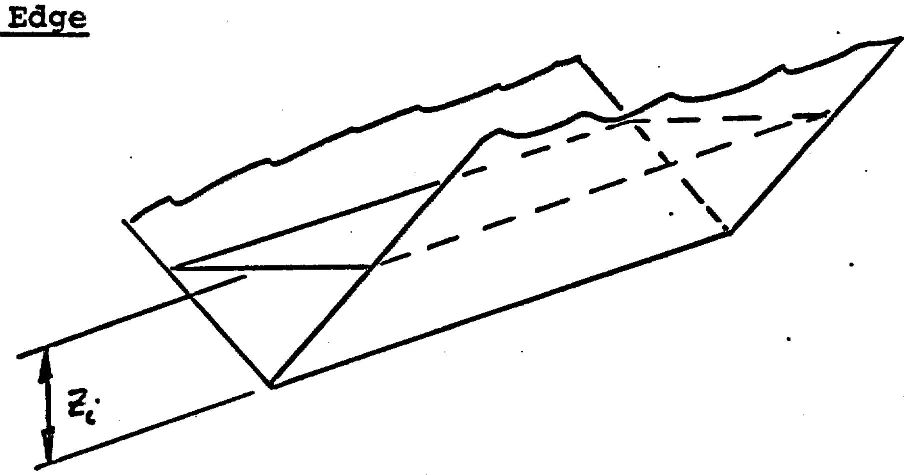
Tabular Data - Forces (F_i) are defined versus relative deflections (z_i). A control flag defines compression memory springs. If non-linear tension-compression springs are desired, both positive (compression) and negative (tension) portions of the load deflection relation must be defined.

Extrapolation beyond the last point is allowed thereby automatically accommodating input of linear spring characteristics and precluding computational aborts.

Spring 2 is unique and must be defined as a tabular tension-compression spring, $K_i = 1$. This spring must be defined by 4 pairs of (X,Y) data since it represents a bilinear bysteretic element depicting the so called Bauschinger Effect. It has been found necessary to incorporate this feature to adequately depict the dynamics of the two body problem.

Built-In Subroutines:

(a) Rectangular Edge



$$F_i = F_F + F_S$$

Where:

F_F = Force due to crushable media

$= 2 z_i \ell \sigma_{cr}$

F_S = Force due to plastic deformation (bending) of external edge sheets

$= \frac{\sigma_{yp} \ell t}{10}$, (Assumes 5t bend radius)

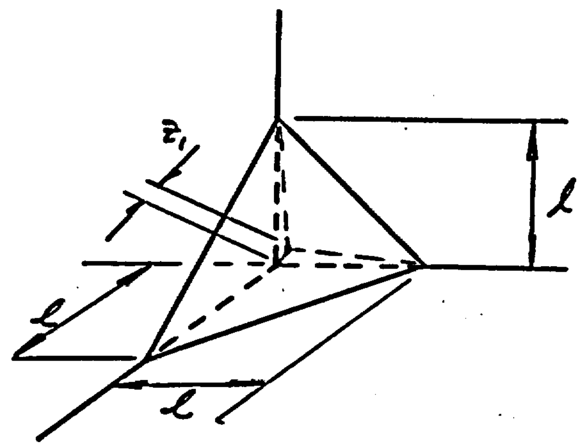
σ_{cr} = crush stress of media

σ_{yp} = yield stress of external sheet

t = thickness of sheet

ℓ = edge length

(b) <u>Rectangular Corner</u>



$$F_i = F_F + F_S$$

$$z_1 = \frac{\ell}{\sqrt{3}}$$

Where: F_F = Force due to crushable media

$= A_\ell \cdot \sigma_{cr} = \frac{3\sqrt{3}}{2} z_i^2 \sigma_{cr}$

F_S = Force to edge sheet plastic bending

$= \frac{3\sqrt{6}}{10} z_i \sigma_{yp} t$, (5t bend radius)

Discussion of the Model:

This impact model represents an intermediate solution between the single degree of freedom approaches possessing limited validity/applicability and computationally inefficient multi mass non-linear impact models. Its validity remains to be fully demonstrated; none-the-less it offers potential solutions to many limitations of prior models; namely:

- ability to accommodate the "hardening" characteristics of crushable media in the final stages of compression.

- ability to study the "two-body" effects when the payload is normally supported on a "soft" vibration isolation system for normal transport; e.g. fuel rods.

- approximate representation of separate interieal force deflection relations.

- approximate representation of external sheet plastic deformation capabilities. Testing is required to fine-tune these features.

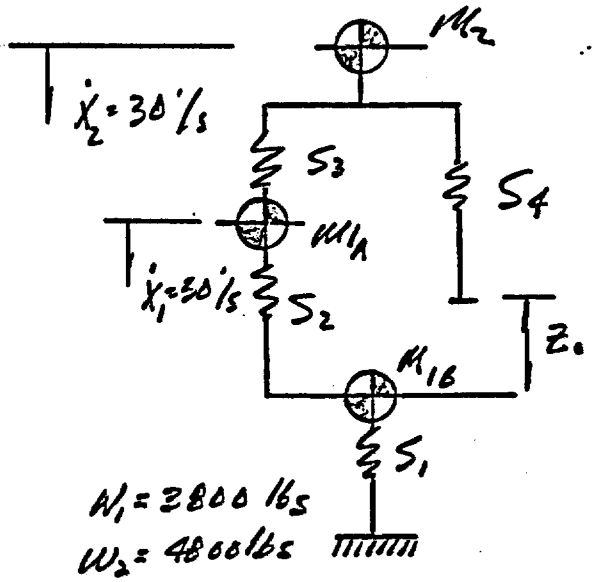
- near "fool-proof" selection of compute and print intervals - thereby eliminating trial and error selection. A major portion of this task is accomplished by the error checks within the Merson variable step integration routine.

1.7.1.1.2 Impact Evaluation

This analysis determines the maximum accelerations and deformations of the overpack and fuel assembly when subjected to a 30 foot drop on an unyielding surface. Four impact orientations are considered critical:

- Flat Side - for maximum acceleration
- Long Edge - for maximum deformation
- Corner - for maximum deformation
- Short Edge - for maximum internal forces

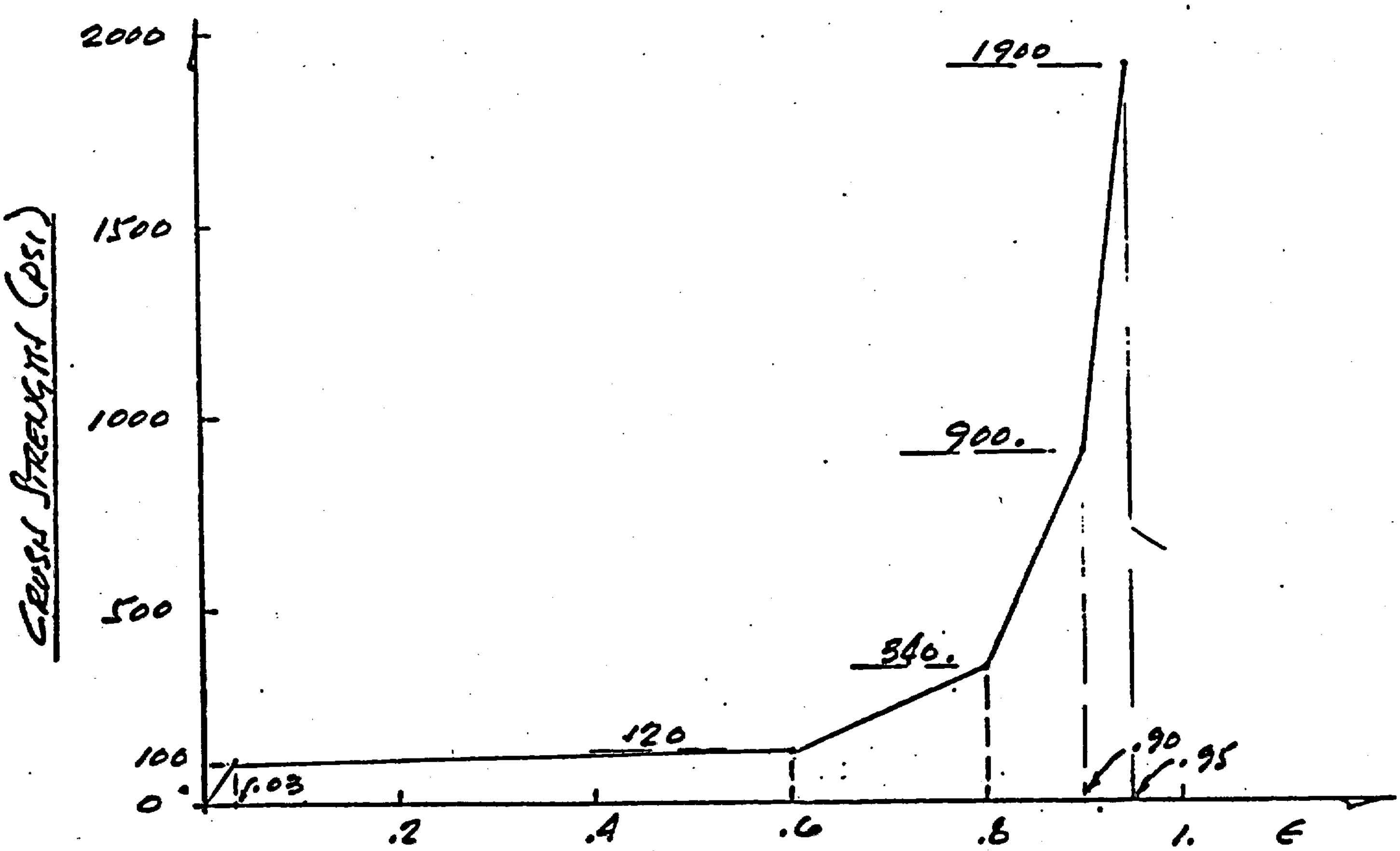
The basic math model is comprised of three degrees of freedom: an overpack mass and a fuel assembly mass. The overpack mass is subdivided into a lower impact zone mass, M_{1A}, and a mid-body mass, M_{1B}. Mass, M_{1B}, equals arrested mass plus 1/4 of moving mass.



Non linear springs S_1 and S_2 represent the characteristics of the overpack. Spring S_3 represents the vibration isolation attachment of overpack to fuel assembly strongback. Spring S_4 represents the deformation characteristics of the strongback to overpack contact which occurs when the normal clearance, Z_o, has been consumed through relative deformation of overpack and fuel assembly.

1.7.1.1.2.1 Development of N-L Spring Properties

BASIC LOAD DEFLECTION RELATION FOR OVERPACK FOAM (4.5 LB/FT³):



SPRING ① ~ OVERPACK CONTACT ZONE

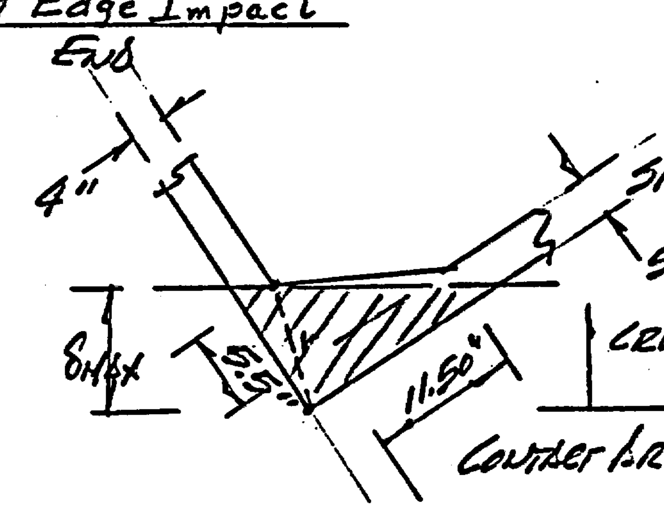
.1.1 FLAT BOTTOM/TOP IMPACT (FOAM ONLY)

$$AREA = \frac{(47)(206)}{144} = 67.24 \; FT^2$$

THICKNESS = 4/12 = 0.33 FT.

STRAIN	STRESS	⟹	DEFL.	LOAD
0.	0.		0.	0.
.03	100.		.010	968,200.
.6	120.		.200	1161840.
.8	340.		.267	3291880.
.9	900.		.300	8 713 800
.95	1900.		.317	18 395 800.

.1.2 Long Edge Impact



$\delta_{MAX} = r \cos\beta$

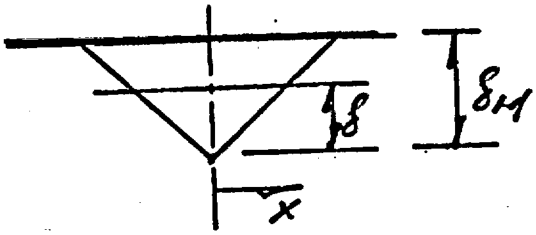
$r = [(5+5.5)^2 + 4^2]^{1/2}$

$\beta = 45° - \tan^{-1}\left(\frac{4}{5+5.5}\right)$

$\delta_M = 10.25" = .854$

CONTACT AREA $= 28\ell$; $\ell = 206"$

TO CONSIDER "HARDENING" EFFECTS WITHIN THE FOAM THE FOLLOWING GEOMETRY IS CONSIDERED:



AT ANY x LOCATION ON THE CRUSH PLANE DEFINED BY δ THE TOTAL STRAIN IS:

$$\epsilon_x = \left(\frac{\delta - x}{\delta_M - x}\right)$$

THE TOTAL FORCE, F_Z IS:

$$F_{Z\delta} = 2\ell \int_0^{\delta} \sigma_Z \, dx \quad ; \text{WHERE: } \sigma_Z = \sigma_{CR}(1 + \alpha e^{\beta \epsilon^2})$$

$\alpha = 0.03911641 4$

$\beta = 6.5786213$

NOTE: σ_E EQUIVALENT TO DEFLECTION RELATION ON PAGE 1-26

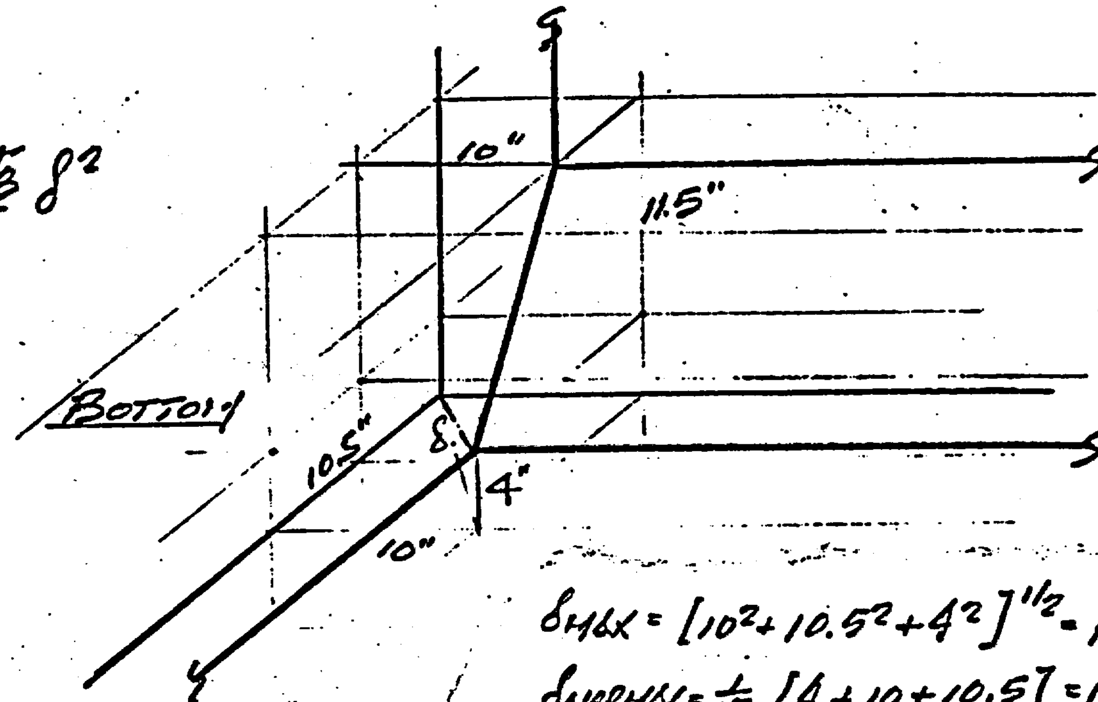
THE BELOW TABLE IS CALCULATED USING A 20 STEP NUMERICAL INTEGR.

DEFLECTION		FORCE (LBS)	
IN.	FT.	HARDENING	NO HARDENING
0.	0.	0. (USED)	0.
1.	.083	42848.	41200.
2.	.167	85946.	82400.
3.	.250	129723.	123600.
4.	.333	175098.	164800.
5.	.417	224358.	206000.
6.	.500	283976.	247200.
7.	.583	375044.	288400.
8. / 8.5	.667 / .708	579029. / 813170.	329600. / 358200.
9.	.750	1296707	370800.
9.738	.812	3557744.	401206.

IMPACT (A) - CONT'D

1.3. CORNER IMPACT - CORNER GEOMETRY

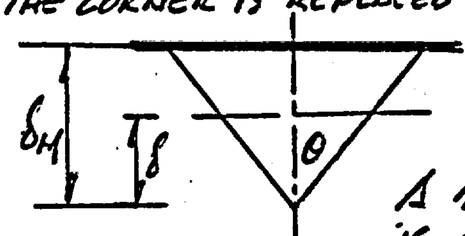
$AREA = \frac{3\sqrt{3}}{2} \delta^2$



$\delta_{MAX} = [10^2 + 10.5^2 + 4^2]^{1/2} = 15.042$

$\delta_{NORMAL} = \frac{1}{\sqrt{3}} [4 + 10 + 10.5] = 14.145$

THE CORNER IS REPLACED BY AN EQUIVALENT CONE: $\theta = \tan^{-1}\left[\frac{3\sqrt{3}}{2\pi}\right]^{1/2}$



$F_Z = 2\pi \int_0^{\delta \tan\theta} \sigma_Z \, r \, dr$: $\sigma_Z = \sigma_{CR}(1 + \alpha e^{\beta \epsilon^2})$

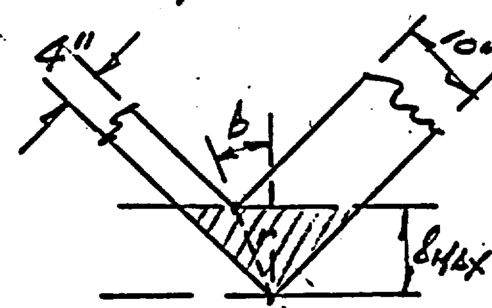
$\epsilon = \frac{\delta - r\cot\theta}{\delta_m - r\cot\theta}$

A 20 STEP NUMERICAL INTEGRATION IS USED TO CALCULATE THE TABLE BELOW

DEFLECTION		FORCE (LBS)	
IN	FT	HARDENING	NO HARDENING
0	0.	0. (USED)	0.
1.	.083	270.	260.
3.	.250	2436.	2338.
5.	.417	6808.	6495.
7.	.583	13574.	12731.
8.	.667	18061.	16628.
9.	.750	23654.	21044.
10.	.833	31247.	25981.
11.	.917	43616.	31437.
12.	1.–	71047.	37412.
13.4	1.117	272092.	46651.

1.4 SHORT EDGE IMPACT ~ OVERPACK CONTACT ZONE

THIS ANALYSIS CLOSELY PARALLELS THE ANALYSIS USED FOR LONG EDGE IMPACT. THE GEOMETRY IS AS FOLLOWS:



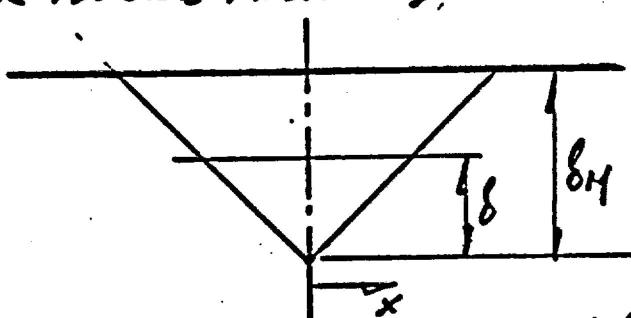
$\delta_{MAX} = r\cos\beta$

$r = [4^2 + 10^2]^{1/2}$

$\beta = 45° - \tan^{-1}[4/10]$

$\delta_{MAX} = 9.899'' = 0.825'$

DUE TO THE GEOMETRY, THE HARDENING "EFFECTS" ARE CONSIDERED RATHER MINOR. NONE-THE-LESS THEY ARE APPROXIMATELY TREATED IN AN UPPER BOUND FASHION, AS FOLLOWS:



AT ANY x LOCATION THE TOTAL STRAIN IS:

$$\epsilon_x = \frac{\delta - x}{\delta_M - x}$$

THE TOTAL FORCE F_z IS: $F_z = 2b\int_0^{\delta} \sigma_z dx$; $\sigma_z = \sigma_{cr}(1 + \alpha e^{\beta\epsilon^2})$

$b = 47''$

THE FORCE DEFLECTION RELATION IS THEREFORE:

DEFLECTION IN	DEFLECTION FT	FORCE (LBS)
0.	0.	0.
1.	.083	9777.
2.	.167	19615.
3.	.250	29626.
4.	.333	40052.
5.	.417	51534.
6.	.500	65993.
7.	.583	90158
8.	.667	152693
9.	.750	418396.
9.405	.784	784206

IMPACT ⟨A⟩ ~ CONT'D

.2. SPRING ② - OVERPACK MID BODY

THIS SPRING (NORMALLY VERY ROBUST) IS REPRESENTED AS A BILINEAR HYSTERETIC SPRING WHICH INCLUDES SIDE WALL WRINKLING/CRIPPLING EFFECTS IN AN APPROXIMATE, BUT CONSERVATIVE MANNER.

IN GENERAL, THIS SPRING IS COMPOSED OF A FOAM COMPONENT PLUS SIDEWALL CONTRIBUTION:

$$F_T = F_F + F_S .$$

.2.1. FLAT SIDE IMPACT.

. FOAM AREA VARIES LINEARLY AS FOLLOWS:

$\delta = 0$: $A_F = (47)(206) - (26)(206-20) = 4846.$ in

$\delta = 11.5''$: $A_F = (47)(206) - (37)(206-20) = 2800.$ in

THE FOAM CONTRIBUTION IS THUS:

STRAIN	STRESS	⇒ DEFL.	LOAD
0.	0.	0.	0.
.03	100.	.029	478 462.
.1	102.5	.096	475 744.
.2	106.	.192	470 301.
.3	109.5	.288	463 426.
.4	113.	.383	455 119.
.5	116.5	.479	445 380.
.6	120.	.575	434 208.
.7	230.	.671	785 174.
.8	340.	0.767	1 091 128.
.9	900.	0.863	2 704 140.
.95	1900.	0.910	5 514 370.

IMPACT ⟨A⟩ - CONT'D

.2.1 FLAT SIDE - CONT'D

THE STEEL SIDES OF THE OVERPACK PROVIDE ADDITIONAL LOAD CARRYING CAPABILITY COMPLEMENTING THE CONTAINED FOAM. A CONSERVATIVE APPROXIMATION IS ACHIEVED BY USE OF CONVENTIONAL CRIPPLING EXPRESSIONS FOR FLAT SHEET. THIS APPROXIMATION CONSERVATIVELY NEGLECTS RESTRAINT OFFERED BY THE FOAM TO THE SHEET.

STEEL SHEET ASSUMPTIONS:

$t = 0.1046$ (12GA.)

THE FULL AREA OF SHELL IS AVAILABLE UP TO A STRESS LEVEL OF:

$$F_{CR} = \frac{\pi^2 E}{12(1-\mu^2)} \left(\frac{t}{a}\right)^2$$

WHERE: $E = 3 \times 10^7$
$\mu = .33$
$t = .1046$
$a = 1/2$ HEIGHT $= 19/2$

$\therefore$ $F_{CR} = 3365.18$ psi

AREA $= (.1046)(2)[(206+47) + (186+37)]$

$F_c = 335102$ LBS

AT STRESS LEVELS ABOVE 3365 psi MID REGIONS OF THE SHELL CANNOT DEVELOP INCREASED RESISTANCE. LOCALLY, AT CORNERS, HIGHER STRESSES MAY BE DEVELOPED IN ACCORDANCE WITH THE CRIPPLING EXPRESSION:

E_t = Tangent Modulus

$$F_{CR} = K E_t \left(\frac{t}{b}\right)^2$$; WHERE $K = 0.385$

(PEERY FOR SIMPLY SUPPORTED ENDS, ONE FREE AND ONE SUPPORTED EDGE)

IMPACT ⟨A⟩ - CONTINUED

2.1 FLAT SIDE IMPACT - CONT'D.

SOLVING FOR THE EFFECTIVE WIDTH, b, GIVES:

$$b = t\sqrt{\frac{KE_\epsilon}{F_{CR}}}$$

THE FORCE CARRIED BY THIS SHEET IS:

$$F = F_{CR} \cdot b \cdot t = t^2\sqrt{KE_\epsilon F_{CR}}$$

SINCE A 2b WIDTH ACTS AT EACH OF THE 8 CORNERS, THE TOTAL FORCE IS

$$F = 16\, t^2\sqrt{KE_\epsilon F_{CR}}$$

COMBINING THIS WITH THE ELASTIC FLAT SHEET CRIPPLING EXPRESSION GIVES THE TOTAL OVERPACK SHELL CONTRIBUTION:

$$F_S = 3365.18\, t\left[952 - 16b\right] + 16 F_{CR}\, t\, b$$

$$b = t\sqrt{KE_\epsilon / F_{CR}}$$

DEFORMATION IS FOUND FROM

$$\epsilon = \sigma/E_S \;;\; \delta = l\epsilon \;;\; l = 19 - 4 = 15''$$

$$\delta = \frac{l\, F_{CR}}{E_S} \;;\; E_S = \text{Secant Modulus}$$

STRESS (PSI)	ELAST. DEFL (FT)	FS.
0.	0.	0.
1000.	4.17×10^{-5}	99579.
3000.	1.25×10^{-4}	298738.
3365.	1.40×10^{-4}	335102.
5000.	2.08×10^{-4}	348857.
10000.	4.17×10^{-4}	374575.
15000.	6.25×10^{-4}	391620

(CONT'D)

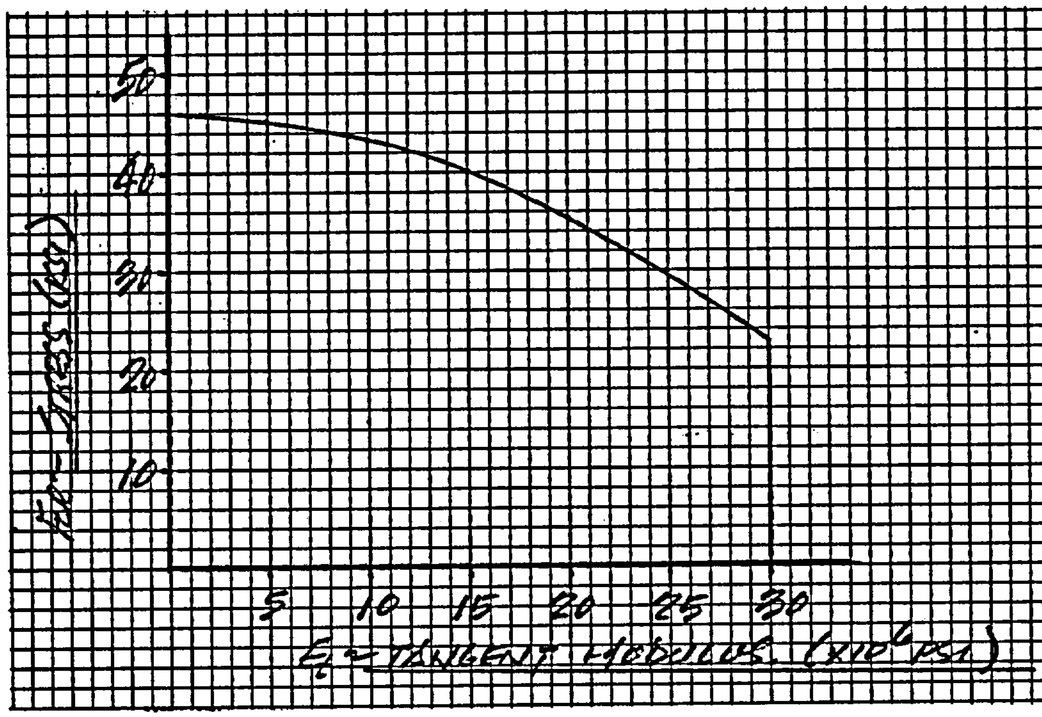
STRESS.	ELASTIC DEFL.	FS.
20000.	8.33×10^{-4}	405082
30000.	1.25×10^{-4}	426590
40000.	1.667×10^{-4}	444080
50000.	2.08×10^{-3}	459181.
60000.	2.5×10^{-3}	472629.
58000	2.41×10^{-3}	470070.

IMPACT (A) ~ CONTINUED

.2.1 FLAT IMPACT ~ CONT'D

SOLVING FOR EFFECTIVE SHEET WIDTH:

$b = t\sqrt{KE_t/F_{CR}}$; BUT E_t VARIES WITH F_{CR} AS SHOWN BELOW:



THE FORCE CARRIED BY THIS SHEET IS:

$$F = F_{CR} \cdot b \cdot t = t^2\sqrt{KE_tF_{CR}}$$

SINCE A 2b WIDTH EXISTS @ EACH OF THE 8 CORNERS:

$$F = 16t^2\sqrt{KE_tF_{CR}}$$

COMBINING WITH THE ELASTIC FLAT SHEET FORCE GIVES THE TOTAL CONTRIBUTION DUE TO THE SHELL:

$$F_S = \underbrace{3305.18\,t\,[952 - 16b]}_{\text{DUE TO FLATS}} + \underbrace{16t^2\sqrt{KE_tF_{CR}}}_{\text{DUE TO CORNERS}}$$

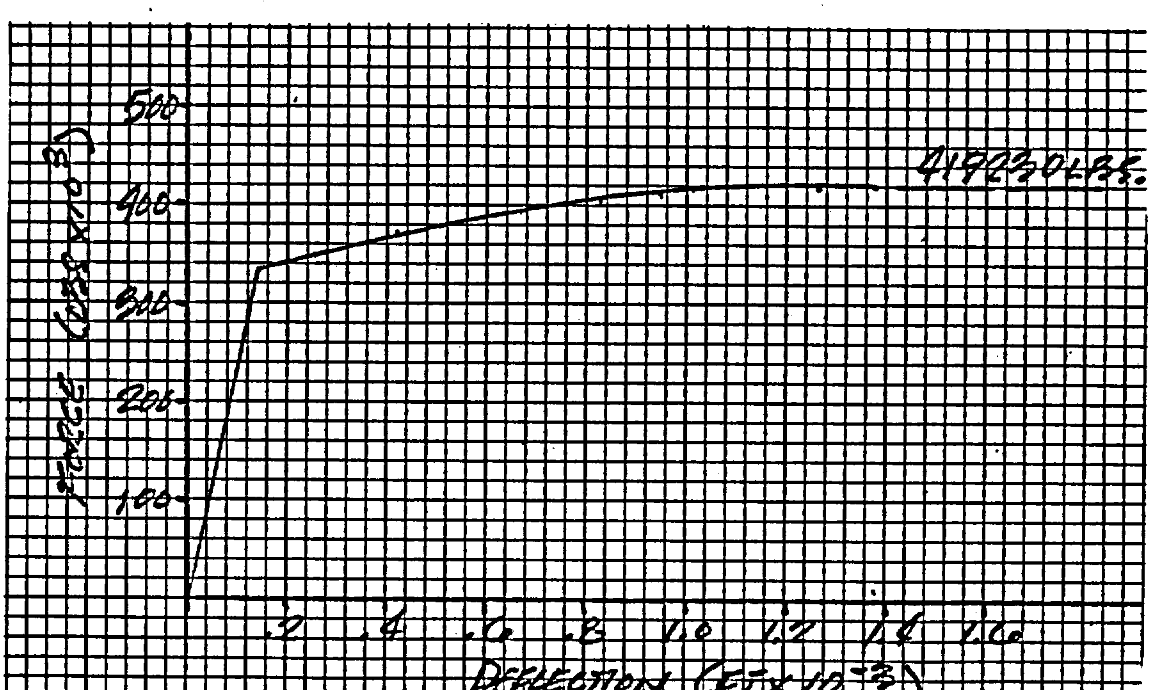
THIS FUNCTION IS DEPICTED VS STRAIN & DEFLECTION ($\delta_L = 19 - 4 = 15''$) ON THE FOLLOWING SHEET.

STEEL SHELL LOAD-DEFLECTION RELATION

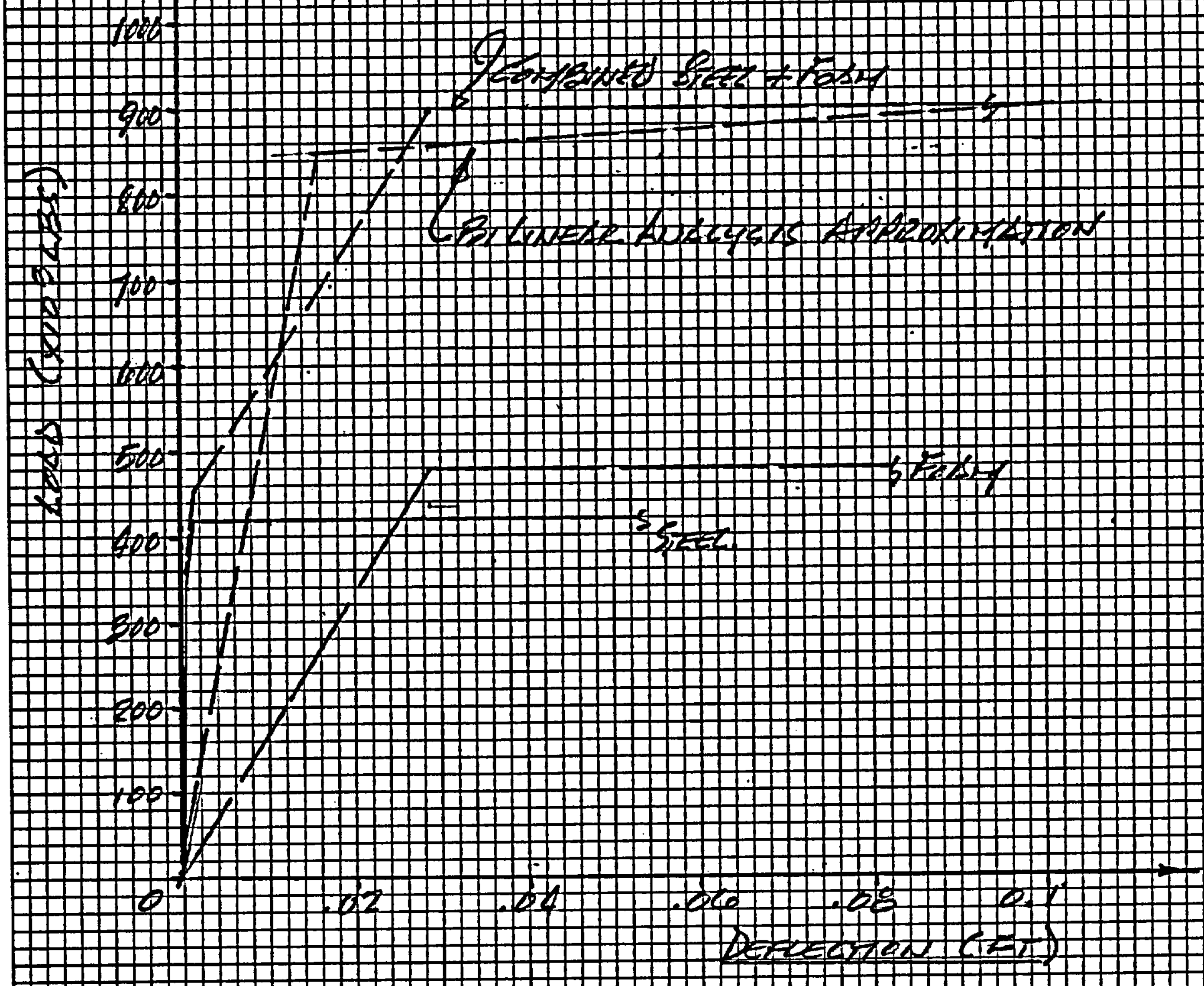
DEFLN (FT)	STRAIN	STRESS (psi)	TANG. MODULUS ($\times 10^6$ psi)	FORCE (LB)
0.	0.	0.	30.	0.
1.402×10^{-4}	1.1217×10^{-4}	3365.18	30.	335102.
9.583 ✓	7.667×10^{-4}	23000.	30.	412128.
1.065×10^{-3}	8.52×10^{-4}	25,480	28.33	415200.
1.171 ✓	9.37×10^{-4}	27,880	26.67	417366.
1.278 ✓	1.022×10^{-3}	30030	25.00	418671.
1.384 ✓	1.107×10^{-3}	32090	23.33	419230. ← MAX.
1.491 ✓	1.193×10^{-3}	34000	21.67	419110.
1.598 ✓	1.278×10^{-3}	35780	20.00	418346
1.916 ✓	1.533×10^{-3}	40250.	15.00	417465.
2.5×10^{-4}	2×10^{-4}	6000	30.	355339.
4.167 ✓	3.33×10^{-4}	10000	30.	374575.
6.25 ✓	5.00×10^{-4}	15000	30.	391620.
8.33 ✓	6.67×10^{-4}	20000	30.	405082.

EXPAND

AS PLOTTED THIS BECOMES:

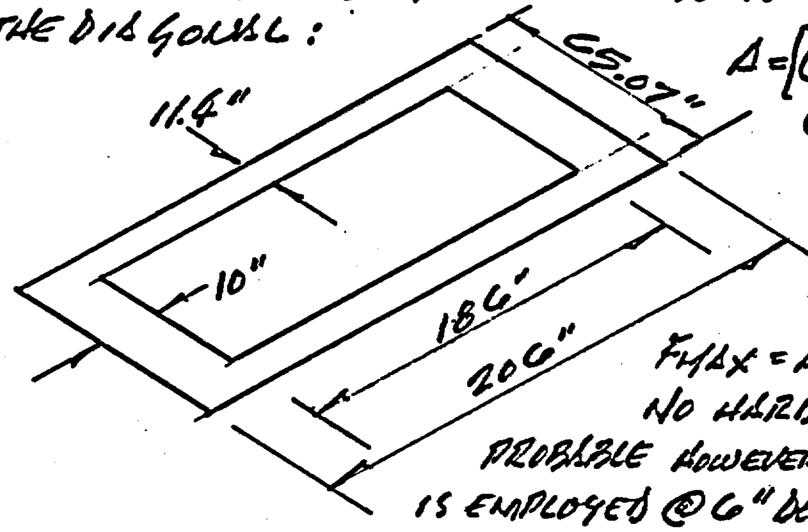


2.1 FLAT SIDE IMPACT – CONT'D
CONSOLIDATED FOAM + STEEL SHELL – SPRING 2



.2.2 LONG SIDE IMPACT

SPRING S_2 BEHAVES SIMILARLY TO THE COMPARABLE FLAT IMPACT SPRING; PARA 2.1, PAGE 1-32 EXCEPT THAT EFFECTIVE SECTION REPRESENTS A SLICE ALONG THE DIAGONAL:



$$A = [(11.4)(2)(186) + (65.07)(20)] = 5542.2 \text{ in}$$

$F_{MAX} = A(\sigma_{CR} = 100) = 554220$ LB

NO HARDENING IS CONSIDERED PROBABLE HOWEVER A 20% INCREASE IS EMPLOYED @ 6" DEFLECTION TO AVOID COMPUTATIONAL SINGULARITY.

.2.3 CORNER IMPACT

THE ANALYSIS PARALLELS THE "FLAT" CASE TECHNIQUE EXCEPT THE X-SECTION IS A TRANSVERSE SLICE. SINCE FOAM CANNOT BE TRAPPED, IT CANNOT SIGNIFICANTLY HARDEN. NONE-THE-LESS, A 20% INCREASE IS EMPLOYED @ 18" TO AVOID COMPUTATIONAL SINGULARITY.

$$\text{AREA} = (47)(45) - (37)(45-8) + (7)^2 + (11.5)(5.5) = 858 \text{ in}$$

HENCE:

δ (FT)	F_E (LBS)
.02	85825.
0.5	107990.

THE CONFIGURATION IS ASSUMED TO BE COMPOSED OF 8 EXTERNAL CORNERS WITH 12 OUTSTANDING "FLANGES" OF WIDTH, b PLUS EDGE CLOSURE AREAS AS FOLLOWS:

CLOSURE AREA:

QUANTITY	SECT.	AREA/SECT	AREA TOTAL
2	2x6x3/16 □	2.738	5.476
2	LWR ⌴	.377	.754
2	LWR PL	.183	.366
2	UPPER CL.	.711	1.422
			8.018 IN²

2.3 CORNER IMPACT ~ CONT'D

THE TOTAL LOAD CARRIED BY THE SHELL IS COMPOSED OF THAT CARRIED BY THE 12 EXTERNAL CORNER FLANGES PLUS THAT CARRIED BY THE EDGE CLOSURE DETAILS:

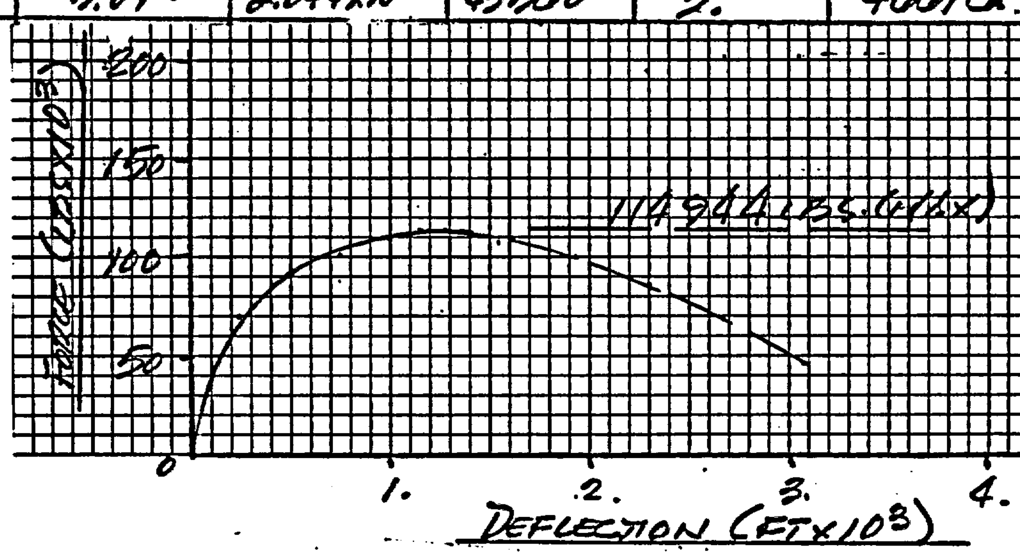
$$F_S = F_{EX} + F_{CL} = A_{EX} \cdot F_{CR_{EX}} + 12\,b\,t\,F_{CR}$$

WHERE: $F_{CR_{EX}} = \mathrm{Min}\left| F_{CR},\ \frac{\pi^2 E_t}{(L/\rho)^2} \right|$

$b = t\sqrt{K E_t / F_{CR}}$

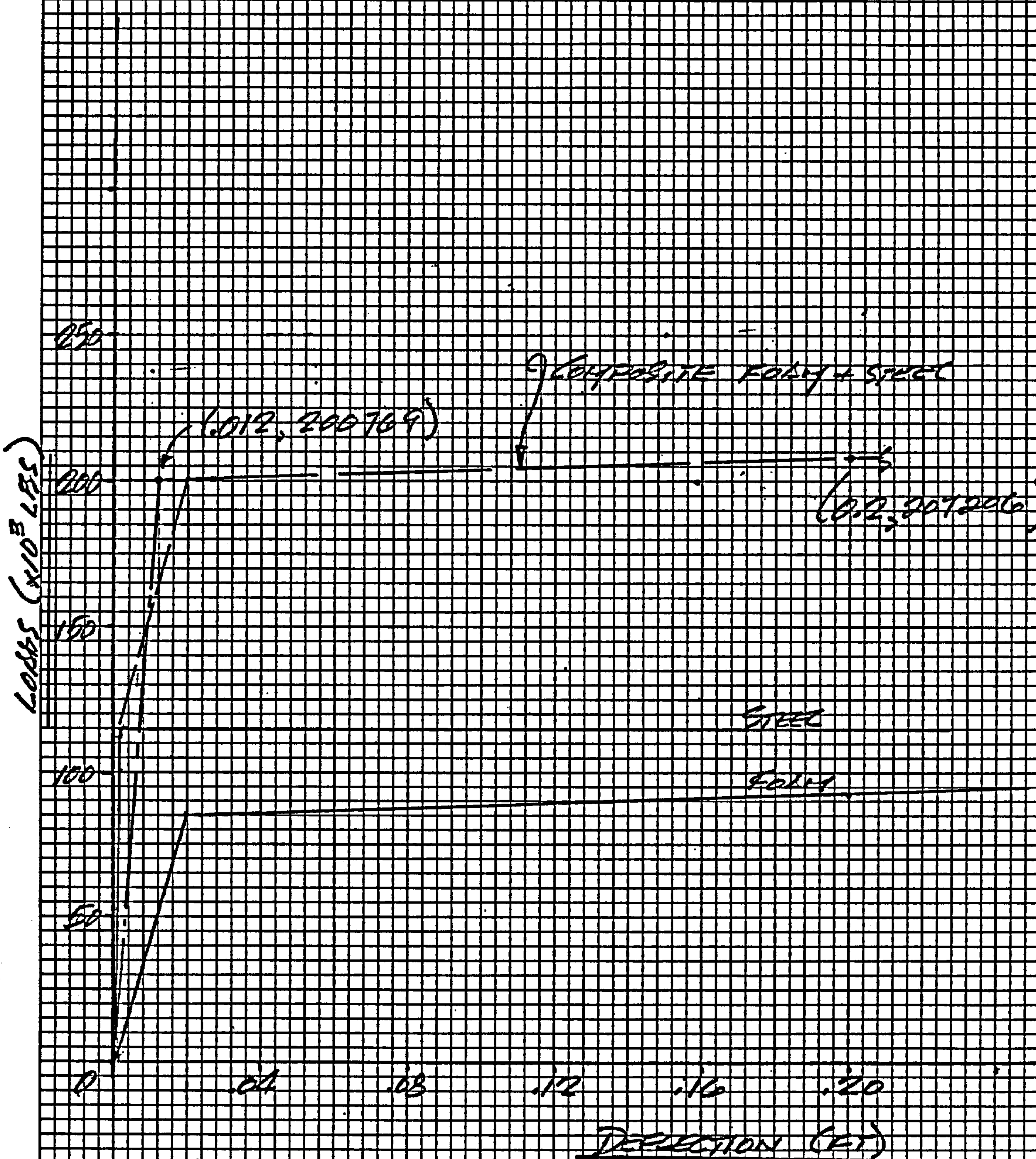
$L = 186.$
$\rho = 0.63_{IN}$ (2×3×3/16 ∟)
$A_{EX} = 8.018_{IN^2}$
$t = .1046$
$K = .385$

DEFL'N (FT)	STRAIN	(FCR) STRESS (PSI)	(Et) TAN MOD. (×10⁶ PSI)	FORCE (LB)
0.	0.	0.	30.	0
2.5×10⁻⁴	1.67×10⁻⁴	5000.	↓	71642.
5.0×10⁻⁴	3.3×10⁻⁴	10000.		91894.
7.5×10⁻⁴	5.×10⁻⁴	15000.		101922.
1.×10⁻³	6.67×10⁻⁴	20000.		110377
1.15 ✓	7.67×10⁻⁴	23000.	30	114944
1.28 ✓	8.52×10⁻⁴	25480.	28.33	113857.
1.42 –	9.37×10⁻⁴	27830.	26.67	112211
1.53 ✓	1.022×10⁻³	30030	25.00	109981.
1.92 ✓	1.278×10⁻³	35780.	20.	100430.
2.3 ✓	1.53×10⁻³	40250.	15.	86937.
2.68 ✓	1.789×10⁻³	43440	10.	69451
3.07 ✓	2.046×10⁻³	45360	5.	46676.



2.3 CORNER IMPACT - CONTINUED

CONSOLIDATED FOAM + STEEL - SPRING ?



.3. SPRING (3) ~ VIBRATION ISOLATORS.

THE 3 IMPACT CASES CONSIDERED IN THIS ANALYSIS ALL LOAD THE CYLINDRICAL ISOLATORS IN TRANSVERSE SHEAR.

THERE ARE A TOTAL OF 18 BARREL ISOLATORS PER OVERPACK / FUEL ASSY.

INDIVIDUAL UNIT ⟹ COMPLETE ASSY

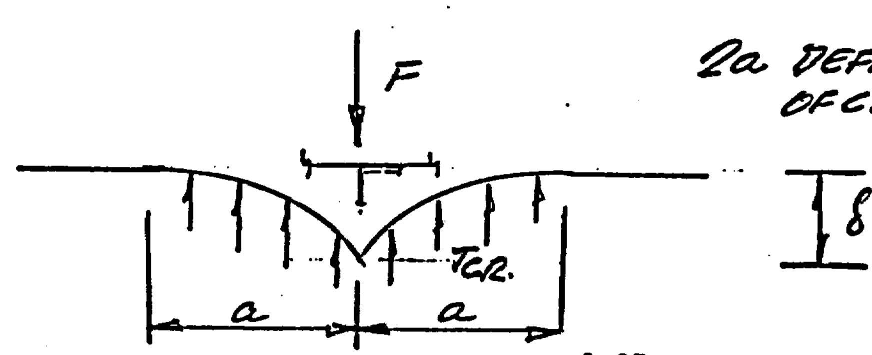
DEFL (IN)	LOAD (LBS)	DEFL (FT)	LOAD. (LBS)
0.	0.	0.	0.
.5.	1030.	.417	18540.
7.25	1380.	.604	24840.
11.	2120.	.917	38160.

.4 SPRING (4) ~ FUEL ASSEMBLY ARRESTING STOPS.

SPRING 4 BECOMES OPERATIVE ONLY WHEN RELATIVE MOTION BETWEEN CONTAINER AND FUEL ASSY IS SUFFICIENT TO OVERCOME NORMAL GAP (VIBRATORY ENVELOPE.)

.4.1 FLAT SIDE (BOTTOM) IMPACT

WHEN IMPACTING ON THE BOTTOM SURFACE 8 OUTSTANDING LEGS OF 2" ANGLES CONTACT THE 12 GA. INNER SHELL OF THE OVERPACK OVER A 20" LENGTH. THE LOAD DEFLECTION RELATION IS DETERMINED BY CONVENTIONAL MECHANICS APPROACHES AS FOLLOWS



2a DEFINES WIDTH OF CRUSHED FORM.

.4.1 FLAT IMPACT ~CONT'D

KARMAN & BIOT (P. 261) GIVE THE BASIC EQUATIONS FOR SUCH A SITUATION. EQUILIBRIUM EQUATIONS ARE AS FOLLOWS:

$$\frac{d}{dx}(P\cos\theta) = 0$$

$$\frac{d}{dx}(P\sin\theta)\,dx + \sigma_{CR}\,dx = 0$$

SINCE $H = P\cos\theta$ IS CONSTANT, $P = H/\cos\theta$ AND THE SECOND EQUATION BECOMES:

$$\frac{d}{dx}\left(H\tan\theta\right) = -\sigma_{CR} \qquad \text{OR}$$

$$H\frac{d}{dx}\left(\tan\theta\right) = -\sigma_{CR}$$

SINCE: $\tan\theta = \frac{dw}{dx}$

$$H\frac{d^2w}{dx^2} = -\sigma_{CR}$$

SOLUTION IS OBTAINED BY DIRECT INTEGRATION

$$\frac{d^2w}{dx^2} = -\frac{\sigma_{CR}}{H}$$

$$\frac{dw}{dx} = -\frac{\sigma_{CR}}{H}x + C_1$$

$$w = -\frac{\sigma_{CR}}{H}\frac{x^2}{2} + C_1x + C_2$$

BOUNDARY CONDITIONS ARE:

$\underline{x = a}$: $\frac{dw}{dx} = 0$

$x = 0$: $w = 0$

$\frac{dw}{dx} = \tan\theta_0$

.4.1 FLAT IMPACT – CONT'D

APPLICATION OF THESE B.C. INDICATE:

$$x = a: \quad 0 = -\frac{\sigma_{CR}}{H} a + C_1 \implies C_1 = \frac{\sigma_{CR} a}{H}$$

$$x = 0: \quad 0 = -\frac{\sigma_{CR}}{H} \cdot \frac{0^2}{2} + C_1 0 + C_2 \implies C_2 = 0$$

$$\tan\theta_0 = C_1 = \frac{\sigma_{CR}}{H} a$$

BUT $\frac{F}{2} = P_0 \sin\theta_0 = H \tan\theta_0$

$$\frac{F}{2} = H\left[\frac{\sigma_{CR}}{H} a\right]$$

$$a = \frac{F}{2\sigma_{CR}}$$ (THIS IS EVIDENT BY OBSERVATION)

TOTAL DEFLECTION IS THUS:

$$w = -\frac{\sigma_{CR}}{H}\frac{x^2}{2} + \frac{\sigma_{CR} a}{H} x$$

$$= -\frac{\sigma_{CR}}{H} \cdot \frac{a^2}{2} + \frac{\sigma_{CR}}{H} a^2$$

$$w = \frac{\sigma_{CR} a^2}{2H}$$

BUT $H = t\sigma_{yp}$; THEREFORE:

$$w = \frac{\sigma_{CR} a^2}{2t\sigma_{yp}} = \frac{\sigma_{CR}}{2t\sigma_{yp}}\left(\frac{F}{2\sigma_{CR}}\right)^2$$

$$\boxed{w = \frac{F^2}{8t\sigma_{yp}\sigma_{CR}}}$$

F = LB/IN
t = IN
σ_{yp} & σ_{CR} = LB/IN²
∴ w = IN. DEFL'N

NOTE: $F_{TOTAL} = (20)(8) F$

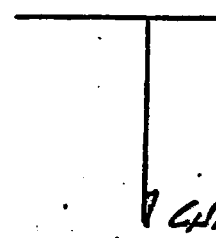
$\therefore \quad F = \frac{F_{TOTAL}}{160}$

(20" PER ANGLE
8 ANGLES.)

4.1 FLAT IMPACT – CONT'D

NOW THE "BOTTOM-OUT" LOAD-DEFLECTION OF SPRING (4) CAN BE SUMMARIZED AS FOLLOWS FOR FLAT BOTTOM IMPACT:

	DEFL (FT)	LOAD (LBS)
	0.	0.
(.5")	.042	197150.
(1")	.083	277148.
(1.5")	.125	340116.
(2.0")	.167	393125.
	.267	1144100.
	.300	3028500.
	.317	6393500.

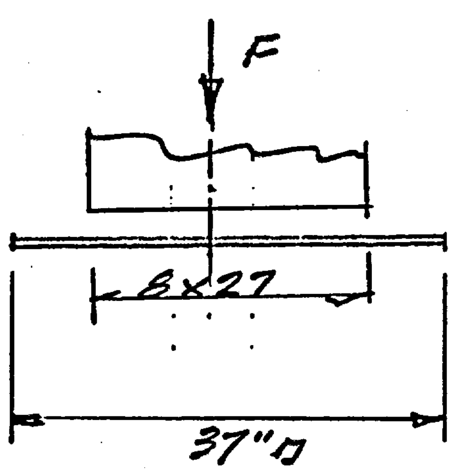


4.2 LONG SIDE IMPACT

USE SAME SPRING AS FOR BOTTOM IMPACT

4.3. CORNER IMPACT

THE PRIMARY ARRESTING MECHANISM CONSISTS OF THE IMPACT OF THE RECTANGULAR ENDS OF THE FUEL ASSEMBLY CONTACTING THE 3/8" R END OF THE OVERPACK.



4.3. CORNER IMPACT ~CONT'D

THE EFFECTIVE FOAM AREA ASSUMES
(1) AT 3t BEND RADIUS ON 3/8 PL.
(2) A CONE ANGLE OF 30° WRT THE DIRECTION OF LOAD APPLICATION IN FOAM

$$\therefore A = (8 + (2)(3/8)(3) + 2\delta \sin 30°) \cdot (27 + (2)(3/8)(3) + 2\delta \sin 30°)$$

DEFL. (IN)	AREA (IN²)	STRAIN RATIO	σcr. (psi)	DEFLN (FT)	FORCE (LBS)
0	299.81	0	0	0.	0
.3	311.75	.03	100	.025	31175
2.	382.81	.2	106		40578
3.	427.31	.3	109.5		46791.
4.	473.81	.4	113.		53541
5.	522.	.5	116.5		60849
6.	573	.6	120	.500	68738
7.	625	.7	230		143822
8.	680	.8	340	.667	231136
9.	736	.9	900	.750	662681
9.5	765.31	.95	1900	.792	1454094.

1.7.1.1.3 Summary

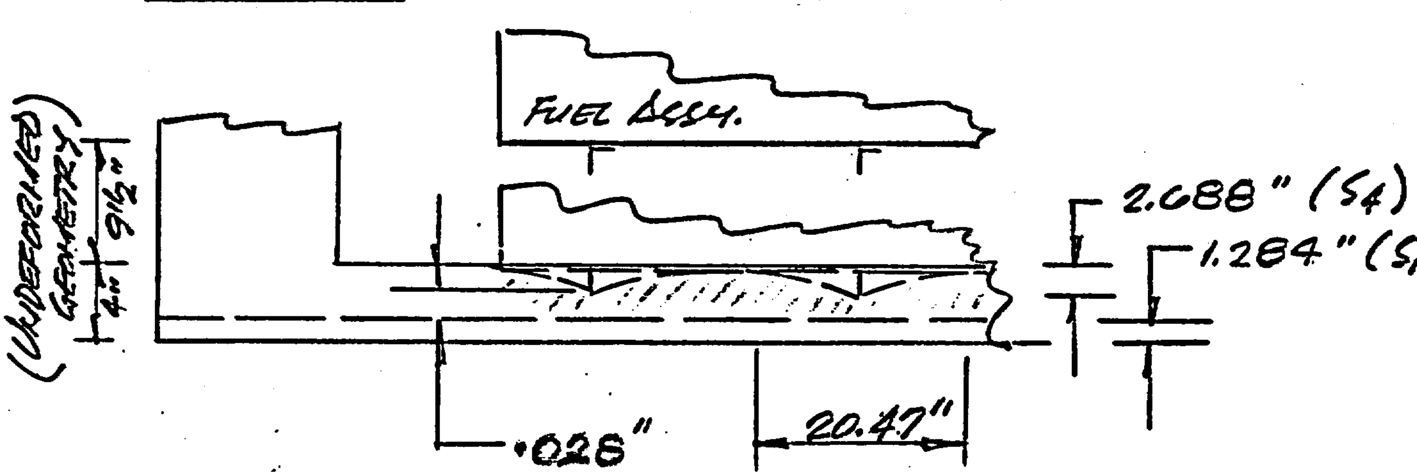
As noted in Section 1.1.2, Design Criteria, the prime function of the overpack is to provide thermal insulation to the fuel rods. Therefore, damage resulting from the drop conditions are used primarily to modify the thermal model to account for loss of insulation. Maximum rod acceleration was found to be less than 178 g's. Since the rods are special form, they can withstand a 30 foot drop unprotected, the reduced environment will be beneficial and safe.

The summary impact results table presents maximum deformations for each of the four deformable elements of the impact model versus the three selected orientations. The purpose of this section is to summarize these results in a graphical and easily understood fashion.

.3.1 Flat Drop

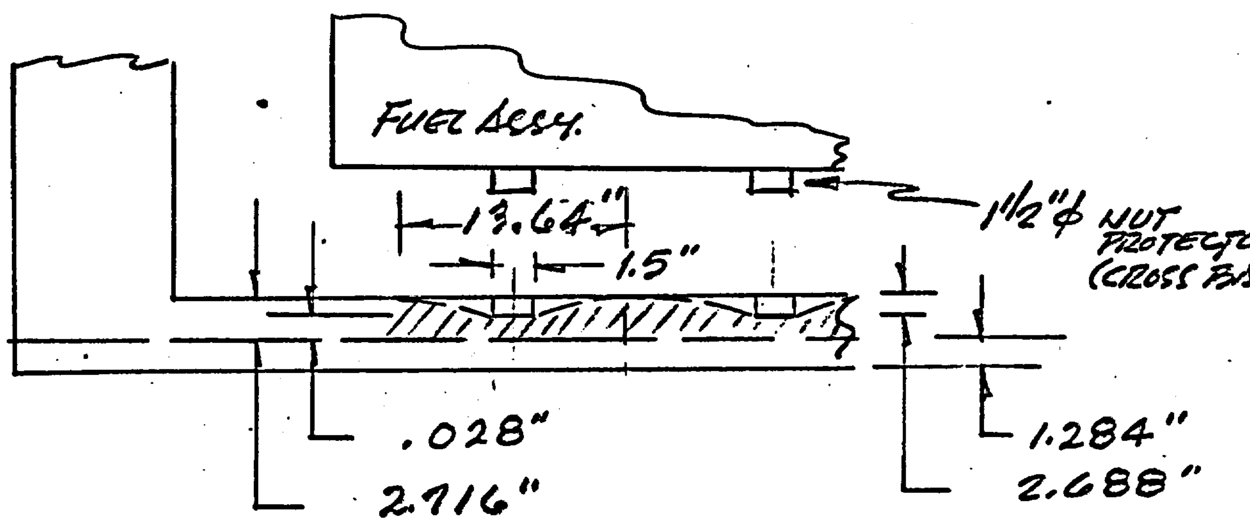
Results are interpreted for impact on the top and bottom surfaces.

(a) Bottom Impact (Side View)



The above sketch illustrates the net section remaining after impact. The original 4" section is reduced to 2.716" by uniform crushing on the bottom surface. The section is further reduced by fuel assembly impact on the inner surface. This inner surface impact locally reduces the remaining thickness to 0.028" at each transverse support frame angle. The transition between 2.716" and 0.028" thickness follows a typical catenary shape due to the membrane behavior of the inner container skin backed by the crushable foam.

(b) Top Impact Side View)



The shaded area represents net section remaining after impact. The original 4" section is reduced to 2.716" by uniform crushing of the bottom surface. At each of the 18 cross bar nut protectors (fuel assembly), the section is reduced to 0.028". Note: In the thermal analysis a slightly more conservative approach is taken which further reduces this net section at nut protectors. Section 1.7.2 demonstrates that the skin does not tear.

(c) STRONGBACK REBOUND EVALUATION

DURING THE IMPACT SEQUENCE, THE SHOCK MOUNTS STORE ENERGY AS THE STRONGBACK STROKES DOWNWARD RELATIVE TO THE OVERPACK. SUBSEQUENTLY, THIS ENERGY ACCELERATES THE STRONGBACK UPWARD AND SECONDARY IMPACT OCCURS BETWEEN THE STRONGBACK AND THE OVERPACK LID. THIS EVALUATION DETERMINES THE MAGNITUDE OF THIS FORCE (FOR LATCH EVALUATION) AND THE NATURE OF PUNCTURE DAMAGE TO THE LID.

THE TOTAL DEFORMATION OF THE SHOCK MOUNT DOWNWARD IS:

$$\delta_3 = 0.983' = 11.796'' \quad (\text{"FLAT"}; p1\text{-}47)$$

THE TOTAL CLEARANCE UPWARD IS:

$$4.50'' \quad (\text{DWG. } 1581F50)$$

THE SPRING CONSTANT OF THE SHOCK MOUNT ASSEMBLY IS:

$$k = \left(\frac{38160 \text{ LBS}}{.917 \text{ FT}}\right) \quad (\text{SEE p. } 1\text{-}35)$$

THUS, THE TOTAL STRAIN ENERGY STORED IN THE SHOCK MOUNTS AT TIME OF CONTACT WITH THE LID IS:

$$K.E. = \tfrac{1}{2} k \delta^2 = \frac{1}{2}\left(\frac{38160}{.917}\right)\left[\left(\frac{11.796}{12}\right)^2 - \left(\frac{4.5}{12}\right)^2\right]$$

$$= 17179.57 \text{ FT-LBS.}$$

SINCE THE IMPACT OCCURS AT 18 CROSS BAR NUT PROTECTORS (1½"φ) THE ENERGY ABSORBED BY AN INDIVIDUAL NUT PROTECTOR IMPACT ON THE LID IS:

$$\frac{17179.57}{18} = 954.42 \text{ FT-LBS.}$$

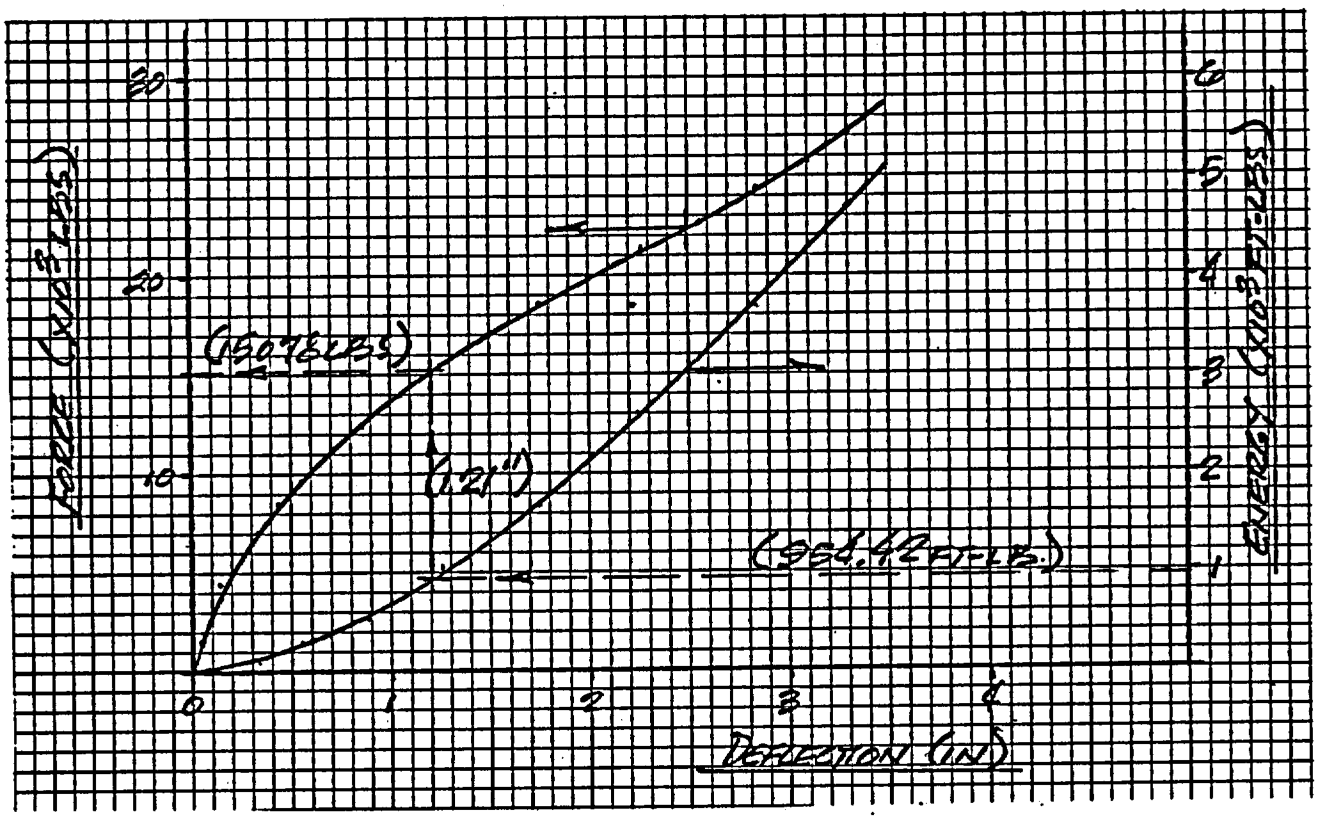
THE INNER LID SKIN IS CONSTRUCTED OF A 10GA. (.1345") STEEL SHEET. THE EFFECTS OF THIS IMPACT ARE DETERMINED USING THE "PUNCH" COMPUTE PROGRAM IN AN OPTIONAL ANALYSIS MODE OUTPUTTING LOAD-DEFLECTION RELATIONS. FOR THIS ANALYSIS, PUNCH WAS USED WITH A NON-UNIFORM (HARDENING) RELATION FOR THE FOAM (4" NET SECTION) TABULAR OUTPUT AND GRAPHICAL FORCE/ENERGY VS. DEFLECTION FOLLOWS:

FORCE-DEFLECTION TABLE

I	F	Z	R	THETA
1	1.7671459E+02	2.7951564E-17	7.5000000E-01	6.8330951E-17
2	1.5525775E+03	4.4390833E-02	2.2230627E+00	3.4463324E-02
3	2.9284404E+03	1.4340575E-01	3.0531157E+00	5.8967667E-02
4	4.3043033E+03	1.4346304E-01	2.9700991E+00	1.0353087E-01
5	5.6801662E+03	2.2730194E-01	3.4427056E+00	1.3812391E-01
6	7.0560291E+03	3.2729157E-01	3.8408168E+00	1.7293887E-01
7	8.4318920E+03	4.4357834E-01	4.1803443E+00	2.0803640E-01
8	9.8077549E+03	5.7470103E-01	4.4928384E+00	2.4339926E-01
9	1.1183618E+04	7.1989498E-01	4.7936301E+00	2.7905105E-01
10	1.2648025E+04	8.8993140E-01	5.1003925E+00	3.1738550E-01
11	1.4112431E+04	1.0764228E+00	5.3872385E+00	3.5620281E-01
12	1.5576838E+04	1.2800524E+00	5.6530169E+00	3.9557231E-01
13	1.7041245E+04	1.5018244E+00	5.9034053E+00	4.3555385E-01
14	1.8505652E+04	1.7430279E+00	6.1446590E+00	4.7621093E-01
15	1.9970058E+04	2.0043445E+00	6.3756938E+00	5.1759505E-01
16	2.1434465E+04	2.2836916E+00	6.5857131E+00	5.5967142E-01
17	2.2898872E+04	2.5731638E+00	6.7615064E+00	6.0218446E-01
18	2.4363279E+04	2.8566701E+00	6.9015575E+00	6.4451090E-01
19	2.5827686E+04	3.1115713E+00	7.0231967E+00	6.8561848E-01
20	2.7292092E+04	3.3197930E+00	7.1342162E+00	7.2434034E-01
21	2.8756499E+04	3.4965360E+00	7.1216390E+00	7.6028784E-01
.1345	7.122	28756 3.50	5099 107.8	43.6*DESIGN VALUE

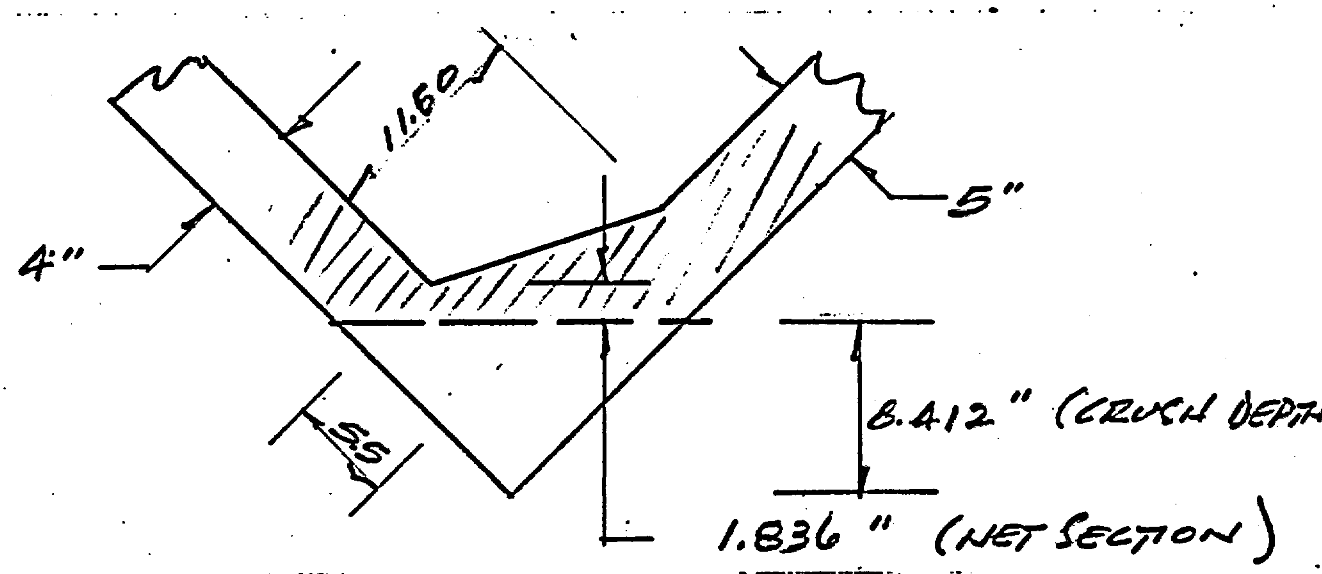
THE FOLLOWING PLOT DEMONSTRATES THAT AT A DEFLECTION OF 1.21 INCHES THE REBOUND ENERGY IS TOTALLY ABSORBED BY LID DEFORMATION. THE PLOT ALSO SHOWS THAT EACH NUT PROTECTOR EXERTS A FORCE OF 15078 LBS ON THE LID. THUS THE TOTAL REBOUND FORCE EXERTED ON THE LID IS:

$$F_{TOTAL} = (18)(15078) = \underline{271404 \text{ LBS}}$$



.3.2 Long Edge Impact

The geometry of the long edge is as follows:

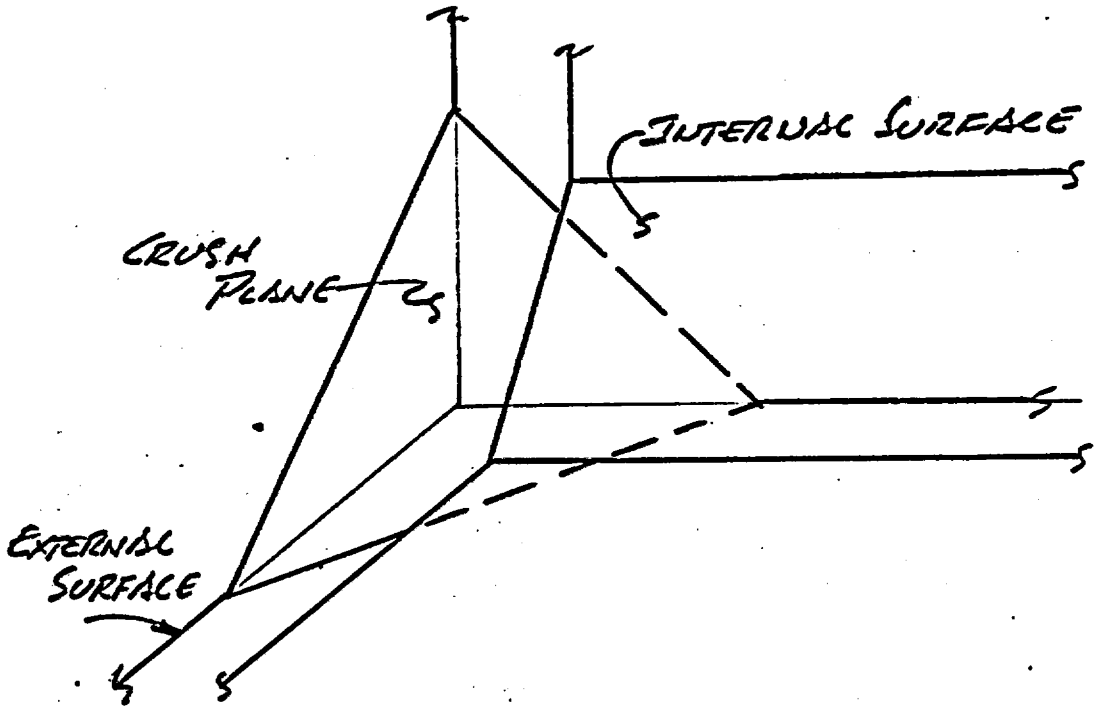


Impact is assumed to occur symmetrically along the long edge. Based on this assumption, the minimum distance between inner and outer skins is 1.836". This net section, exists only along a "line", elsewhere, the net section exceeds this value.

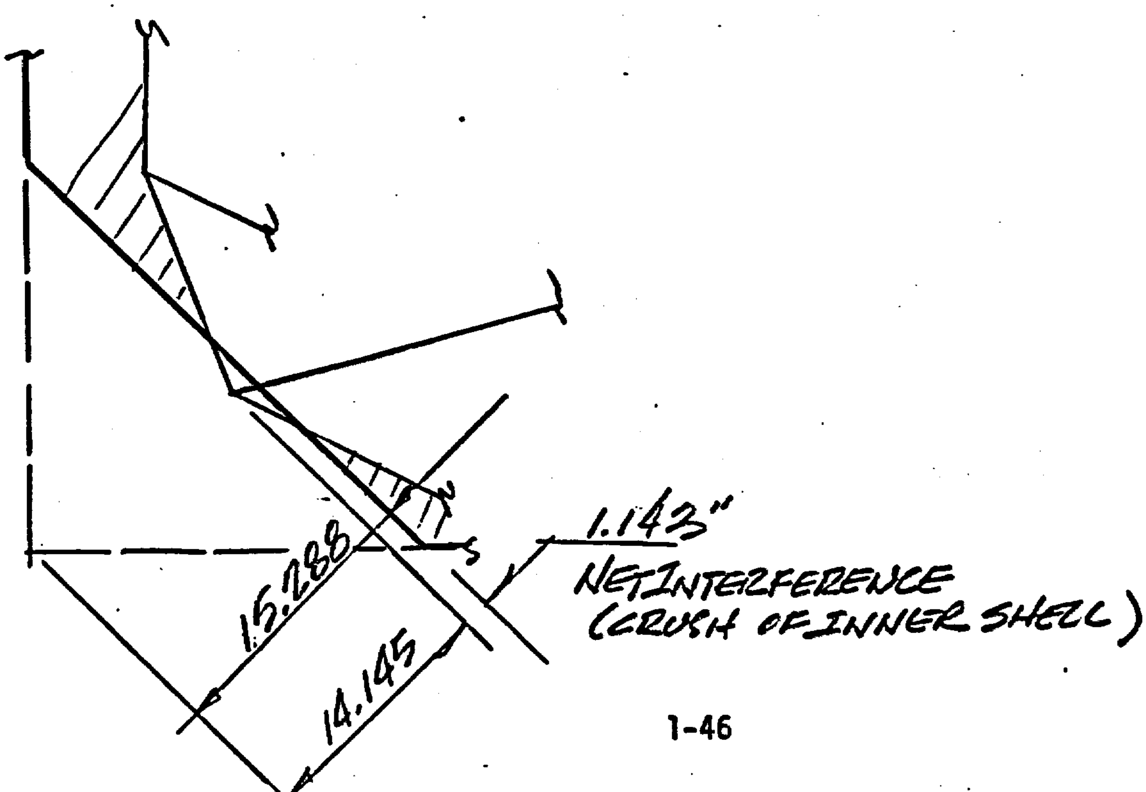
Importantly, this case is considerably less critical from a thermal viewpoint than the flat impact, Section 4.1.

.3.3 Corner Impact

The graphics of the impact surface and inner container surface become rather involved. The following two sketches attempt to separately depict the geometry in a schematic fashion:



IN CRUSH PLANE:

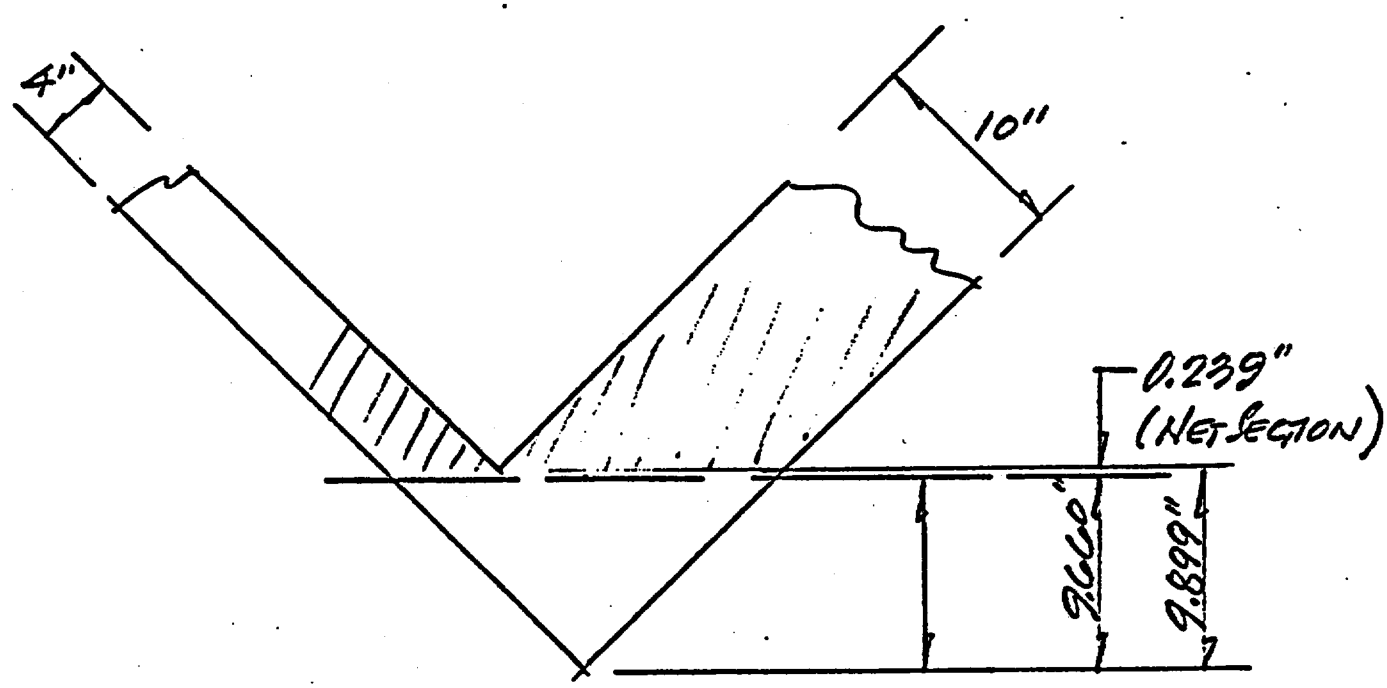


SHORT EDGE IMPACT

The geometry of the short edge is shown in the sketch shown below. Impact is assumed to occur symetrically along the short edge. Based on this assumption, the minimum distance between inner and outer skins is 0.239 inches "along a line" defined by the inner corner. This impact is considered less critical from a thermal viewpoint than the previously discussed "flat" impact.

```
MAXIMUM ACCELERATION OF CONTAINER =   2665.8 AT TIME =.0492 SECONDS
MAXIMUM ACCELERATION OF  PAYLOAD  =  -7129.3 AT TIME =.0508 SECONDS

MAXIMUM FORCE IN SPRING 1=    1014088 AT TIME =.0528
MAXIMUM FORCE IN SPRING 2=     211956 AT TIME =.0580
MAXIMUM FORCE IN SPRING 3=      41845 AT TIME =.0502
MAXIMUM FORCE IN SPRING 4=    1025783 AT TIME =.0508
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 1=    .805 AT TIME =.0528
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 2=    .339 AT TIME =.0580
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 3=   1.004 AT TIME =.0502
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 4=    .769 AT TIME =.0508
```



RESPONSE QUANTITY	IMPACT CASE		
	FLAT	EDGE	CORNER
<u>Spring Rel. Deflection (in)</u>			
Spring 1 (Base)	1.284	8.412	15.288
Spring 2 (Midbody)	1.008	.300	3.240
Spring 3 (Shock)	11.796	12.444	13.884
Spring 4 (Contact	2.688	2.616	9.024
<u>Spring Forces (lb)</u>			
Force 1	1,067,386	775,848	541,704
Force 2	888,790	555,372	209,596
Force 3	40,987	43,271	48,394
Force 4	818,978	778,933	695,204
<u>Accelerations (g)</u>			
Fuel ($\ddot{X}_2$)	177.89	170.21	153.92
Container (Midbody) ($\ddot{X}_1$)	305.11	211.91	87.15

RUN 1 CASE 4 SHORT EDGE DROP NUPAC FUEL OVERPACK

CONSTANTS

NAME	VALUE	UNITS
G	3.22000000E+01	FT/SEC2

TABLE 1
CONTAINER FOAM

X	Y
.0	.0
8.30000000E-02	9.77700000E+03
1.67000000E-01	1.96150000E+04
2.50000000E-01	2.96260000E+04
3.33000000E-01	4.00520000E+04
4.17000000E-01	5.15340000E+04
5.00000000E-01	6.59930000E+04
5.83000000E-01	9.01580000E+04
6.67000000E-01	1.52693000E+05
7.50000000E-01	4.18396000E+05
7.84000000E-01	7.84206000E+05

TABLE 2
CONTAINER MIDBODY

X	Y
-1.00000000E+00	-2.34597000E+05
-1.20000000E-02	-2.00769000E+05
1.20000000E-02	2.00769000E+05
1.00000000E+00	2.34597000E+05

TABLE 3
VIBRATION ISOLATORS

X	Y
-9.17000000E-01	-3.81600000E+04
-6.04000000E-01	-2.48400000E+04
-4.17000000E-01	-1.85400000E+04
.0	.0
4.17000000E-01	1.85400000E+04
6.04000000E-01	2.48400000E+04
9.17000000E-01	3.81600000E+04

TABLE 4
FUEL FOAM CONTACT

X	Y
.0	.0
2.50000000E-02	3.11750000E+04
5.00000000E-01	6.87380000E+04
6.67000000E-01	2.31136000E+05
7.50000000E-01	6.62681000E+05
7.92000000E-01	1.45409400E+06

SPRING DATA

1	2	3	4

RUN 1 HUPAC FUEL OVERPACK

CASE 1 FLAT DROP-BOTTOM

CONSTANTS

NAME	VALUE	UNITS
G	3.22000000E+01	FT/SEC2

TABLE 1

CONTAINER FOAM

X	Y
.0	-.0
1.00000000E-02	9.65200000E+05
2.00000000E-01	1.16184000E+06
2.67000000E-01	3.29188000E+06
3.00000000E-01	8.71380000E+06
3.17000000E-01	1.83958000E+07

TABLE 2

CONTAINER MIDBODY

X	Y
-5.00000000E-01	-1.12479700E+06
-1.60000000E-02	-8.50000000E+05
1.60000000E-02	8.50000000E+05
5.00000000E-01	1.12479700E+06

TABLE 3

VIBRATION ISOLATORS

X	Y
-9.17000000E-01	-3.81600000E+04
-6.04000000E-01	-2.48400000E+04
-4.17000000E-01	-1.85400000E+04
.0	.0
4.17000000E-01	1.85400000E+04
6.04000000E-01	2.48400000E+04
9.17000000E-01	3.81600000E+04

TABLE 4

FUEL FOAM CONTACT

X	Y
.0	.0
4.20000000E-02	1.97150000E+05
8.30000000E-02	2.77148000E+05
1.25000000E-01	3.40116000E+05
1.67000000E-01	3.93125000E+05
2.67000000E-01	1.14410000E+06
3.00000000E-01	3.02850000E+06
3.17000000E-01	6.39350000E+06

SPRING DATA

	1	2	3	4
SPRING FLAG	-1	1	1	-1
ASSOCIATED TABLE	1	2	3	4

RUN 1 NUPAC FUEL OVERPACK

CASE 2 EDGE DROP-LONG SIDE

CONSTANTS

NAME	VALUE	UNITS
G	3.22000000E+01	FT/SEC2

TABLE 1

CONTAINER FOAM

X	Y
.0	.0
8.30000000E-02	4.28480000E+04
1.67000000E-01	8.59460000E+04
2.50000000E-01	1.29723000E+05
3.33000000E-01	1.75098000E+05
4.17000000E-01	2.24358000E+05
5.00000000E-01	2.83976000E+05
5.83000000E-01	3.75044000E+05
6.67000000E-01	5.79029000E+05
7.08000000E-01	8.13170000E+05
7.50000000E-01	1.29670700E+06
8.12000000E-01	3.55774400E+06

TABLE 2

CONTAINER MIDBODY

X	Y
-5.00000000E-01	-6.65064000E+05
-2.00000000E-02	-5.54220000E+05
2.00000000E-02	5.54220000E+05
5.00000000E-01	6.65064000E+05

TABLE 3

VIBRATION ISOLATORS

X	Y
-9.17000000E-01	-3.81600000E+04
-6.04000000E-01	-2.48400000E+04
-4.17000000E-01	-1.85400000E+04
.0	.0
4.17000000E-01	1.85400000E+04
6.04000000E-01	2.48400000E+04
9.17000000E-01	3.81600000E+04

TABLE 4

FUEL FOAM CONTACT

X	Y
.0	.0
4.20000000E-02	1.97150000E+05
8.30000000E-02	2.77148000E+05
1.25000000E-01	3.40116000E+05
1.67000000E-01	3.93125000E+05
2.67000000E-01	1.14410000E+06
3.00000000E-01	3.02850000E+06
3.17000000E-01	6.39350000E+06

RUN 1 NUPAC FUEL OVERPACK

CASE 3 CORNER DROP

CONSTANTS

NAME	VALUE	UNITS
G	3.22000000E+01	FT/SEC2

TABLE 1
CONTAINER FOAM

X	Y
.0	.0
8.30000000E-02	2.70000000E+02
2.50000000E-01	2.43600000E+03
4.17000000E-01	6.80800000E+03
5.83000000E-01	1.35740000E+04
6.67000000E-01	1.60610000E+04
7.50000000E-01	2.36540000E+04
8.33000000E-01	3.12470000E+04
9.17000000E-01	4.36160000E+04
1.00000000E+00	7.10470000E+04
1.11700000E+00	2.72092000E+05

TABLE 2
CONTAINER MIDBODY

X	Y
-2.00000000E-01	-2.07206000E+05
-1.20000000E-02	-2.00769000E+05
1.20000000E-02	2.00769000E+05
2.00000000E-01	2.07206000E+05

TABLE 3
VIBRATION ISOLATORS

X	Y
-9.17000000E-01	-3.81600000E+04
-6.04000000E-01	-2.48400000E+04
-4.17000000E-01	-1.85400000E+04
.0	.0
4.17000000E-01	1.85400000E+04
6.04000000E-01	2.48400000E+04
9.17000000E-01	3.81600000E+04

TABLE 4
FUEL FOAM CONTACT

X	Y
.0	.0
2.50000000E-02	3.11750000E+04
5.00000000E-01	6.87380000E+04
6.67000000E-01	2.31136000E+05
7.50000000E-01	6.62681000E+05
7.92000000E-01	1.45409400E+06

SPRING DATA

1 2 3 4

CASE 1 FLAT DROP BOTTOM

MAXIMUM ACCELERATION OF CONTAINER = 9824.6 AT TIME =.0245 SECONDS
MAXIMUM ACCELERATION OF PAYLOAD = -5728.0 AT TIME =.0340 SECONDS
MAXIMUM FORCE IN SPRING 1= 1067386 AT TIME =.0330
MAXIMUM FORCE IN SPRING 2= 886790 AT TIME =.0315
MAXIMUM FORCE IN SPRING 3= 40987 AT TIME =.0245
MAXIMUM FORCE IN SPRING 4= 818978 AT TIME =.0340
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 1= .107 AT TIME =.0330
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 2= .084 AT TIME =.0315
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 3= .983 AT TIME =.0245
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 4= .224 AT TIME =.0340

CASE 2 EDGE DROP

MAXIMUM ACCELERATION OF CONTAINER = 6823.5 AT TIME =.0382 SECONDS
MAXIMUM ACCELERATION OF PAYLOAD = -5480.9 AT TIME =.0400 SECONDS
MAXIMUM FORCE IN SPRING 1= 775848 AT TIME =.0476
MAXIMUM FORCE IN SPRING 2= 555372 AT TIME =.0448
MAXIMUM FORCE IN SPRING 3= 43271 AT TIME =.0387
MAXIMUM FORCE IN SPRING 4= 778933 AT TIME =.0400
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 1= .701 AT TIME =.0476
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 2= .025 AT TIME =.0448
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 3= 1.037 AT TIME =.0387
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 4= .218 AT TIME =.0400

CASE 3 CORNER DROP

MAXIMUM ACCELERATION OF CONTAINER = 2806.2 AT TIME =.0612 SECONDS
MAXIMUM ACCELERATION OF PAYLOAD = -4956.1 AT TIME =.0610 SECONDS
MAXIMUM FORCE IN SPRING 1= 541704 AT TIME =.0642
MAXIMUM FORCE IN SPRING 2= 209596 AT TIME =.0460
MAXIMUM FORCE IN SPRING 3= 48394 AT TIME =.0612
MAXIMUM FORCE IN SPRING 4= 695204 AT TIME =.0610
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 1= 1.274 AT TIME =.0642
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 2= .270 AT TIME =.0460
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 3= 1.157 AT TIME =.0612
MAXIMUM RELATIVE DISPLACEMENT IN SPRING 4= .752 AT TIME =.0610

.3.4 Lid Retention

a) Capability

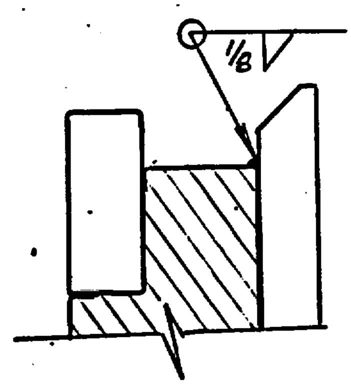
From drawing 1581F50 it can be seen that the lid is secured to the body by means of 12 ratchet binders and 12 double shear ball lock pins. Both react tension loads. Shear loads are reacted by the ball lock pins, their brackets, ratchet binder brackets and the package shear lip (Reference, Drawing 1581F50, Detail A). These capabilities are calculated as follows:

1. Ratchet Binders

Ultimate braking strength of each 7/8 inch diameter binder is given as:

P_t = 32,000 lbs. (Ref. attached data sheet)

Shear loads are reacted by the lower binder support bracket lip as shown below.



Shear loads are reacted by the bracket and its attachment weld. Therefore, its shear strength capacity is equal that of the attachment weld. For conservatism, assume only the top filled weld to be effective.

$$P_{s1} = F_{su} A_{weld}$$

Where

$$F_{su} = 35,000 \text{ psi}$$

$$A = (4 \text{ in}) (1/8 \text{ weld}) (\sin 45^{o})$$

$$= .354 \text{ in}^{2}$$

$$P_{s1} = (35000) (.354)$$

$$P_{s1} = 12390 \text{ lbs/Bracket}$$

Therefore, each ratchet support bracket can react 13,381 lbs. prior to shearing.

2. <u>Ball Lock Pins</u>

The ultimate double shear strength for a CL-10-BLP-L-4.5 pin is 51,400 lbs per manufacturers data. The critical area is not the pin but bearing capacity of the pin sleeve to container interface. Bearing strength can be calculated as follows:

$$P_{brg} = F_{brg} A$$

Where

$$F_{brg} = 90,000 \text{ psi} \quad \text{(Mil-HDBK-V)}$$

$$A = (.875) (.109)$$

$$= .095 \text{ in}^{2}$$

$$B_{brg} = (90000) (.095)$$

$$= 8583 \text{ lbs.}$$

Since pin loads are reacted in bearing at two locations (double shear) the total capacity is:

$$P_{s2} = 2\ P_{brg}$$

$$= 18,128\ \text{lbs.}$$

Therefore, each ball lock pin can react 18128 lbs in lateral shear. Shear loads parallel to the pin are reacted by the external lug in the same manner as the ratchet binder lug above.

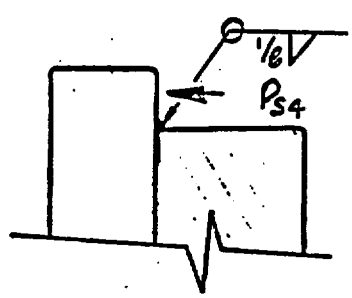
$$P_{s3} = F_{su}\ A_{weld}$$

$$= (2\ \text{in})\ (1/8\ \text{in})\ (35000\ \text{psi})\ (\sin 45^{\circ})$$

$$= 6187\ \text{lbs.}$$

3. Shear Lip

From the drawing it can be seen that the full perimeter of the package is equipped with a deep shear lip. The lip is held in contact by the tension capability of the binders and ball lock pins. Shear in the outward direction is reacted by the brackets as noted above. An inward load is reacted primarily by the 1/8 weld between the rectangular tube and skin shown above.



A unit length capability can be calculated as follows:

$$P_{s4} = F_{su}\ A_{weld}$$

$$F_{su} = 35000\ \text{psi}$$

$$A_{weld} = (1\ \text{in})\ (1/8)\ (\sin 45^{\circ})$$

P_{s4} = (35000) (.088 in^2)

P_{s4} = (3080 lbs/in)

b) Loads

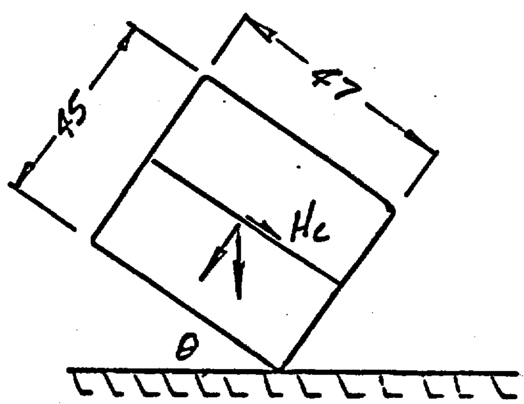
From the Summary Impact Results, page 1-47, it can be seen that the container body experiences the following accelerations during impact orientations.

Long Edge drop	=	211.9 g's
Short Edge drop	=	82.79 g's
Corner drop	=	87.15 g's (Ref. 1-46a)

c) Margin of Safety

1. Edge Drop

The edge drop will produce the following loads that must be reacted by the shear pins, etc., from above



tan θ = 45/47

θ = 43.8°

H_e = (211.9 g's) (cos θ)

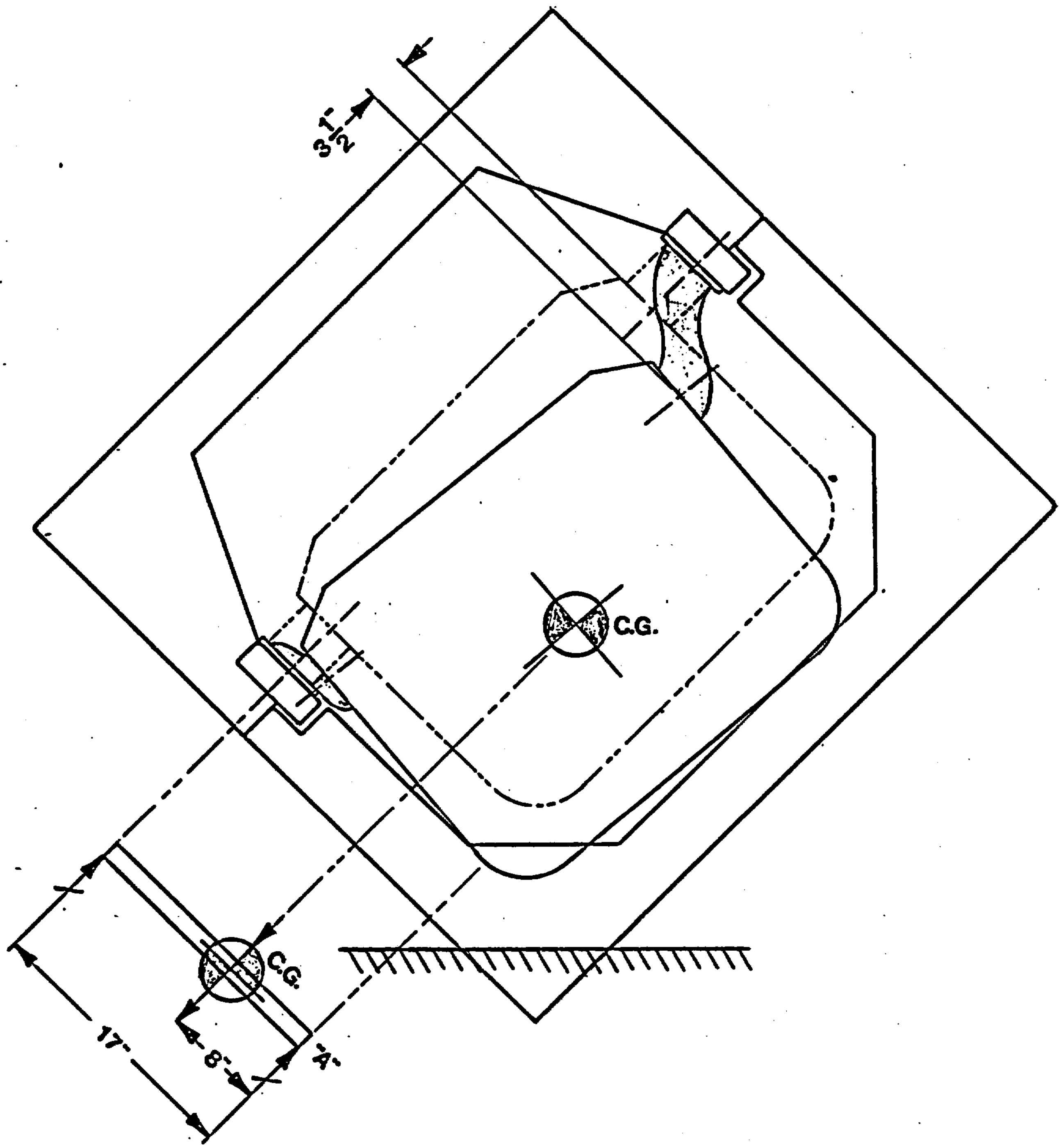
H_e = 153 g's

Using a lid weight of 1900 lbs., the total shear force to be reacted will be:

P_{He} = (1900 lbs) (153 g's)

= 290,810 lbs.

If the package were to impact on its lid, secondary impact loads from the fuel assembly would produce additional lateral shear loads.



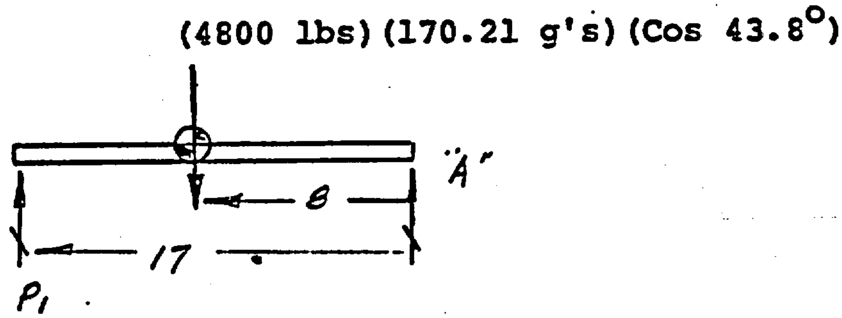
On impact, the soft support mounts will provide a tension load to the upper side and a compression load to the lower edge. From the sketch it can be seen that the upper mount will elongate or stretch

3 1/2 inches until full contact is made with the opposite side. This load contribution can therefore be calculated as follows:

$$P_u = (3.5 \text{ in}) (1030 \text{ lb/in per pg 1-35}) (9 \text{ mounts})$$

$$P_u = 32,445 \text{ lbs.}$$

For conservatism, assume the strong back will come to rest, and be supported by the fully compressed mount and point "A" on the outer shell. This can be represented as follows:



$$P_1 = (8/17) (4800) (170.21) (\text{Cos } 43.8^o)$$

$$P_1 = 277,500 \text{ lbs.}$$

If these loads were conservatively added, the total lateral or shear load will be:

$$P = P_{He} + P_u + P_1$$

$$P = 290,810 + 32,445 + 277,500$$

$$P = 600,753 \text{ lbs.}$$

This will be reacted by the following:

5 Shear Ratchet Brackets (P_{s1}) one side only	=	61,950
4 Shear Pins (P_{s2}) ends only	=	72,512
4 Shear Pin Brackets (P_{s3}) one side only	=	24,748
200 in. Shear Lip (P_{s4}) one side only	=	616,000
		775,210 lbs.

Therefore, the lid can react a lateral shear load of:

Lat_s = 775,210 lbs.

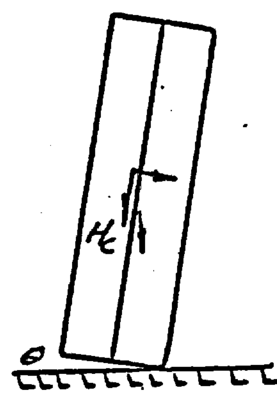
Margin of Safety:

M.S. = 775,210/600,753 - 1

M.S. = + .29 (Edge Drop)

---

2. Corner Drop



NOTE:
From page 1-51d, it can be seen that corner drop produces higher accelerations than the short edge drop. Energies are absorbed more uniformly during edge impact.

H_c = (87.15 g's) cos 12.3°

H_c = 85.14 g's

Using the lid weight of 1900 lbs. the total shear force to be reacted will be:

P_{Hc} = (1900 lbs) (85.14 g's) + spring (13.9 in)(2470 lb/in)

= 161,770 lbs. + 48220 lbs = 209,990 lbs.

This will be reacted by the following:

1 ratchet bracket (P_{s1}) end only	=	12,390 lbs.
8 shear pins (P_{s2}) sides only	=	145,024 lbs.

2 shear brackets (P_{s3}) ends only	=	12,374 lbs.
41 inches shear lip (P_{s4}) one end only	=	126,280 lbs.
		296,068 lbs.

Therefore the lid can react a longitudinal shear load of 296,068 lbs.

$Long_s$ = 296,068 lbs.

Margin of Safety:

M.S. = 296,068/209,990 - 1

M.S. = + .41 (Corner Drop)

3. <u>Flat Drop</u>

From the impact analysis shown on page 1-41c, the rebound load experienced by the lid will be 271,404 lbs. This load will be reacted by the binders and ball lock pins. (Ref. pages 1-51h, and 1-51i

Margin of Safety:

$$M.S. = (12\ P_{binders} + 12\ P_{pins})/P_{rebound} - 1$$

$$= (12)\ (28125) + (12)\ (16786)\ /\ 271,404 - 1$$

$$= (337,500 + 253,116)/271,404 - 1$$

$$= + .96$$

CONCLUSION

It can therefore be concluded that impact loads on the container can be safely reacted by the lid attachment mechanism. The redundancy and independence of these mechanisms will assure that localized damage will have a small impact on the containers overall ability.

.3.5 Ratchet Binder Closure Latch Mechanism

As can be seen from drawing number 1581F50, the ratchet binders are enclosed within a heavy structural steel channel. The channel provides localized protection for the binder as well as a system of load distribution into the overpack shell. Loads are reacted through the lower end by a 3/4" diameter bolt.

The upper end of the binder is pinned to a similar inverted chanel by means of a 5/8" diameter ball lock pin.

To open the package, the binder is loosened sufficiently to allow the ball lock pin to be depressed and withdrawn. The binder is then rotated down and flush with the package sides. After removal of the adjacent ball lock shear pins and binders, the package lid can be removed.

Structural capacity for the critical areas is shown below.

1) Ratchet Binder - per manufacturers data the binders ultimate strength is given as 32,000 pounds each.

2) Ball lock pin - per manufacturers data, the ultimate strength in double shear of the ball lock pin is given as 51,400 pounds each.

3) 3/4" diameter bolt - the ultimate double shear strength of a 3/4" diameter bolt is given as 31,800 pounds each.

4) Bearing stress capacity is given as:

$$P_{brg} = F_{ult} A$$

Where

$$F_{ult} = 90{,}000 \text{ psi (Mill-HDBK-V) (Bearing Stress)}$$

$$A = (5/8)\ (.25)\ (2)$$

$$= .313 \text{ in}^2$$

$$P_{brg} = (90{,}000 \text{ psi})\ (.313 \text{ in})$$

$$= 28{,}125 \text{ lbs. each}$$

5) Lower channel weld to skin

$$P_w = F_{ty} A_{weld}$$

$$F_{ty} = 35000$$

$$A_{weld} = (20 \text{ in})\ (1/8)\ (\sin 45^o)$$

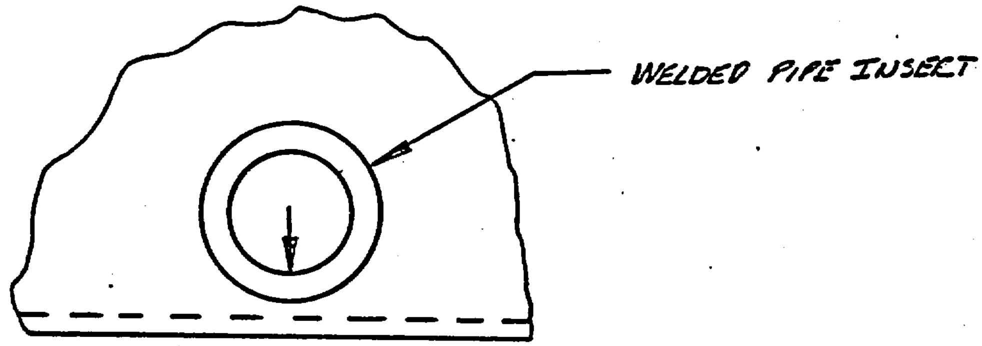
$$= 1.76 \text{ in}^2$$

$$P_w = (35000 \text{ psi})\ (1.76 \text{ in})$$

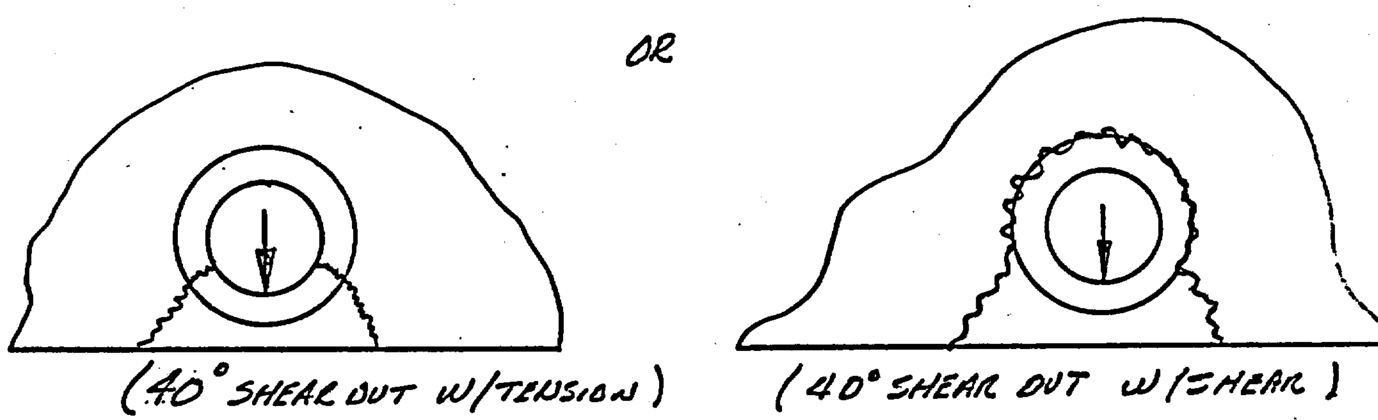
$$= 61600 \text{ lbs.}$$

Therefore, it can be concluded that the ratchet binder closure latch has a minimum capacity of 28,125 lbs. each (from number four above).

.3.5 Shear Pin Tearout Capability



Since the pipe insert is welded to the skin, shear out loads will be reacted by over a 360° circumference. Loads along the lower edge can be calculated using the standard 40° shear out. For the pin to tear free of the pipe it must fail in tension or tear the weld free.



Tension:

$P_A = F_{tu}A =$ (55000psi)(.109 thick) (1.0 long)

$P_A = 5995$ lbs/side

Shear

$$P_B = (35000 \text{ psi}) (\pi/2) (.875) (.109 \text{ thick})$$

$$P_B = 5243 \text{ lbs/side}$$

40^o Shear Out

$$P_s = F_{su} \; 2t \quad (EM - d/2 \cos 40)$$

$$= (35000) \; (2) \; (.109) \; (.75 - .44 \; (.766))$$

$$= 3150 \text{ lbs}$$

From above it can be seen that shear out is critical. Therefore maximum capability is as follows:

$$P = (P_B + P_s) \; 2 \text{ side}$$

$$= (5243 + 3150) \; 2$$

$$= 16786 \text{ lbs.}$$ (Pin Tension Capability)

1.7.2 Puncture Evaluation

Puncture analyses are conducted using the "punch" program developed by Mechanics Research, Inc., MRI-TR-560-(70)1,2/70. The purpose of these analyses is to predict the behavior of container shell material when impacted by localized protruberances. Applicable federal regualtions require the container to not fail when impacting a 6" diameter punch in a 40" free fall. This requirement defines the performance of the outer container shell. Similiarly, the performance of the internal shell is defined by the 30 foot drop and the characteristics of protuberances existnat on the fuel assembly.

The "Punch" computer code employs straight forward principals of mechanics and ultimate materials properties. Despite its simplicity, excellent correlation with test data has been demonstrated; i.e., Figure 2.2 of ORNL-NSIC-68 has been analytically duplicated. "Punch" treats the shell as an axismmetric membrane and the foam as a backing media exhibiting purely plastic (constant stress) resistance to imposed deformations. With these assumptions, deformations of the punch into the backing media may be determined. Knowing deformation the resisting force is obtained from the membrane geometry. Both membrane tensile force and energy absorbed may thus be determined.

For both external and internal impacts the "punch" program results are used to determine required shell thickness versus punch pin stroke depth into backing media.

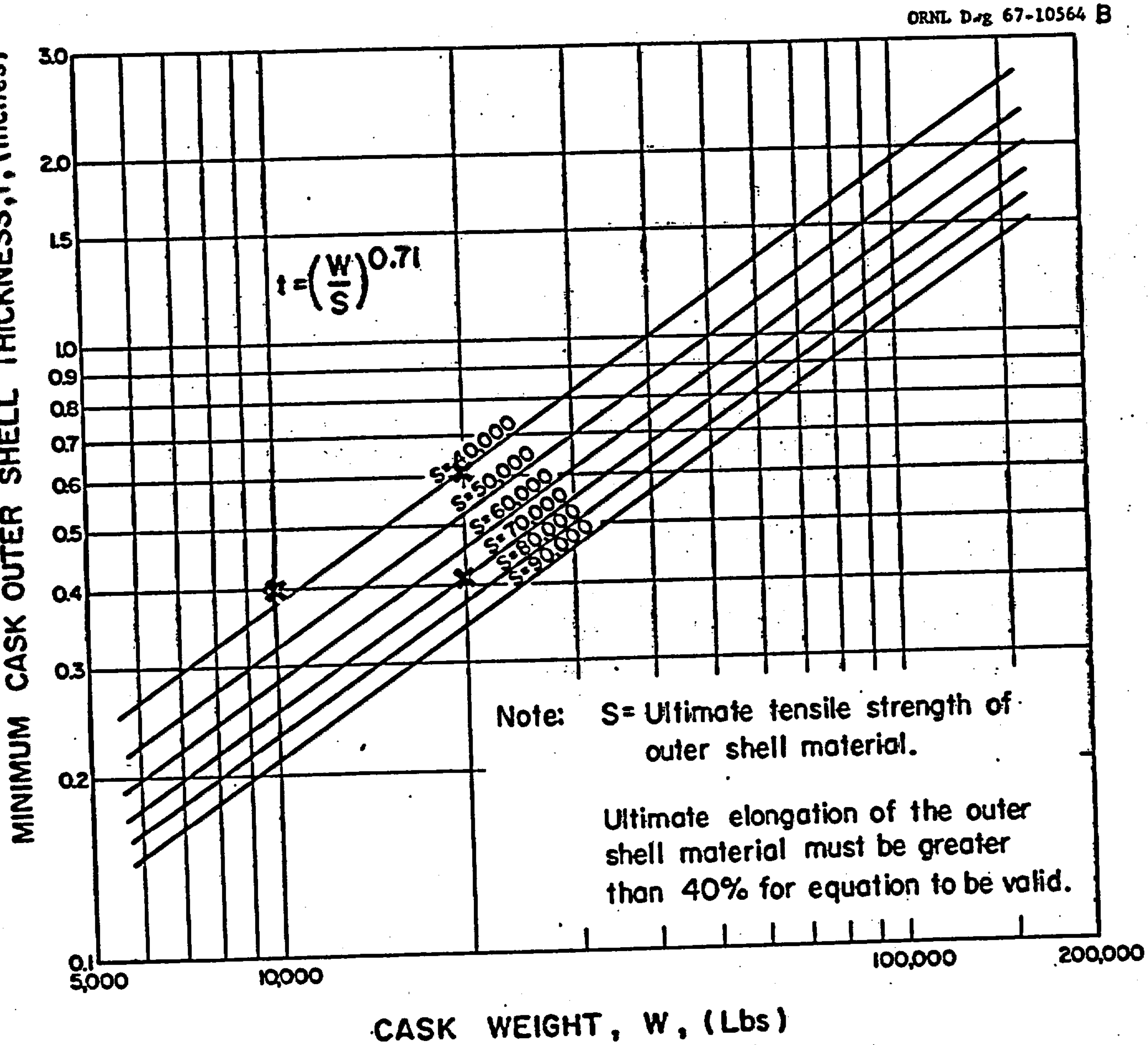


Fig. 2.2. Graph to Estimate Minimum Outer Shell Thickness fo Lead-Shielded Casks, Based on Eq. (2.1).

X = Predictions Using Punch

1.7.2.1 External Shell Puncture

Using the "Punch" code the following required shell thickness was calculated.

STATIC INELASTIC MEMBRANE PUNCTURE ANALYSIS

*** BASIC ENGINEERING DATA

PACKAGE WEIGHT (LB) = 8000.0

DROP HEIGHT (IN) = 40.0

KINETIC ENERGY TO ABSORB (FT-LB) = 26667

ULTIMATE STRESS OF MEMBRANE (PSI) = 65000

ULTIMATE ELONGATION OF MEMBRANE (PERCENT) = 38

RADIUS OF PUNCTURE PIN (IN) = 3.0

EDGE RADIUS OF PUNCTURE PIN (IN) = .25

NUMBER OF TRIAL LOOP CYCLES = 1

*** TRIAL CASE DATA*

CRUSH STRENGTH OF BACKING MEDIA (PSI) = 100

BACKING MEDIA THICKNESS (IN) = -.00

INITIAL THICKNESS OF MEMBRANE SHEET (IN) = .080

INCREMENTAL THICKNESS OF MEMBRANE SHEET (IN) = .0100

*** PUNCTURE DESIGN TRIAL CASES

********** VALUES AT MEMBRANE FAILURE **********

SHEET THICK (IN)	CRUSH RADIUS (IN)	TOTAL FORCE (LB)	CRUSH DEPTH (IN)	TOTAL ENERGY (FT-LB)	PEAK ACCEL (G)	SHEET ANGLE (DEG)	
.0800	14.744	68295	7.44	29214	7.9	43.6	
.0900	15.605	76480	8.01	35140	5.9	43.6	*DESIGN VALUE*

Therefore, the design minimum skin thickness should be .090 in. From the drawing it can be seen that the overpack is constructed from 12 gauge (.1042 in) material.

It should be noted that for conservatism the subsequent thermal analysis model of Section 1.7.3 assumes that the external shell does puncture. For this analysis a 12 in. diameter hole was assumed to exist in the external shell and insulation.

1.7.2.2 Internal Shell Puncture

An impact on the top surface of the overpack is considered most critical since it tends to drive the 18 nuts of the strongback cross bars into the foam backed top inner surface.

To minimize shell thickness, each bolt is fitted with a large diameter nut (1 1/2" diameter). The requirements of this puncture analysis are thus:

Drop Height	=	30 feet
Puncture Pin	=	1 1/2 inches
Weight/Pin	=	4800/18 = 267 lbs
Steel & Foam	-	See Section 1.7.2.1

The following sheet summarizes relevant relations for required inner shell thickness versus stroke. Some explanation of this figure is warranted. Three primary curves are shown for foam strengths of 75, 100, and 150 psi. For the 100 psi foam, the influence of various protector diameters is illustrated (4" ø, 3" ø, 2" ø, 1 1/2" ø).

Required shell thickness may be found knowing stroke. Two approaches are utilized and tear margins determined for the 10 gauge (.1345") inner shell:

Most Conservative

Max Stroke = Foam Thickness = 5"

Thickness Req'd = 0.1265"

MS_{tear} = .1345/.1265 -1 = +0.06

Most Realistic

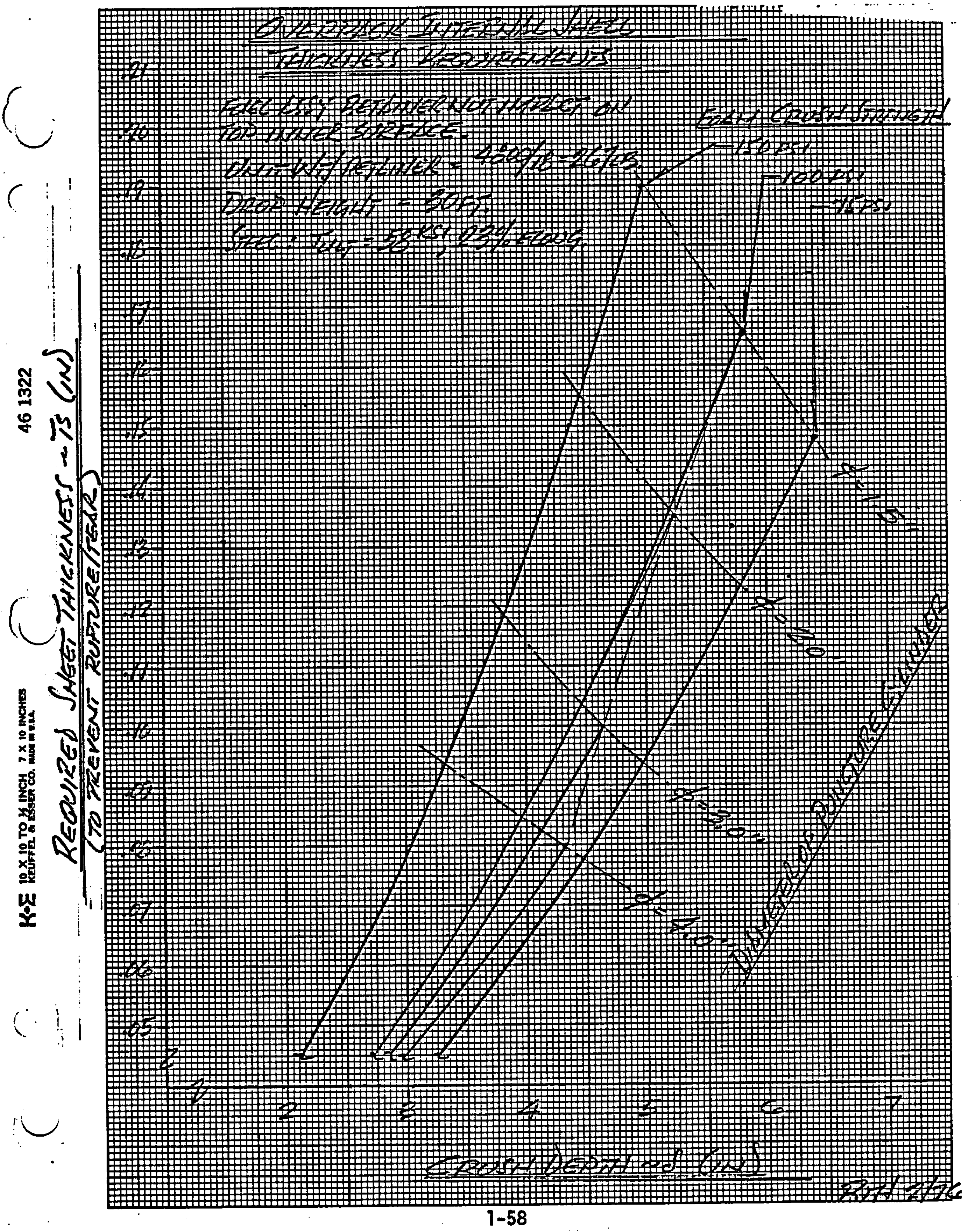
Max Stroke = $\bar{Z}$4 max (Impact Flat Drop) = (.222)(12)

= 2.66"

Thickness Req'd = 0.044

MS_{tear} = .1345/.044 -1 = +2.06

∴ The inner shell does not tear.


OVERPACK INTERNAL SHELL
THICKNESS REQUIREMENTS
DROP HEIGHT = 30 FT
EQ'L CRUSH STRENGTH
150 PSI
100 PSI
75 PSI
DIAMETER OF PUNCTURE CYLINDER
CRUSH DEPTH ~ δ (IN)
REQUIRED SHEET THICKNESS ~ TS (IN)
(TO PREVENT RUPTURE/TEAR)
RH 2/76

1.7.3 Thermal

The following thermal evaluation of the package demonstrates its ability to meet the normal transport and hypothetical accident conditions.

1.7.3.1 Summary of Pressures and Temperatures

Under steady state conditions, assuming a 24 hour day at maximum solar heat load and an internal heat load of 400 watts, the maximum rod temperature was found to be 232°F. External package temperature was less than 173°F.

Rod temperatures rose to a maximum of approximately 340°F when the package was subjected to the hypothetical fire condition.

From the above it can be safely concluded that thermal conditions will have little effect on the fuel rods.

1.7.3.2 Thermal Analysis

This analysis treats both normal transport and hypothetical accident conditions. Specifically, conditions evaluated include:

Normal Transport - 400 Watts Decay Heat

- Sheltered - 70°F Ambient Air
- Exposed - Maximum Solar Flux
  - 100°F Ambient Air (Design Criteria)
  - 130°F Ambient Air

Hypothetical Accident Condition

Overpack Condition

Undamaged

Composite Damage Case

Fire Exposure

30 Minute Fire @ 1475°F

400 Watts Decay Heat

Surface Emissivity = 0.8

Initial Conditions - 100°F Ambient Air

Cooling - Radiation Free Convection --- 70°F Ambient Air

The model employed for this analysis follows these introductory remarks. Briefly the model consists of a 13 node lumped parameter irealieation. A single node is used to represent the external overpack shell. Four nodes are used to represent the foam insulation separating inner and outer container shells. The inner shell is represented by three nodes, one for the rectangular tube closure rail surrounding the opening, one for the shell bottom (adjacent to the fuel bundle cradle) and finally, one node representing the remainder of the inner shell surface. The fuel transport assembly is represented by a total of four nodes, one for the cradle and three for the fuel bundle. The three nodes assigned to the fuel correspond to annular rings of fuel pins. The outermost ring consists of only the outermost row of fuel pins. The next ring consists of the second and third rows of fuel pins. Finally, the third and last fuel node consists of the innermost fuel pins (row 4 and inward).

The overpack outer shell is linked to the external environment (ambient air or fire source) by a pair of resistors, one represents radiation effects and one represents convection effects (free). During the 30 minute fire, the convection resistor is switched off. Solar flux is applied by a direct heat input to the outer shell.

Heat transfer through the foam insulation is represented by conduction resistors. To account for the possibility of foam char, the resistors are defined versus temperature such that the foam is replaced by an equivalent air gap at 400°F. Gases generated from decomposition of the foam (temperature $>$ 600°F) are vented through six 1½ inch diameter holes in the external skin. These vents are closed with a standard ABS plastic pipe plug that melts well before off gasing starts.

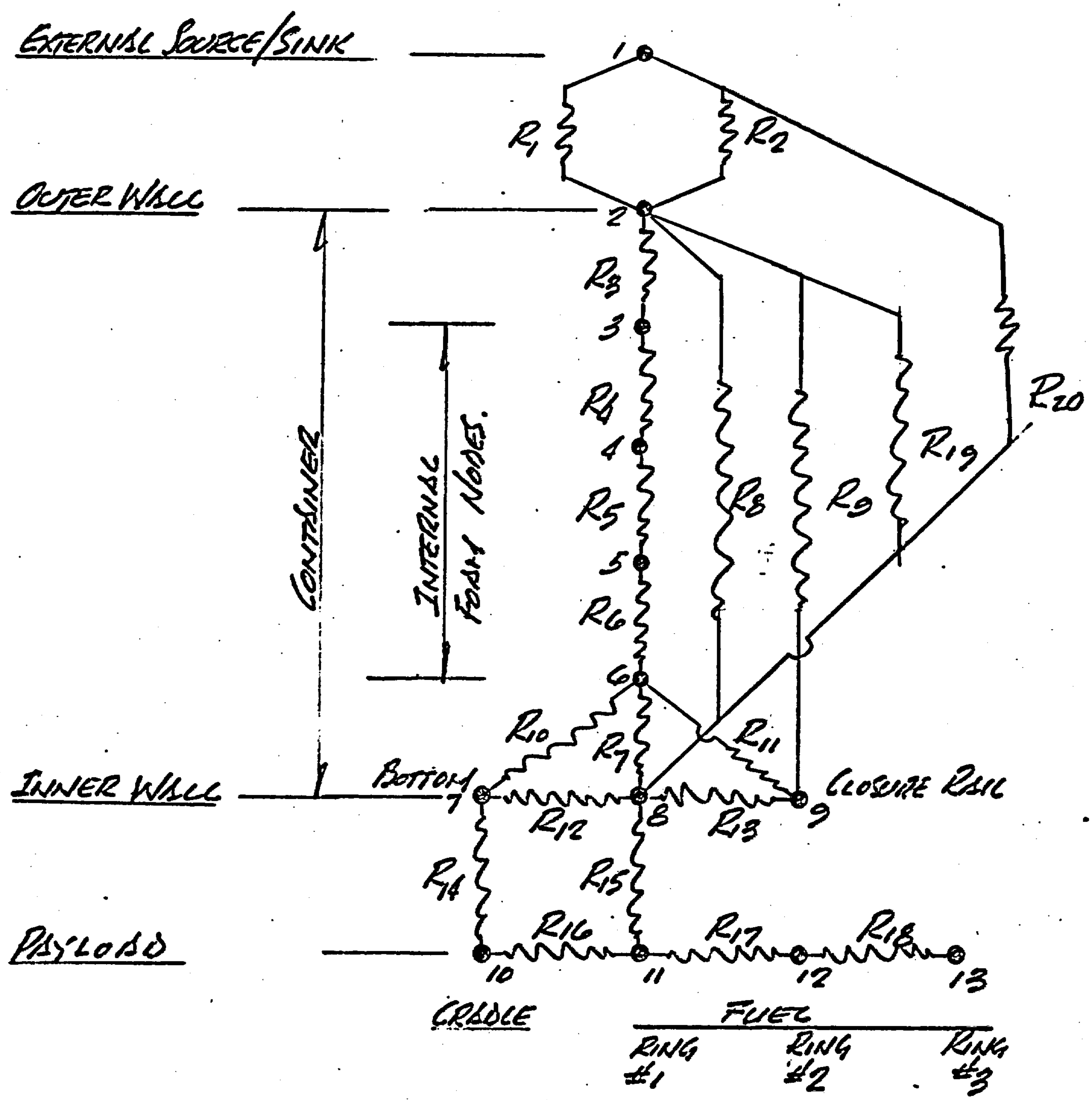
Heat transfer in the lip closure area is represented by metallic conduction resistors. Heat transfer between the inner shell and fuel assembly is represented by radiation resistances.

Damage effects are represented by a composite conduction resistor linking inner and outer shells.

Solution of steady state (normal transport) and transient (fire) cases is achieved by a conventional thermal analyzer program, THAN, based on the well known Lockheed Thermal Analyzer.

1.7.3.2.1

THERMAL ANALYSIS MODEL



RESISTOR CATEGORIES:

CONDUCTION	~	$R_3, R_4, R_5, R_6, R_7, R_8, R_9, R_{10}, R_{11}, R_{12}, R_{13}$
CONVECTION	~	R_2
RADIATION	~	$R_1, R_{14}, R_{15}, R_{16}, R_{17}, R_{18}$
DAMAGE	~	R_{19} (IMPACT CONDUCTION)
	~	R_{20} PUNCTURE RADIATION

Page 1-63 intentionally left blank.

1. CONDUCTIVE HEAT TRANSFER

CONDUCTION RESISTORS REPRESENT HEAT TRANSFER THROUGH FOAM INSULATION AND CERTAIN PORTIONS OF THE OVERPACK SHELL. THEY ARE AS FOLLOWS:

FOAM: R_3 - OUTER SHELL TO 1/5 DEPTH
R_4 - 1/5 TO 2/5 DEPTH FROM OUTER SHELL
R_5 - 2/5 TO 3/5 " " " "
R_6 - 3/5 TO 4/5 " " " "
R_7 - 4/5 DEPTH TO INNER SHELL, SIDES & TOP
R_{10} - 4/5 DEPTH TO INNER SHELL, BOTTOM
R_{11} - 4/5 DEPTH TO LWR. CLOSURE RAIL

STEEL: R_8 - UPPER LIP CLOSURE
R_9 - LOWER LIP CLOSURE
R_{12} - CONDUCTION WITHIN INNER SHELL
R_{13} - " " " "

FOAM CONDUCTION

THE BASIC FORM OF THE CONDUCTION RESISTOR IS:

$$R_{ij} = \frac{t_{ij}}{k_{ij} A_{ij}}$$

WHERE: t_{ij} = SLICE THICKNESS.
k_{ij} = CONDUCTIVITY
$= .3 \frac{Btu\text{-}in}{ft^2\text{-}hr\text{-}°F}$
A_{ij} = EFFECTIVE SECTION AREA OF SLICE.

RESISTORS R_3, R_4, R_5, R_6 WILL BE DEVELOPED AS TEMPERATURE DEPENDENT RESISTORS TO REFLECT THE POSSIBILITY OF FOAM CHAR. CHAR TEMPERATURE WILL BE ASSUMED TO BE 400°F. AT THAT TEMPERATURE EACH FOAM RESISTOR WILL BE REPLACED BY AN AIR GAP OF EQUIVALENT GEOMETRY.

FOAM OUTER RESISTORS $[R_3, R_4, R_5, R_6]$

EACH RESISTOR IS COMPUTED AS THE PARALLEL SUM OF 3 INDIVIDUAL RESISTORS. THE SUCCESSIVE PARALLEL SUM IS COMPUTED AS:

$$R = \frac{R_1 R_2}{R_1 + R_2}$$

THE THREE INDIVIDUAL COMPONENTS CONSIST OF:

- SIDES, R_{SH}
- TOP & BOTTOM, R_{SW}
- ENDS, R_E

THE SIDES: $R_{SH} = \frac{t}{KA}$; $t = 1''$; $K = .3$; $A = (37)(186)(2)/144$

$$= 34.874 \times 10^{-3} \ \frac{°F\text{-}HR}{BTU}$$

THE TOP & BOTTOM:

$R_{SW} = \frac{t}{KA}$; $t = 3/4''$; $K = .3$; $A = (37)(186)(2)/144$

$$= 26.155 \times 10^{-3}$$

COMBINING SIDES, TOP & BOTTOM:

$$R_S = 14.946 \times 10^{-3}$$

THE ENDS:

$R_E = \frac{t}{KA}$; $t = 1''$; $K = .3$; $A = (47)(45)(2)/144 = 29.38\ FT^2$

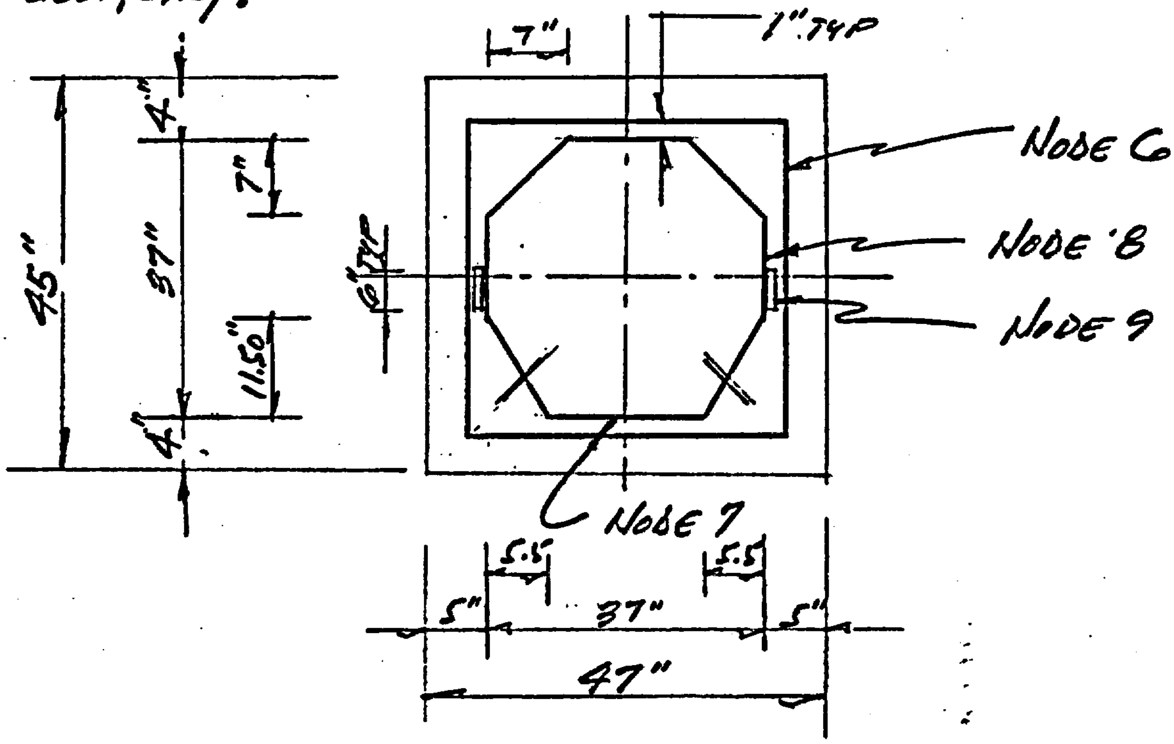
$$= .11345$$

THE FINAL SUM OF R_S & R_E GIVES:

$$R_{3\text{-}6} = \frac{R_E R_S}{R_E + R_S} = 13.206 \times 10^{-3} \left(\frac{°F\text{-}HR}{BTU}\right)$$

FOAM INNER RESISTORS.

FOAM RESISTORS R_7, R_{10} & R_{11} ARE SOMEWHAT MORE COMPLEX ~ A CROSS SECTION OF THE CONTAINER ILLUSTRATES GEOMETRY:



THE FLAT SIDE AREAS EQUAL:

(6-8) $A_{S_7} = \left(\frac{186}{144}\right)\left[2(37-7-11.50)+(37-11)\right] - A_{S_{11}}$

$= 81.38 - 15.50 = 65.88 \text{ FT}^2$

$A_{S_{10}} = \left(\frac{186}{144}\right)\left[(37-11)\right] = 33.58 \text{ FT}^2$

$A_{S_{11}} = \left(\frac{186}{144}\right)(2)(6) = 15.50 \text{ FT}^2$

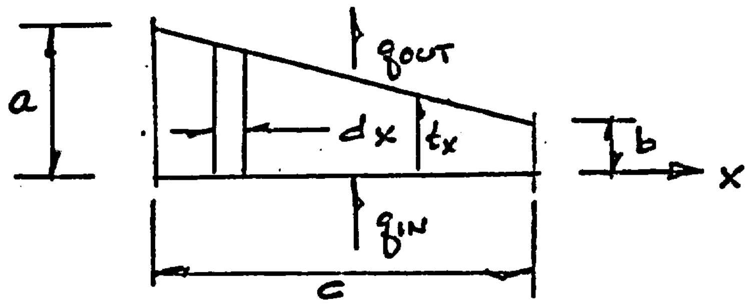
AND THE CORRESPONDING FLAT SIDE RESISTORS EQUAL:

$R_{S7F} = 50.6009 \times 10^{-3}$ (NODES 6-8)

$R_{S10F} = 99.2654 \times 10^{-3}$ (NODES 6-7)

$R_{S11F} = 215.054 \times 10^{-3}$ (NODES 6-9)

RESISTORS R_{S_7} & $R_{S_{10}}$ CONTAIN COMPONENTS REFLECTING HEAT TRANSFER VIA THE TAPERED FOAM BLOCKS. THE EQUIVALENT HEAT TRANSFER OF THIS REGION IS ESTIMATED AS FOLLOWS:



$$q_{IN} = q_{OUT} = \frac{\Delta T}{R_{EQUIV}} = +\int_0^c \frac{k(l\,dx)\Delta T}{t_x}$$

$$t_x = \frac{(b-a)}{c}x + a = mx + a$$

$$\frac{\Delta T}{R_{EQ}} = +kl\Delta T\int_0^c \frac{dx}{mx+a} = +kl\Delta T\left[\frac{1}{m}\ln(mx+a)\right]_0^c$$

$$= \frac{+kl\Delta T}{m}\left[\ln(mc+a) - \ln(a)\right]$$

$$= \frac{+kl\Delta T}{(b-a)/c}\cdot\ln\left[\frac{\left(\frac{b-a}{c}\right)c + a}{a}\right]$$

$$\frac{\Delta T}{R_{EQ}} = \frac{+kl\Delta T c}{(b-a)}\cdot\ln\left(\frac{b}{a}\right)$$

$$R_{EQ_T} = \frac{+(b-a)}{k\,l\,c\,\ln(b/a)} = \frac{+144(b-a)}{(.3)\,l\,c\,\ln(b/a)}$$

FOR RESISTOR 7: TREAT TOP CORNERS AS 4 HALF DIAGONALS
FOR EACH: $c = \frac{1}{2}\sqrt{2(7)^2}$ $a = 3.5+1$, $b = 1$

$R_{EQ}\big|_{7_T \text{ EACH TOP}} = 1.21323$; $R_{EQ\,7_T}\big|_{TOP} = \frac{1}{4} R_{EQ}\big|_{7_T\ \text{EA. TOP}} = 0.303$

RESISTOR 7 (CONT'D)

TREAT TWO LOWER CORNERS AS TWO HALF DIAGONALS:

$$c = \frac{1}{2}\sqrt{5.5^2 + 11.5^2} \qquad a = 1 + 5.5/2 \qquad b = 1$$

$$R_{EQ}\,_{7T}/_{\text{EACH BOTT.}} = .84239 \Rightarrow R_{EQ}\,_{7T}/_{\text{BOTT}} = \frac{1}{2}(.84239) = .42119$$

RESISTOR 10

TREAT TWO LOWER CORNERS AS TWO HALF DIAGONALS:

$$c = \frac{1}{2}\sqrt{5.5^2 + 11.5^2} \qquad a = 1 + 11.5/2 \qquad b = 1$$

$$R_{EQ}\,_{10T}/_{\text{EA. BOTT}} = 1.21919 \Rightarrow R_{EQ}\,_{10T}/_{\text{BOTT}} = \frac{1}{2}(1.21919) = .609$$

END CONTRIBUTIONS TO HEAT TRANSFER ARE ESTIMATED AS FOLLOWS:

$$\text{TOTAL AREA/END} = \frac{1}{144}(37^2 - 7^2 - 11.5 \times 5.5) = 8.73\ FT^2$$

$$A_{7E} = 2\left[8.73(.75) - \frac{(37)(6)}{144}\right] = 10.00\ FT^2$$

$$A_{10E} = 2[8.73(.25)] = 4.36\ FT^2$$

$$A_{11E} = 2\left[\frac{(37)(6)}{144}\right] = 3.08$$

SINCE ENDS ARE 10" THICK, $t_E = 10 - 4 = 6"$

$$R_{i_E} = \frac{6}{(.3)A_i}$$

REST. NR.	A_i (FT^2)	R_E
7	10.00	2.00
10	4.36	4.58716
11	3.08	6.49351

SUMMATION OF CONTRIBUTIONS TO FOAM RESISTORS R_7, R_{10}, R_{11}:

NOTE: CONTRIBUTIONS ARE ALL PARALLEL RESISTORS

CONTRIBUTION	PAGE	R_7	R_{10}	R_{11}
FLAT SIDES.	1-66	50.6009×10^{-3}	99.2654×10^{-3}	215.054×10^{-3}
TOP CORNERS	1-67	.303307	-	-
LOWER CORNERS	1-68	.421195	.609593	-
ENDS.	1-68	2.	4.58716	6.49351
	PARALLEL SUM:	38.5599×10^{-3}	83.8051×10^{-3}	208.16×10^{-3}

[NOTE: SUM OF $R_7 + R_{10} + R_{11} = 23.4356 \times 10^{-3}$

FOAM CHAR CORRECTION

DEFINE: $R_F = R_{AIR}/R_{FOAM} = \dfrac{\frac{t}{A\,k_{AIR}}}{\frac{t}{A\,k_{FOAM}}} = \dfrac{k_{FOAM}}{k_{AIR}} = \dfrac{0.3}{k_{AIR}}$

$= \dfrac{.3}{12\bar{k}_{AIR}}$

TEMPERATURE °F	°R	$\bar{k}_{AIR}$* $\left(\frac{Btu}{hr\text{-}ft\text{-}°F}\right)$	R_F
70°	530.	–	1.
400	860.	–	1.
401	861.	.0212	1.1792
500	960.	.0231	1.0823
600	1060.	.0250	1.000
700	1160.	.0268	0.9328
800	1260.	.0286	0.8741
900	1360.	.0303	0.8251
1000	1460.	.0319	0.7837
1500	1960.	.0400	0.6250
2000	2460.	.0471	0.5308

NOTE: $\bar{k}_{AIR}$ & k_{AIR} HAVE DIMENSIONAL DIFFERENCES

$\bar{k}_{AIR} = \dfrac{Btu}{hr\text{-}ft\text{-}°F}$

$k_{AIR} = \dfrac{Btu\text{-}in}{hr\text{-}ft^2\text{-}°F}$

$\therefore k_{AIR} = 12\bar{k}_{AIR}$

* KREITH, PRINCIPLES OF HEAT TRANSFER, TABLE A.3, p. 595.

STEEL SHELL CONDUCTION

RESISTORS R_8, R_9, R_{12}, R_{13} ASSUME A CONDUCTIVITY OF:

$$k = 25 \frac{Btu}{hr\cdot ft\cdot °F} = 2.08\bar{3} \frac{Btu}{hr\cdot in\cdot °F}$$

$$R_i = \frac{l_i}{k\, t_i\, w_i}$$

; l_i = PATH LENGTH (IN)
t_i = SHEET THICKNESS (IN)
w_i = SHEET WIDTH (IN)
$k = 2.08\bar{3}$

RESISTOR NR. (i)	PATH LENGTH (l_i)	SHEET THICKNESS (t_i)	SHEET WIDTH (w_i)	RESISTOR VALUE	NODES.	LOCATION OR ELEMENT
8	4.25	.1046	2(186)	52.427×10^{-3}	2-8	LIP-SIDES
	9.25	.1046	2(47)	451.57×10^{-3}		LIP-ENDS
				46.973×10^{-3}	←	// SURF
9	3.00	.0747	2(186+47)	41.367×10^{-3}	2-9	
12	12.75	.1046	2(186)	157.28×10^{-3}	7-8	SIDES
	11.50	.375	37	397.84×10^{-3}		END LT.
	11.50	.188	37	793.56×10^{-3}		END RT.
				98.699×10^{-3}	←	// SURF
13	4.	.1046	2(186)	49.343×10^{-3}	8-9	SIDES
	9.	.1046	2(37)	558.11×10^{-3}		END
				45.335×10^{-3}	←	// SURF

EXTERNAL CONVECTION

R_2 IS OPERATIVE DURING NORMAL TRANSPORT AND SUBSEQUENT TO THE HYPOTHETICAL ACCIDENT FIRE. IN EFFECT, THE RESISTOR PROVIDES CONVECTIVE COOLING OF THE EXTERNAL CONTAINER SURFACE. COOLING IS ASSUMED TO OCCUR OVER ALL BUT THE LOWER SURFACE OF THE RECTANGULAR CONTAINER.

THE FILM COEFFICIENT, h, FOR HORIZONTAL AND VERTICAL SURFACES IN AIR IS GIVEN BY McADAMS AS:

- HORIZONTAL SURFACES: $h = .27 \left(\frac{\Delta T}{L}\right)^{1/4}$
- VERTICAL SURFACES: $h = .29 \left(\frac{\Delta T}{L}\right)^{1/4}$

WHERE: h = Btu/hr-ft²-°F

L = VERTICAL OR HORIZONTAL DIMENSION (F

SINCE: $L_H = \frac{47}{12} = 3.92$; $L_V = \frac{45}{12} = 3.75$

$$h_H = 0.191926 \quad \Delta T^{1/4}$$

$$h_V = .208396 \quad \Delta T^{1/4}$$

$$\text{AREA, HORIZONTAL} = \frac{47 \times 206}{144} = 67.236 \text{ FT}^2$$

$$\text{AREA VERTICAL} = \frac{1}{144}\left[45 \times 206 \times 2 + 45 \times 47 \times 2\right] = 158.12$$

$$\bar{h} = \left[\frac{(67.236)(.191926) + (158.125)(.208396)}{67.236 + 158.125}\right] \Delta T$$

$$\bar{h} = 0.203482\ \Delta T^{1/4}$$

IN THAN:

$$h = GK\,\Delta T^{m} \text{ WHERE } G = f(\text{TIME}) \quad (2)$$

$K = .20348$ (1)

$m = .25$

$A_{EFF} = 225.36$ FT²

RADIATION RESISTORS

$$K_{ij} = \frac{\sigma A_i}{\left(\frac{1}{\epsilon_i}-1\right) + \frac{1}{F_{ij}} + \frac{A_i}{A_j}\left(\frac{1}{\epsilon_j}-1\right)}$$

$$\sigma = 0.1714 \times 10^{-8} \; \frac{Btu}{hr\text{-}ft^2\text{-}°R^4}$$

EXTERNAL RADIATION, R_1

$\epsilon = 0.8$ (10CFR71)

$$A_1 = \frac{1}{144}\left[(2)(206)(47+45)+2(45)(47)\right] = 292.60\,FT^2$$

$$K_1 = \sigma A \epsilon = \underline{401.21 \times 10^{-9}}$$

INTERNAL RADIATION

$\epsilon = 0.8$ (ASSUMED)

OVERPACK TO FUEL ASSY R_{14}, R_{15}

RESISTOR R_{14} REPRESENTS THE RADIANT HEAT TRANSFER BETWEEN OVERPACK BOTTOM AND THE FUEL ASSY CRADLE. THE GEOMETRY IS APPROXIMATED AS TWO PARALLEL PLATES 27" x 173" OFFSET 9.5" FROM ONE ANOTHER. ACCORDING TO KREITH, RADIATION HEAT TRANSFER, THE VIEW FACTOR F_{ij} IS GIVEN (FIG V-13) AS:

$$\left.\begin{array}{l} x = b/c = \frac{173}{9.5} = 18.211 \\ y = a/c = \frac{27}{9.5} = 2.842 \end{array}\right\} F_{1,2} = 0.7$$

$$A_1 = A_2 = \frac{27 \times 173}{144} = 32.438\,FT^2$$

$$\therefore \; K_{14} = \underline{28.829 \times 10^{-9}}$$

RADIATION RESISTOR 15 WILL BE DERIVED FROM THE PRINCIPAL OF AN ENCLOSED BODY [$F_{12} = 1.$] AND THE VIEW FACTOR USED FOR RESISTOR 14 AND THE BASIC DECOMPOSITION LAW:

$$A_1 F_{12} = A_j F_{j2} + A_k F_{k2} + \cdots$$

LET: A_1 = THE TOTAL PAYLOAD AREA

$$= \frac{2}{144}\left[23 \cdot 173 + 27 \cdot 173 + 23 \cdot 27\right] = 128.76$$

A_j = THE BOTTOM AREA (RESISTOR 14)

$$= 32.438 \text{ FT}^2$$

A_k = THE NET AREA (RESISTOR 15)

$$= 128.764 - 32.438 = 96.326 \text{ FT}^2$$

$F_{12} = 1$; $F_{j2} = .76$; F_{k2} = UNKNOWN

$$F_{k2} = \frac{(128.764)(1) - (32.438)(.7\ \ )}{96.326} = 1.101$$

$A_i = 96.326$

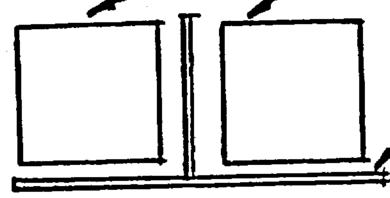
A_j = INNER SURFACE OF OVERPACK

$$= \left[(4)(37)(186) + (2)(37^2)\right]/144 = 210.18 \text{ FT}$$

$$K_{15} = \underline{129.71 \times 10^{-9}}$$

RADIATION WITHIN FUEL ASSY

RESISTOR 16 REPRESENTS RADIANT COUPLING BETWEEN THE CRADLE AND FUEL ASSEMBLY



EACH OF 4 SURFACES: $a = 8.4$, $b = 151.635$, $c = 1"$

$x = b/c = 151.6$

$y = 8.4$

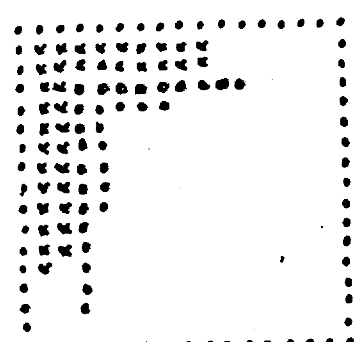
$\Rightarrow F_{ij} = 0.9$

$A = (151.635)(8.4)/144 = 8.8454 \text{ FT}^2$

$K_{ij} = 9.4103 \times 10^{-9}$

$K_{16} = 4K_{ij} = 37.641 \times 10^{-9}$

RESISTORS R_{17} AND R_{18} REPRESENT RADIANT TRANSFER WITHIN THE FUEL RODS. THE FUEL RODS ARE ASSUMED LOCATED ON A 17×17 GRID. RING 1 REPRESENTS THE OUTER MOST SHELL OF RODS. RING 2 REPRESENTS THE NEXT TWO SHELLS OF RODS. RING 3 REPRESENTS THE INNER MOST RODS.



RING #1 (128 RODS)
RING #2 (208 RODS)
RING #3 (242 RODS)

DIMENSIONS
RING #1 : 7.4" × 7.4"
RING #2 : 6.475 × 6.475
RING #3 : 5.550" × 5.550"

FOR RESISTORS R_{17} & R_{18}:

	R_{17}	R_{18}
A_1 =	$\frac{2}{144}[(4)(6.475)(151.635)] = 54.546$	$\frac{2}{144}[(4)(5.55)(151.635)] = 46.754$
A_2 =	$\frac{2}{144}[(4)(7.4)(151.635)] = 62.339$	54.546
F_{12} =	1.	1.
k =	63.655×10^{-9}	54.727×10^{-9}

INTERNAL DECAY HEAT DISTRIBUTION

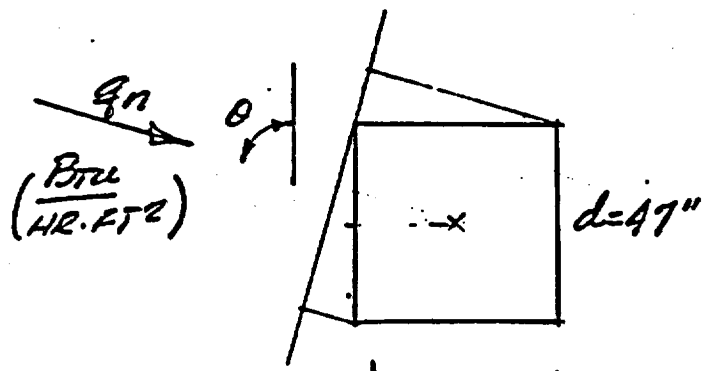
TOTAL INTERNAL HEAT LOAD = 400 WATTS
= 1365.5 BTU/HR

DISTRIBUTION

NODE	RING	RODS	Btu/hr.	%
11	1	128	302.4	22.15
12	2	208	491.4	35.98
13	3	242	571.7	41.87
			1365.5	

SOLAR ILLUMINATION

THIS HEAT LOAD ON EXTERNAL CONTAINER SURFACE IS APPLICABLE ONLY DURING NORMAL TRANSPORT CONDITIONS. THE SOLAR INTENSITY FOR LATITUDE 42°N IS TAKEN FROM SHAPPERT, CASK DESIGNERS GUIDE, FIG 5.3, ORNL-NSIC-68. NORMAL INTENSITY IS USED IN CONJUNCTION WITH THE CONTAINER NORMAL X-SECTION.



$$A_n = \frac{l}{144}\left[d\sin\theta + d\cos\theta\right]; \quad d = 47\text{ IN}, \quad l = 206\text{ IN}$$

$$= 67.24\left[\sin\theta + \cos\theta\right],\ FT^2$$

$$Q_n = A_n q_n \alpha \ ; \quad \alpha = 0.8 \text{ (ASSUMED)}$$

TIME (AM)	θ°	q_n	Q_n (BTU/HR)
4:30	90	0.	0.
5	84	100	5912.
5:30	78	150	9570.
6:	72	180	12200.
6:30	66	210	14913.
7	60	225	16532.
7:30	54	238	17882.
8	48	250	18991.
8:30	42	260	19751.
9	36	270	20286. ← MAX SOLAR LOAD
9:30	30	275	20206.
10	24	280	19885.
10:30	18	285	19317.
11	12	290	18501.
11:30	6	293	17321.
12N	0	295	15868.

CAPACITANCES

VOLUMETRIC ESTIMATES - SHELL

EXTERNAL - NODE NR. 2

TOP, BOTTOM & SIDES. (12GA):

$(2)(.1046)(206)(47+45) = 3965.\ IN^3$

ENDS (12 GA):

$(2)(.1046)(47)(45) = 442.$

LATCHES (12 @ 20 IN³/EA) = 240

Total: $4647\ IN^3$

INTERNAL

BOTTOM (12GA) - NODE 7

$(26)(186)(.1046) = 506\ in^3$

$(.1046)(186)(2)(11.5^2+5.5^2)^{1/2} = 496$

$(11.5)\left(\frac{37+26}{2}\right)(3/8 + 3/16) = 204$

Total: $1206\ IN^3$

CLOSURE RAIL - NODE 9

$[(2)(186)+(2)(39)] \cdot [(2.738) + (4)(.1046)] = 1891\ IN$

REMAINDER - INTERNAL - NODE 8

$(26)(186)(.1345) = 650\ IN^3$

$(.1046)(186)(2)(2 \cdot 7^2)^{1/2} = 385$

$(.1046)(186)(2)(15) = 584$

$\left[(15)(37) + (7)\left(\frac{37+26}{2}\right)\right](3/8 + 3/16) = 436$

Total: $2055\ IN^3$

VOLUMETRIC ESTIMATE ~ FOAM (TOTAL)

$V = V_{OUTER} - V_{INNER}$

$= (45)(47)(206) - (186)[37^2 - 7^2 - (11.5)(5.5)] = 201935 \text{ IN}^3$

VOLUME PER FOAM NODE = 50484 IN^3
(NODES 3, 4, 5, 6)

NODE 10 - FUEL ASSY GRADE - STEEL.

1500# PER WESTINGHOUSE DWG. 686J075

NODES 11, 12 & 13 - FUEL ASSY DIST. [REF WEST. DWG 1182F20]

STL. STEEL	2×36 =	72.
ZIRCALOY	2×264 =	528.
INCONEL	2×13 =	26
URANIUM DIOX.	2×1154 =	2308
CONTR. ROD	2×149 =	298
		3232.

DISTRIBUTION OF THIS FUEL TO NODES 11, 12, 13 FOLLOWS THAT USED IN ¶ 4.0, INTERNAL HEAT DISTRIBUTION.

CAPACITANCE SUMMARY

NODE	VOLUME (IN³)	DENSITY (LB/IN³)	WEIGHT (LB)	Cp (Btu/lb-°F)	Ci (Btu/°F)	
2	4647	.283	1915.10	.113	148.61	
3, 4, 5, 6	50484	4.5/1728	131	.2	26.29	
7	1206	.283	341.3	.113	38.57	
8	2055	.283	581.6	.113	65.72	
9	1891	.283	535.2	.113	60.47	
10	-	-	1500	.113	169.50	
FUEL ASSY		STL. CLRS.	72	.12	8.64	FUEL ASSY. = 235.60
		ZIRC.	528	.0659	34.80	
		INCONEL	26	.101	2.63	
		UO2	2308	.0563	129.94	
		CONTR RD.	298	.2	59.60	
11			22.15%		52.19	
12			35.98%		84.77	
13			41.87%		98.65	

ASSESSMENT OF IMPACT & PUNCTURE DAMAGE TO THERMAL SYSTEM

THE EFFECTS OF IMPACT DAMAGE AND PUNCTURE ARE SEPARATELY TREATED. RESISTOR R_9 REPRESENTS IMPACT DAMAGE AS A CONDUCTIVE RESISTOR. RESISTOR R_{20} REPRESENTS PUNCTURE DAMAGE AS A RADIATION RESISTOR (OUTER SKIN TEAR ASSUMED FOR CONSERVATISM)

IMPACT EFFECTS, R_9

FOR CONSERVATISM THE DAMAGE DUE TO TWO 30' DROPS ARE COMBINED AS THOUGH DUE TO A SINGLE EVENT. THE TWO MOST CRITICAL EVENTS CORRESPOND TO FLAT IMPACT (ON THE TOP SURFACE) AND CORNER IMPACT (WHERE OUTER SKIN CONTACTS INNER SKIN).

1. FLAT IMPACT

THE UNIFORM REDUCTION OF THICKNESS IS CONSIDERED AS THE ONLY SIGNIFICANT VARIABLE:

THE AREA OF THIS CHANGE IS:

$$A = \frac{(186)(26)}{144} = 33.583\ FT^2$$

THE ORIGINAL RESISTANCE WAS:

$$R_0 = \frac{4}{(.3)(33.583)} = 397.02 \times 10^{-3}$$

THE DAMAGED RESISTANCE IS:

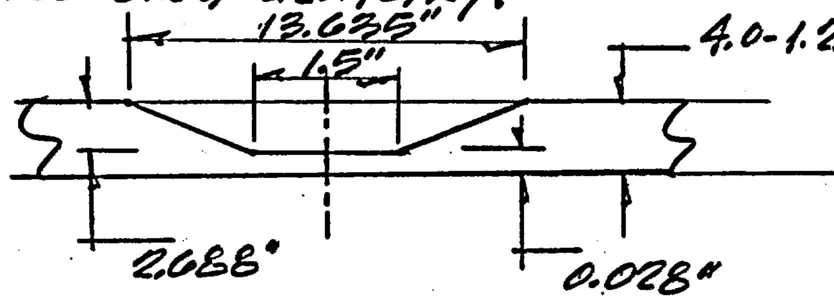
$$R_D = \frac{(4-1.284)}{(.3)(33.583)} = 269.58 \times 10^{-3}$$

THE PARALLEL EQUIVALENT OF THIS DAMAGE IS:

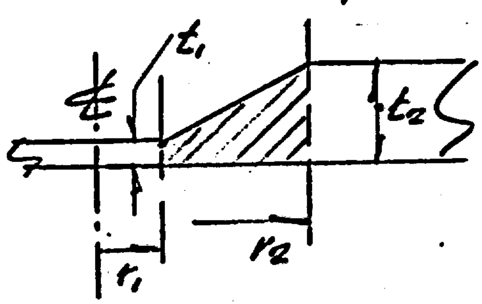
$$R_{FI} = \frac{R_D R_0}{R_0 - R_D} = \underline{839.82 \times 10^{-3}}$$

1. FLAT IMPACT DAMAGE (CONT'D)

IN ADDITION TO THE GENERAL DEFORMATION, LOCALIZED PROTUBERANCES PUNCH 18 CONE SHAPED DENTS IN THE FOAM BACKED INNER SKIN. EACH DENT HAS THE FOLLOWING GEOMETRY:



THE ANALYSIS FOLLOWS A PARALLEL ROUTE TO THAT OUTLINED ON PAGE 1-67. FOR THE CONE THE HEAT TRANSFERRED THRU THE SHADED AREA IS:



$$R_c = \frac{t_1}{K A_{EFF}}$$

$$A_{EFF} = 2\pi t_1 \left(\frac{r_2-r_1}{t_2-t_1}\right)^2 \left\{(t_2-t_1) - \left[t_1 - r_1\left(\frac{t_2-t_1}{r_2-r_1}\right)\right] \ln(\ldots\right.$$

THUS THE RESISTANCE FOR EACH DENT IS:

$$R_{DF} = \frac{.028}{(.3)(5.424/144)} = \underline{2.478} \; ; A = A_{EFF} + \frac{\pi (d^2)}{4}$$

$$= 3.657 + 1.767$$

$$= 5.424$$

FOR 18 DENTS -

$$R_{DI} = \frac{1}{18} R_{DP} = \underline{137.67 \times 10^{-3}}$$

COMBINING THIS WITH THE GENERAL FLAT TERM, R_{FI} GIVES THE TOTAL "FLAT" IMPACT EFFECT:

$$R_F = \frac{R_{DI} \cdot R_{FI}}{R_{DI} + R_{FI}} = \underline{118.28 \times 10^{-3}}$$

2. CORNER IMPACT

AS TABULATED ON PAGE 1-43 THERE IS A NET INTERFERENCE OF 1.143" AS MEASURED AT THE INNER SKIN. ASSUMING A SYMMETRIC IMPACT THE CONTACT AREA BETWEEN THE OUTER SKIN AND INNER SKIN IS:

$$A_c = \frac{3\sqrt{3}}{2}\delta^2 = \frac{3\sqrt{3}}{2}(1.143)^2 = 3.39\,IN^2$$

ASSUMING A FOAM CONTACT FILM THICKNESS OF 0.020"

$$R_c = \frac{.020}{(.3)(3.39/144)} = 235.69\times10^{-3}$$

COMBINING CORNER & FLAT EFFECTS:

$$R_{19} = \frac{R_F \cdot R_c}{R_F + R_c} = \underline{78.757\times10^{-3}}$$

PUNCTURE EFFECTS, R_{20}

THE 6"φ PUNCTURE PIN IS ASSUMED TO TEAR A 12"φ HOLE IN THE OUTER SKIN:

$$K_{20} = \sigma A \epsilon \quad ; \quad \sigma = .1714\times10^{-8}$$
$$\epsilon = .8$$
$$A = \frac{\pi(1)^2}{4} = 0.7854\,FT^2$$

$$K_{20} = \underline{1.0769\times10^{-9}}$$

1.7.3.2.2

RESULTS

DETAILED NUMERICAL RESULTS ARE SEPARATELY BOUND. THIS SECTION PROVIDES SUMMARY RESULTS IN A GRAPHICAL FASHION

1.7.3.2.2.1 NORMAL TRANSPORT

THESE ANALYSES EMPLOY A STEADY STATE SOLUTION TECHNIQUE. THREE SEPARATE ANALYSES WERE PERFORMED, AS MENTIONED PREVIOUSLY. FOR EXPOSED CASES, MAXIMUM SOLAR FLUX ON THE TOP AND SIDE WAS ASSUMED AS A HEAT LOAD. ALL CASES ASSUMED A 400 WATT (INTERUSC) DECAY HEAT LOAD ON FUEL.

SUMMARY RESULTS ARE SHOWN ON THE FOLLOWING SHEET ~ DETAILS ARE SHOWN BELOW.

CASE 1 ~ 130° AMBIENT AIR ~ MAX. SOLAR FLUX

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	130.0000000	2	173.4460814	3	177.1014381	4	180.86036
5	184.9692431	6	189.1308558	7	197.5732650	8	203.83744
9	188.1063866	10	205.0341044	11	210.9765022	12	224.05535
13	232.1963371						

CASE 2 ~ 100° AMBIENT AIR ~ MAX SOLAR FLUX

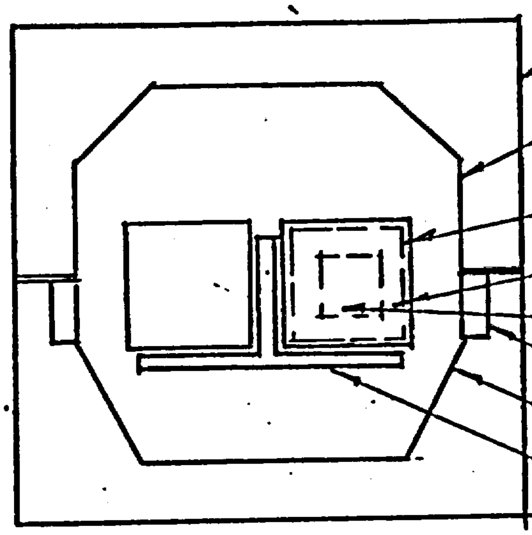
ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	100.0000000	2	148.3295617	3	152.9970641	4	157.79505
5	162.5738395	6	167.4592058	7	176.[illegible]31692	8	183.07970
9	165.1794806	10	185.2347534	11	191.3581863	12	206.47530
13	215.1824223						

CASE 3 ~ 70°F AMBIENT AIR ~ NO SOLAR FLUX

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES
1	70.0000000	2	74.7441877	3	79.6480086	4	84.5443
5	89.1547999	6	93.5227252	7	101.3880569	8	107.7151
9	90.9607085	10	111.8113431	11	119.5371269	12	139.6162
13	151.5406616						

SUMMARY OF STEADY STATE THERMAL RESULTS

ALL RESULTS ARE FOR NORMAL TRANSPORT CONDITIONS AND NO DAMAGE.



RESULTS:

EXTERNAL ENVIRONMENTAL CONDITION:	CASE 1	CASE 2	CASE 3
AMBIENT TEMP (°F):	(2) 130°	(3) 100°	(4) 70°
SOLAR FLUX (BTU/HR): (1)	20286.	20286.	0
NODE	TEMPERATURES (°F)		
2	173.4	148.3	74.7
7	197.6	176.4	101.4
8	203.8	183.1	107.7
9	188.1	165.2	90.9
10	205.0	185.2	111.8
11	211.0	191.4	119.5
12	224.1	206.5	139.6
13	232.2	215.2	151.5

NOTES:

(1) MAX. DAILY FLUX, LAT. 42°, AT 9AM. (= 270 BTU/FT²·HR)

(2) EXTREME EXAMPLE USED BY SHAPPERT, ORNL-NSIC-68.

(3) WESTINGHOUSE DESIGN REQMT.

(4) NORMAL CONDITION ~ UNDER ROOF.

1.7.3.2.2.2 Hypothetical Fire Accident

Two analyses have been performed. These analyses are essentially identical in all respects except one reflects the damaged condition and the other the undamaged condition.

The analysis assumes a time programmed source temperature (1475°F for 30 minutes, then 70°F thereafter). Similarly, convection between source and overpack shell is a time programmed function operable only after the 30 minute fire exposure. No artificial cooling was applied.

Summary results are plotted on the following sheet for the damaged case. Comparative points are illustrated for the most significant portion of the undamaged analysis.

This plot shows the following:

1) Overpack shell responds quickly to the source temperature.
2) Within 45 minutes all elements, except fuel have attained maximum temperature and have begun to cool.
3) Innermost fuel pins attain a maximum temperature of about 260°F at about 3.5 hours.
4) Maximum interior wall temperature of about 410°F is attained on the closure rail at about 36 minutes.
5) Outermost fuel pins attain a temperature of 340 °F at about 45 minutes.

TRANSIENT PROBLEM

TIME = .0 SEC.
MINIMUM RC PRODUCT = .0 SEC. ----- FOR NODE 0

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	1475.0000000	2	148.3000000	3	153.0000000	4	157.82000
5	162.6400000	6	167.4600000	7	176.4000000	8	183.10000
9	165.2000000	10	185.2000000	11	191.4000000	12	206.50000
13	215.2000000						

TIME = 5.0000000E-01SEC.
MINIMUM RC PRODUCT = 1.2719246E-02SEC. ----- FOR NODE 2

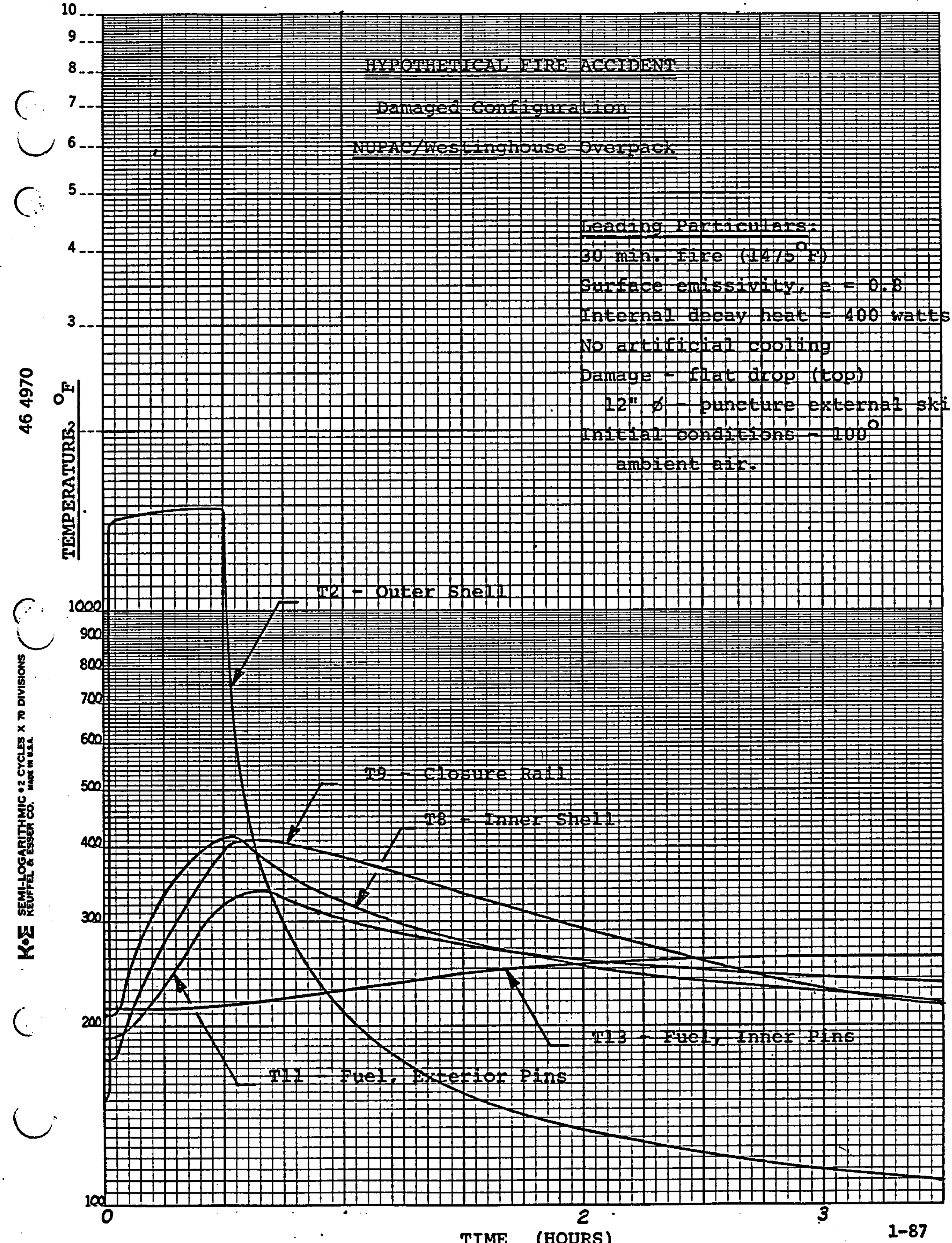
ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	1475.0000000	2	1464.9251100	3	911.8789622	4	456.50784
5	267.2104050	6	206.0004149	7	193.9375739	8	422.08402
9	392.5969816	10	192.5715768	11	316.9001817	12	226.64967
13	216.8313187						

TIME = 6.0000000E-01SEC.
MINIMUM RC PRODUCT = 1.1245470E-01SEC. ----- FOR NODE 11

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES F
1	69.9979955	2	450.5631652	3	796.5729172	4	512.95647
5	304.8161094	6	226.4021996	7	201.2387341	8	401.98817
9	411.7839106	10	197.0269960	11	339.4984180	12	237.79937
13	218.3168822						

TIME = 3.5500000E+00SEC.
MINIMUM RC PRODUCT = 1.6851993E-01SEC. ----- FOR NODE 11

ID	DEGREES F	ID	DEGREES F	ID	DEGREES F	ID	DEGREES
1	69.9322940	2	110.0747763	3	154.5915442	4	191.684
5	218.2689702	6	233.1843869	7	244.3025160	8	218.943
9	209.2440165	10	244.5846284	11	235.9142369	12	253.755
13	261.7544178						


HYPOTHETICAL FIRE ACCIDENT
Damaged Configuration
NUPAC/Westinghouse Overpack
Leading Particulars:
30 min. fire (1475°F)
Surface emissivity, e = 0.8
Internal decay heat = 400 watts
No artificial cooling
Damage - flat drop (top)
12" ø - puncture external ski
Initial conditions - 100°
ambient air.
T2 - Outer Shell
T9 - Closure Rail
T8 - Inner Shell
T13 - Fuel, Inner Pins
T11 - Fuel, Exterior Pins
TEMPERATURE, °F
TIME (HOURS)
10
9
8
7
6
5
4
3
1000
900
800
700
600
500
400
300
200
100
0
2
3
46 4970
K&E SEMI-LOGARITHMIC • 2 CYCLES X 70 DIVISIONS
KEUFFEL & ESSER CO. MADE IN U.S.A.

1.7.4 Water Immersion

The effects of the water immersion test condition for fissile packages can be found in Appendix 5.6

1.7.5 Summary of Damage

As a result of the above assessment, it is concluded that should the Model MO-1 Package be subjected to the hypothetical accident conditions:

1) A reduction of shielding will not occur due to absorber plate location, between the fuel assemblies and sandwiched within the support frame structural members.
2) No radioactive material would be released from the package.

Also, as a result of the assessment described above, it is concluded that, if subjected to the hypothetical accident conditions, the Model MO-1 Package would be subcritical, assuming:

1) The fissile material is in the most credible reactive configuration consistent with the damaged condition of the packaging and the chemical and physical form of the contents;
2) Full light water moderation of the contents consistent with the damage conditions of the contents;
3) Full light water reflection of the contents consistent with the damage condition of the contents.

Refer to Section 5.0 for nuclear safety criteria, assumptions, methods of analysis, and results.

1.8 Special Form

Since Special Form is not claimed, this section of the application is not applicable.

1.9 Fuel Rods

Structurally the fuel rods to be transported in the Model MO-1 Package are identical to those that are currently authorized for shipment in the RCC Package series. As noted in Section 1.1.2, the prime requirement of this package is to provide thermal insulation for the pressurized fuel rods. The analysis of Section 2.0 will demonstrate the overpack's ability to meet this requirement.

1.10 Appendix

Index to Appendix

1.10.1 NRC Certificate No. 5450, Docket 71-5450

1.10.2 Drawing No. 1581F50, Revision 1, Sheets 1 and 2.
General arrangement of Model MO-1 Packaging

1.10.3 W Letter PDD 045-74, dated 08/22/74

APPENDIX 1.10.1

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

APR 15 1981

FCTC:RHO
71-5450

RECEIVED
APR 20
NES LICENSING
SAFEGUARDS & SAFETY

Westinghouse Electric Corporation
ATTN: Mr. A. T. Sabo
P.O. Box 355
Pittsburgh, PA 15230

Gentlemen:

Enclosed is Certificate of Compliance No. 5450, Revision No. 13, for the Model Nos. RCC, RCC-1, RCC-2, RCC-3, and RCC-4 packaging. This certificate supersedes Certificate No. 5450, Revision No. 12, dated January 29, 1981.

Changes made to the enclosed certificate are indicated by vertical lines in the margin.

Those on attached list have been registered as users of these packages under the general license provisions of 10 CFR §71.12(b) or 49 CFR §173.393a.

This approval constitutes authority to use these packages for shipment of radioactive material and for the packages to be shipped in accordance with the provisions of 49 CFR §173.393a.

Sincerely,

Charles E. MacDonald, Chief
Transportation Certification Branch
Division of Fuel Cycle and
Material Safety

Enclosure: As stated

cc w/encl: Mr. Richard R. Rawl
Department of Transportation

Model Nos. RCC, RCC-1, RCC-2, RCC-3, and RCC-4 Packagings
USA/5450/AF

Addressees

Department of Energy
ATTN: Mr. E. L. Barraclaugh
P.O. Box 5400
Albuquerque, NM 87115

Department of Energy
ATTN: Mr. Larry Blalock
P.O. Box E
Oak Ridge, TN 37830

Department of Energy
ATTN: Mr. James M. Peterson
P.O. Box 550
Richland, WA 99352

Duquense Light Company
ATTN: Mr. J. A. Werling
P.O. Box 4
Shippingport, PA 15077

IRT Corporation
ATTN: Mr. K. L. Crosbie
P.O. Box 80817
San Diego, CA 92138

Oak Ridge National Laboratory
ATTN: Mr. William E. Terry
P.O. Box X
Oak Ridge, TN 37830

Sandia Laboratories
ATTN: Mr. W. C. Purchase
P.O. Box 5800
Albuquerque, NM 87115

Tennessee Valley Authority
ATTN: Mr. L. M. Mills
400 Chestnut Street, Tower II
Chattanooga, TN 37401

Virginia Electric Power Company
ATTN: Mr. B. R. Sylvia
P. O. Box 26666
Richmond, VA 23261

Westinghouse Electric Corporation
ATTN: Mr. A. T. Sabo
P.O. Box 355
Pittsburgh, PA 15230

Form NRC-618
(12-73)
10 CFR 71

U.S. NUCLEAR REGULATORY COMMISSION

CERTIFICATE OF COMPLIANCE

For Radioactive Materials Packages

1.(a) Certificate Number	1.(b) Revision No.	1.(c) Package Identification No.	1.(d) Pages No.	1.(e) Total No. Pages
5450	13	USA/5450/AF	1	4

2. PREAMBLE

2.(a) This certificate is issued to satisfy Sections 173.393a, 173.394, 173.395, and 173.396 of the Department of Transportation Hazardous Materials Regulations (49 CFR 170-189 and 14 CFR 103) and Sections 146-19-10a and 146-19-100 of the Department of Transportation Dangerous Cargoes Regulations (46 CFR 146-149), as amended.

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

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

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

3.(a) Prepared by (Name and address):
Westinghouse Electric Corporation
P.O. Box 355
Pittsburgh, PA 15230

3.(b) Title and identification of report or application:
Westinghouse Electric Corporation application dated December 17, 1980, as supplemented.

3.(c) Docket No. 71-5450

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

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

(a) Packaging

(1) Model Nos.:

RCC, RCC-1, RCC-2, RCC-3, and RCC-4.

(2) Description

Steel fuel element cradle assembly consisting of a strongback and adjustable fuel element clamping assembly, shock mounted to a 14-gage steel outer container by shear mounts. Neutron absorber plates are required for the contents as specified. Gross weight for the RCC and RCC-2 is 6,300 lbs., RCC-1 and RCC-3 is 7,200 lbs., and RCC-4 is 8,400 lbs.

(3) Drawings

The packaging is constructed in accordance with Westinghouse Electric Corporation Drawing Nos.: 1596E24, 1596E25, and 1553E30 for the RCC and RCC-2; 1596E24, 1596E25, and 1553E31 for the RCC-1 and RCC-3; and 1596E22, 1596E23, and 1548E55 for the RCC-4.

3 2

(4) Fuel rod container reinforced 13-gage steel box constructed in accordance with Westinghouse Electric Corporation Drawing No. C56J0055.

5. (b) Contents

(1) Type and form of material

(i) Uranium dioxide as zircaloy or stainless steel clad unirradiated fuel elements. Two (2) neutron absorber plates consisting of 0.19" thick full length stainless steel containing 1.3% minimum boron or 0.19" thick OFHC copper are required between fuel elements of the following specifications:

Type	14x14 Zr Clad	15x15 Zr Clad	14x14 SST Clad	15x15 SST Clad	17x17 Zr Clad	16x16 Zr Clad	14x14 Zr Clad
Pellet diameter (nom), in	0.344-0.367	0.367	0.384	0.384	0.308-0.322	0.322	0.3805
Rod diameter (nom), in	0.400-0.422	0.422	0.422	0.422	0.360-0.374	0.374	0.44
Maximum fuel length, in	144	144	120	120	168	144	144
Maximum rods/element	180	204	180	204	264	235	176
Maximum cross section, (nom), in sq	7.8	8.4	7.8	8.4	8.4	7.8	7.98
Maximum U-235/element, kgs	17.7	18.3	18.5	18.7	17.0 (144"L) 19.8 (168"L)	16.6	19.0
Maximum U-235 enrichment, w/o	4.0	3.65	4.0	3.65	3.65	4.0	3.85

(ii) Uranium dioxide as zircaloy or stainless steel clad unirradiated fuel rods of the following specifications:

Type	SST Clad	Zr Clad	Zr Clad
Pellet diameter (nom), in	0.384	0.367	0.322
Rod diameter (nom), in	0.422	0.422	0.374
Fuel length (max), in	144	144	168
Maximum U-235 enrichment, w/o	4.0	4.0	3.65

(2) Maximum quantity of material per package

(i) For the contents described in 5(b)(1)(i):

Two fuel elements.

(ii) For the contents described in 5(b)(1)(ii):

Two inner containers containing not more than 80 kilograms U-235.

(c)	Fissile Class	II and III
	(1) Minimum transport index to be shown on label for Class II	1.2
	(2) Maximum number of packages per shipment for Class III	60

6. Fuel rods shall be closely packed in the fuel rod container on no more than an equivalent metal-to-metal square lattice. Partially loaded fuel rod containers sha be fitted with a minimum of three, equally spaced blocks, of which the noncombustib portion of the blocks and the method by which they are secured shall assure that th rods are maintained on no more than an equivalent metal-to-metal square lattice within the fuel rod container.

7. Each fuel assembly shall be unsheathed or shall be enclosed in an unsealed, polyethylene sheath which will not extend beyond the ends of the fuel assembly. The en of the sheath shall not be folded or taped in any manner that would prevent the flo of liquids into or out of the sheathed fuel assembly.

   Alternatively, the fuel assembly may be enclosed in an elongated plastic bag or sheath along its full length. At the bottom end of the fuel assembly, the bag will be cut off or folded back to assure that the entire cross section of the lower end the assembly is unobstructed. When folding is used, the portion of the sheath that is folded back will be cinched with tape near its end to hold it in place, and the length will be such that when the assembly is loaded in the packaging, the folded sheath will be clamped in place in at least two grid locations. The top end of the bag may be gathered together and taped closed. However, the top end then will be slit on all four sides. The slits will run perpendicular to the axis of the assemb and will extend the inner distance between the top nozzle pads and spring clamps (approximately 60% of the length of each side). The slits will be made in a plane near that formed by the top of the pads and clamps.

8. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR §71.12(b).

9. Expiration date: January 31, 1986.

REFERENCES

Westinghouse Electric Corporation application dated December 17, 1980.

Supplement dated: January 21, 1981.

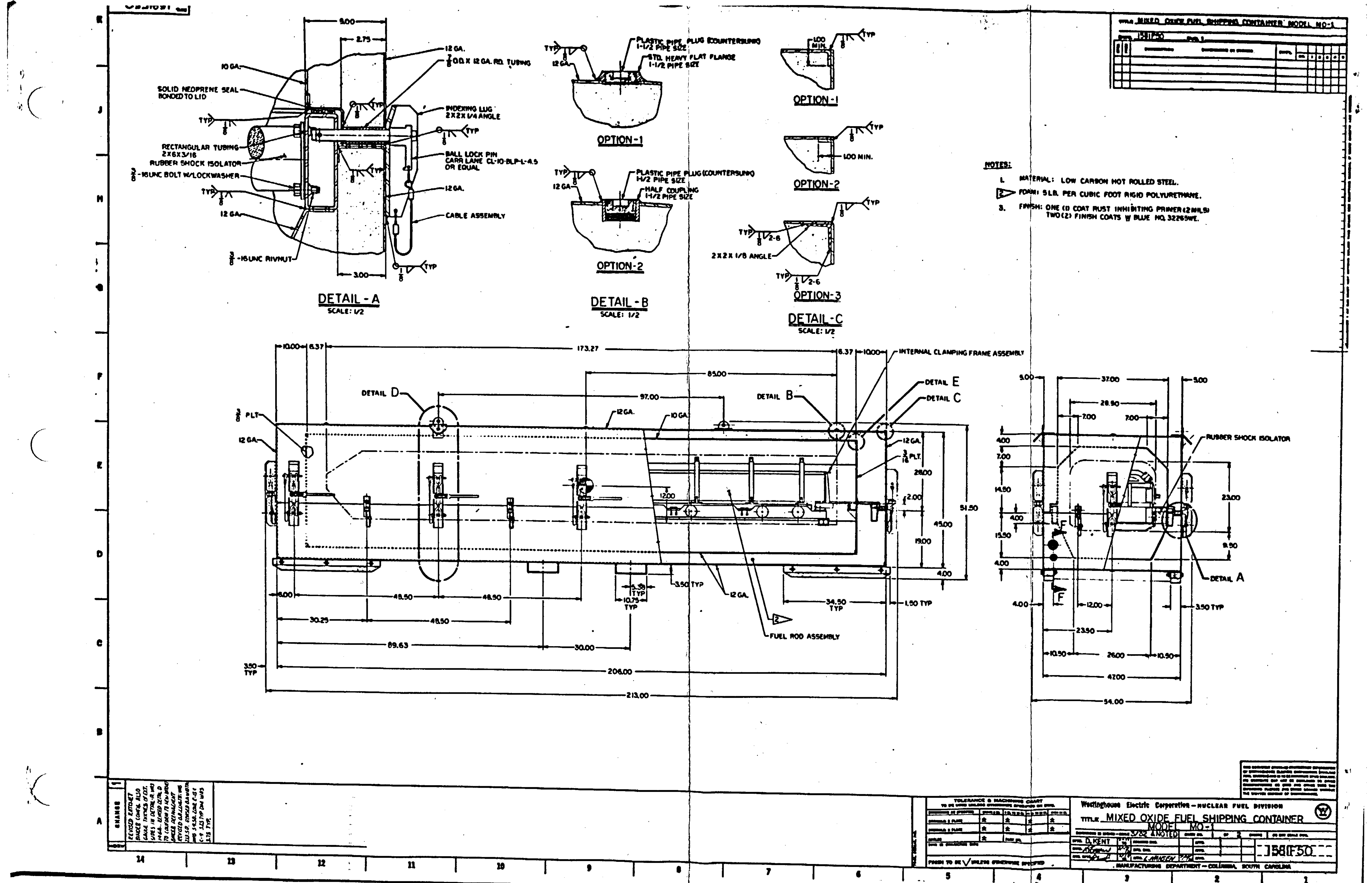
FOR THE U.S. NUCLEAR REGULATORY COMMISSION

Charles E. MacDonald, Chief
Transportation Certification Branch
Division of Fuel Cycle and
Material Safety

Date: APR 15 1981

Page 1-99 intentionally omitted

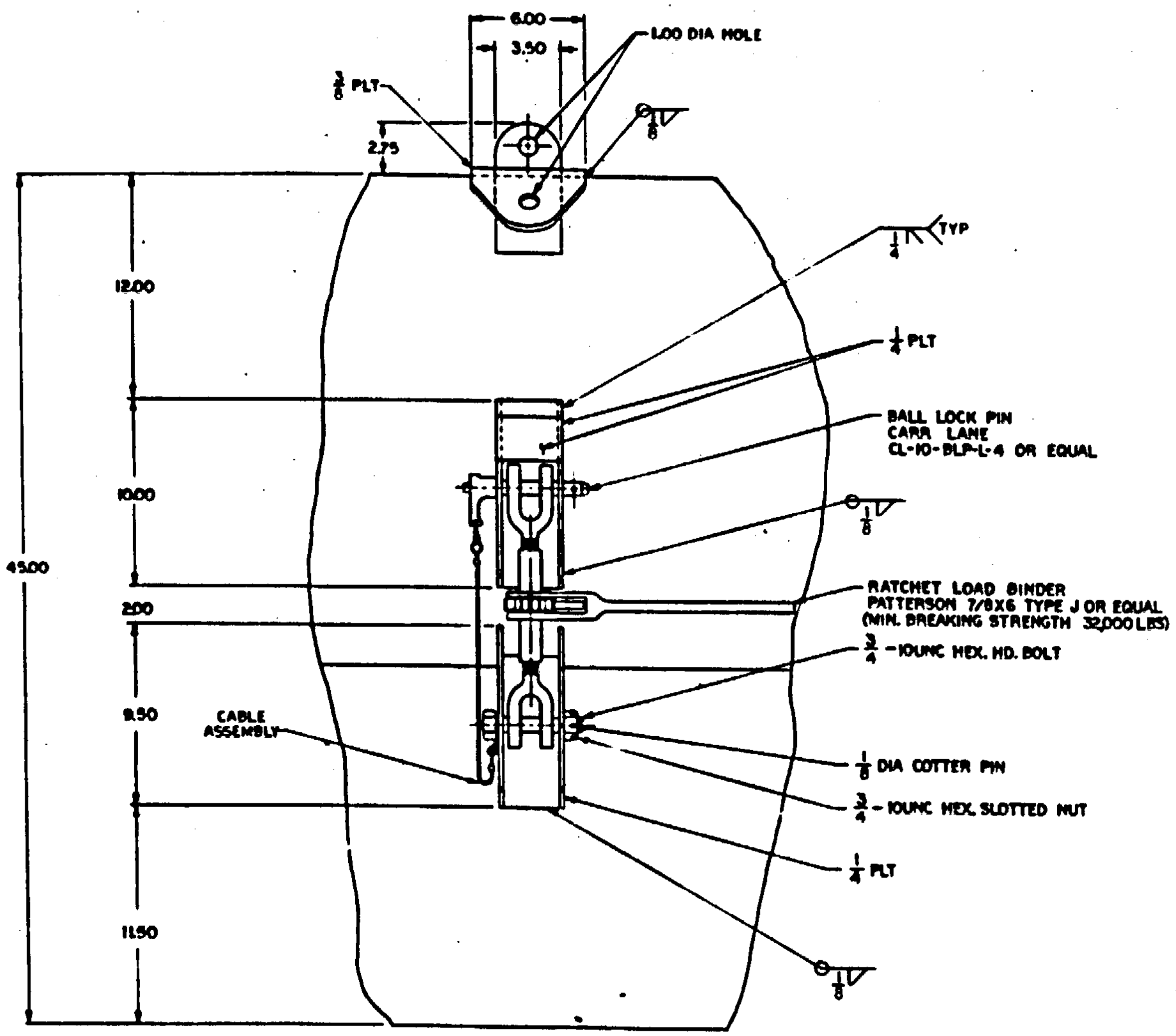
APPENDIX 1.10.2



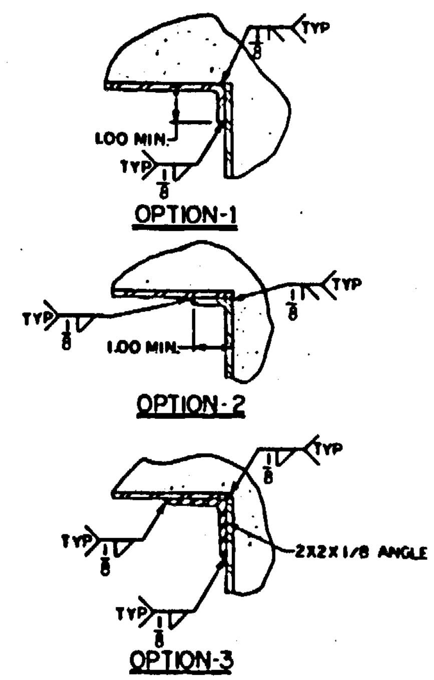
MIXED OXIDE FUEL SHIPPING CONTAINER MODEL MO-1
1581F50
10 GA.
12 GA.
7/8 O.D. X 12 GA. RD. TUBING
SOLID NEOPRENE SEAL BONDED TO LID
INDEXING LUG 2X2X1/4 ANGLE
RECTANGULAR TUBING 2X6X3/16
RUBBER SHOCK ISOLATOR
3/8 -16UNC BOLT W/LOCKWASHER
BALL LOCK PIN CARR LANE CL-10-BLP-L-4.5 OR EQUAL
CABLE ASSEMBLY
3/8 -16UNC RIVNUT
DETAIL - A
SCALE: 1/2
PLASTIC PIPE PLUG (COUNTERSUNK) 1-1/2 PIPE SIZE
STD. HEAVY FLAT FLANGE 1-1/2 PIPE SIZE
OPTION-1
HALF COUPLING 1-1/2 PIPE SIZE
OPTION-2
DETAIL - B
SCALE: 1/2
1.00 MIN.
OPTION-1
OPTION-2
2X2X1/8 ANGLE
OPTION-3
DETAIL - C
SCALE: 1/2
NOTES:
1. MATERIAL: LOW CARBON HOT ROLLED STEEL.
2. FOAM: 5 LB. PER CUBIC FOOT RIGID POLYURETHANE.
3. FINISH: ONE (1) COAT RUST INHIBITING PRIMER (2 MILS) TWO (2) FINISH COATS W BLUE NO. 32265WE.
INTERNAL CLAMPING FRAME ASSEMBLY
DETAIL D
DETAIL B
DETAIL E
DETAIL C
3/8 PLT.
3/16 PLT.
FUEL ROD ASSEMBLY
RUBBER SHOCK ISOLATOR
DETAIL A
173.27
85.00
97.00
206.00
213.00
89.63
30.00
48.50
30.25
51.50
45.00
54.00
47.00
37.00
Westinghouse Electric Corporation — NUCLEAR FUEL DIVISION
TITLE MIXED OXIDE FUEL SHIPPING CONTAINER MODEL MO-1
D. KENT
MANUFACTURING DEPARTMENT — COLUMBIA, SOUTH CAROLINA
TOLERANCE & MACHINING CHART

1581F50

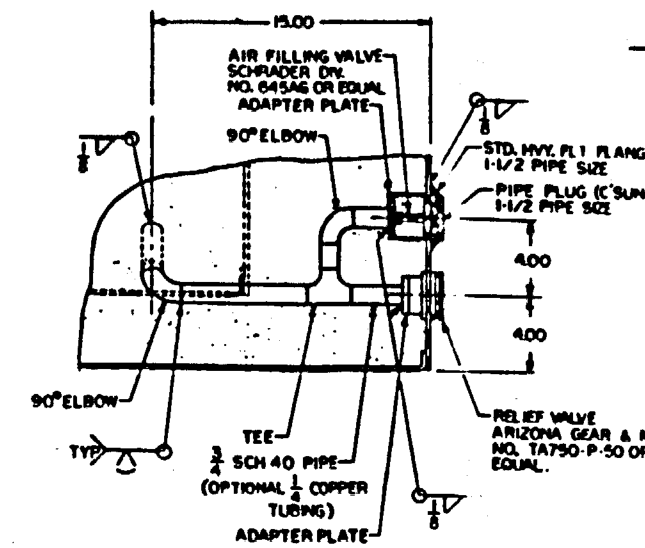
TITLE MIXED OXIDE FUEL SHIPPING CONTAINER MODEL MO-1
DWG. 1581F50



DETAIL - D
SCALE: 1/4



DETAIL - E
SCALE: 1/2



SECTION F-F
SCALE: 1/4

TOLERANCE & MACHINING CHART

FINISH TO BE √ UNLESS OTHERWISE SPECIFIED

Westinghouse Electric Corporation — NUCLEAR FUEL DIVISION

TITLE MIXED OXIDE FUEL SHIPPING CONTAINER MODEL MO-1

SCALE 3/32 & NOTED SHEET NO. 2 OF 2

DRN. D. KENT

1581E50

MANUFACTURING DEPARTMENT — COLUMBIA, SOUTH CAROLINA

CHANGE: SEE SHT 1 of 2

APPENDIX 1.10.3

PDD 045-74

From NFD Engineering
WIN : X-4740
Date : August 22, 1974
Subject: Shipping Container Fire Analysis for Plutonium Rods

NUCLEAR FUEL DIVISION

S. Kmonk, Manager
Standard Product Design II

cc: S. Nakazato
R. T. Meyer
D. D. Seel
D. J. Sperhac

(1) EML Report Job 1943 "Shipping Container Accident - Clad Burst Test", 7/30/74

SUMMARY

As part of the DGRF-05300 Plutonium Transport Design effort, a modeled rod transient temperature behavior during the regulatory specified half-hour fire accident has been devised. The modeling was performed on the present W shipping container with two 14x14 zirc clad assemblies. The analysis indicates that considerable rod burst could occur with the present non-insulated shipping container based on projection of clad burst data, reference (1). By adding insulation to either the shipping container shell ID or boxing in the assemblies with insulation will reduce the clad surface temperatures to preclude rod burst. The results for all cases of interest are summarized in Table 1.

RECOMMENDATIONS

As an alternative to the vendor supplied shipping container modifications, it is recommended that W proceed with in-house design using 3/4-inch Marinite-36 insulation in a box-like arrangement around the fuel assemblies. In order to confirm the design analysis, plans should be made for a reduced scale verification test.

ANALYSIS

The analytical heat transfer model was devised to simulate a fire of a half-hour duration on the present W shipping container used for transporting the 14x14 fuel assemblies. The assumptions and model descriptions, as discussed at the meeting of August 3, will be documented at a later date. Figure 1 shows the different configurations modeled for analysis. Figure 2 displays the arbitrary rod rings used for the lumped-mass analysis of the 14x14 fuel assemblies.

From the clad burst test conducted as of this report, reference (1), it is projected that initial Helium pressurization up to 500 psig will result in rod burst at clad temperatures of $\geq$ 1100°F as illustrated in Figure 3. However to cover uncertainties (mainly, the neglect of natural convection and conduction within the shipping container) in the analytical model, a clad temperature criterion of 600°F has been selected.

RESULTS

When the system was analyzed with no insulation, it can be seen from Figure 4 that the rods do exceed the criteria for rod burst and that some modifications to the present W shipping container will be required. The insulation selected for analysis was Marinite-36, because of its very low value of thermal conductivity (0.067 BTU/hr.-ft-°F). Table 1 displays the cases analyzed along with body temperatures of the selected masses. Temperature profiles for all the cases with insulation are illustrated in Figures 5 thru 8. It should be noted that by placing the insulation in a box-like arrangement around the fuel assemblies, along with the benefits of less material needed and ease in manufacturing and installation, the rods will see a lower temperature than when the insulation is placed on the container wall. Using 1/2-inch Marinite-36 insulation in the box-like array does meet our criterion of 600°F but for additional conservatism our recommendation will be to use 3/4-inch Marinite-36 insulation boxing in the fuel assemblies. However since there was a good deal of simplification and assumption used in the analytical model, testing should be conducted to verify the model and for licensing purposes.

W. D. Rabenstein

W. D. Rabenstein
Product Design & Development

dp

Table 1

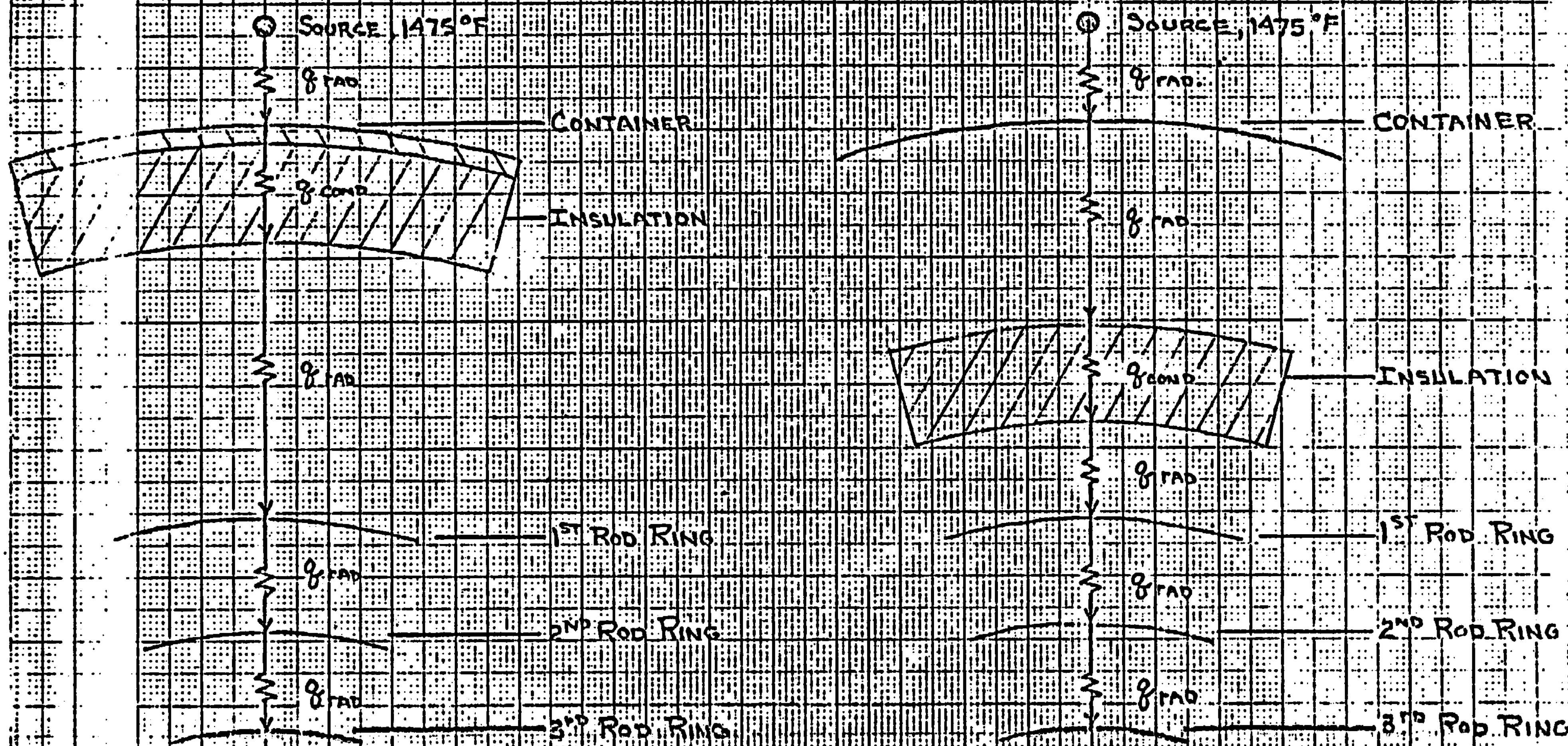
Summary of Shipping Container Temperatures After 1800 Second Fire Accident

Case	Temperatures - °F					
	Container	Insulation OD	Insulation ID	1st Rod Ring	2nd Rod Ring	3rd Rod Ring
No Insulation (Figure 4)	1425	--	--	1345	1200	1030
1/2" Insulation* Model 1+ (Figure 5)	1445		810	675	350	95
1/2" Insulation* Model 2+ (Figure 6)	1460	1440	725	525	235	80
3/4" Insulation* Model 1+ (Figure 7)	1450		615	460	170	~75
3/4" Insulation* Model 2+ (Figure 8)	1460	1450	600	380	140	~75

* Insulation used was Marinite-36

\+ Model 1 has the insulation placed on inside of container wall and Model 2 has the insulation wrapped around the fuel assemblies

FIGURE 1 HEAT TRANSFER MODELS USED*



MODEL 1

INSULATION PLACED ON INSIDE WALL OF CONTAINER.

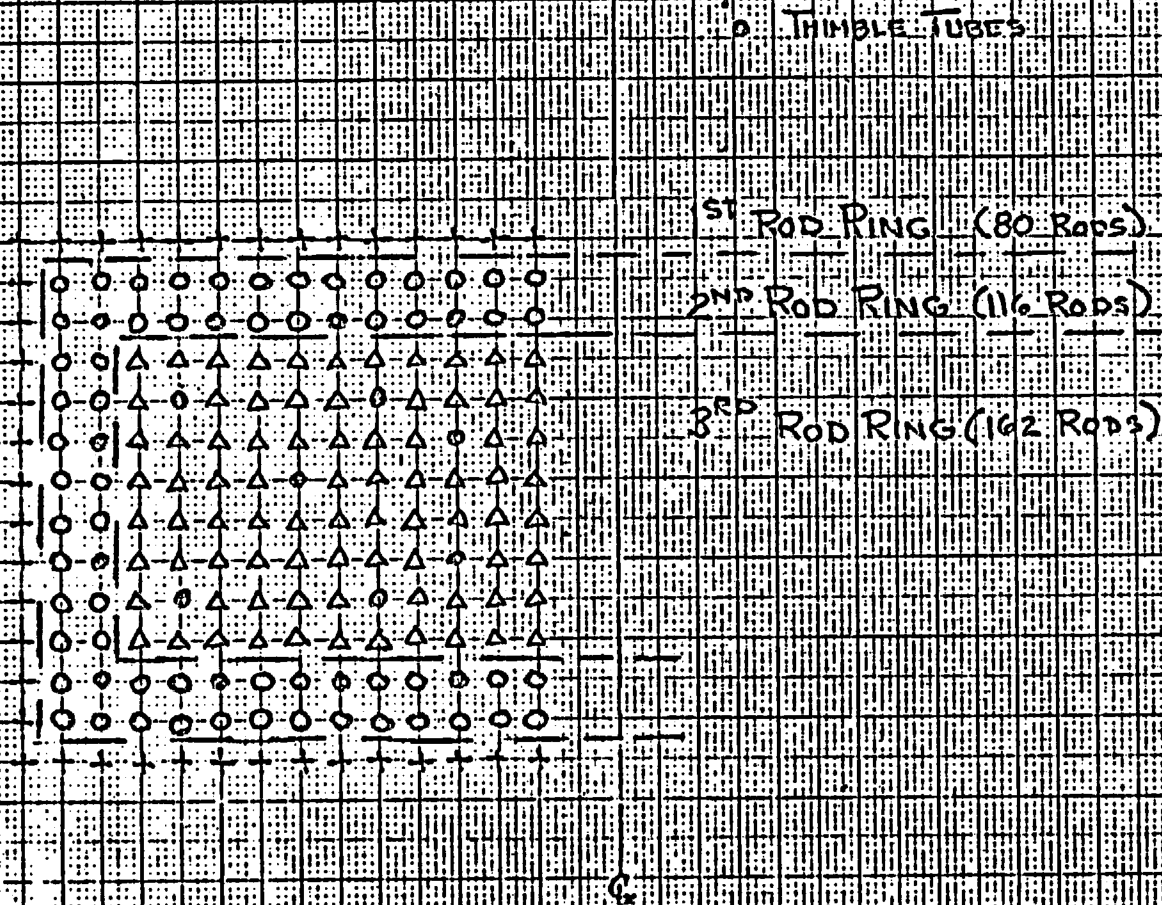
MODEL 2

INSULATION WRAPPED AROUND THE FUEL ASSEMBLIES.

* NOT TO SCALE

8-16-74

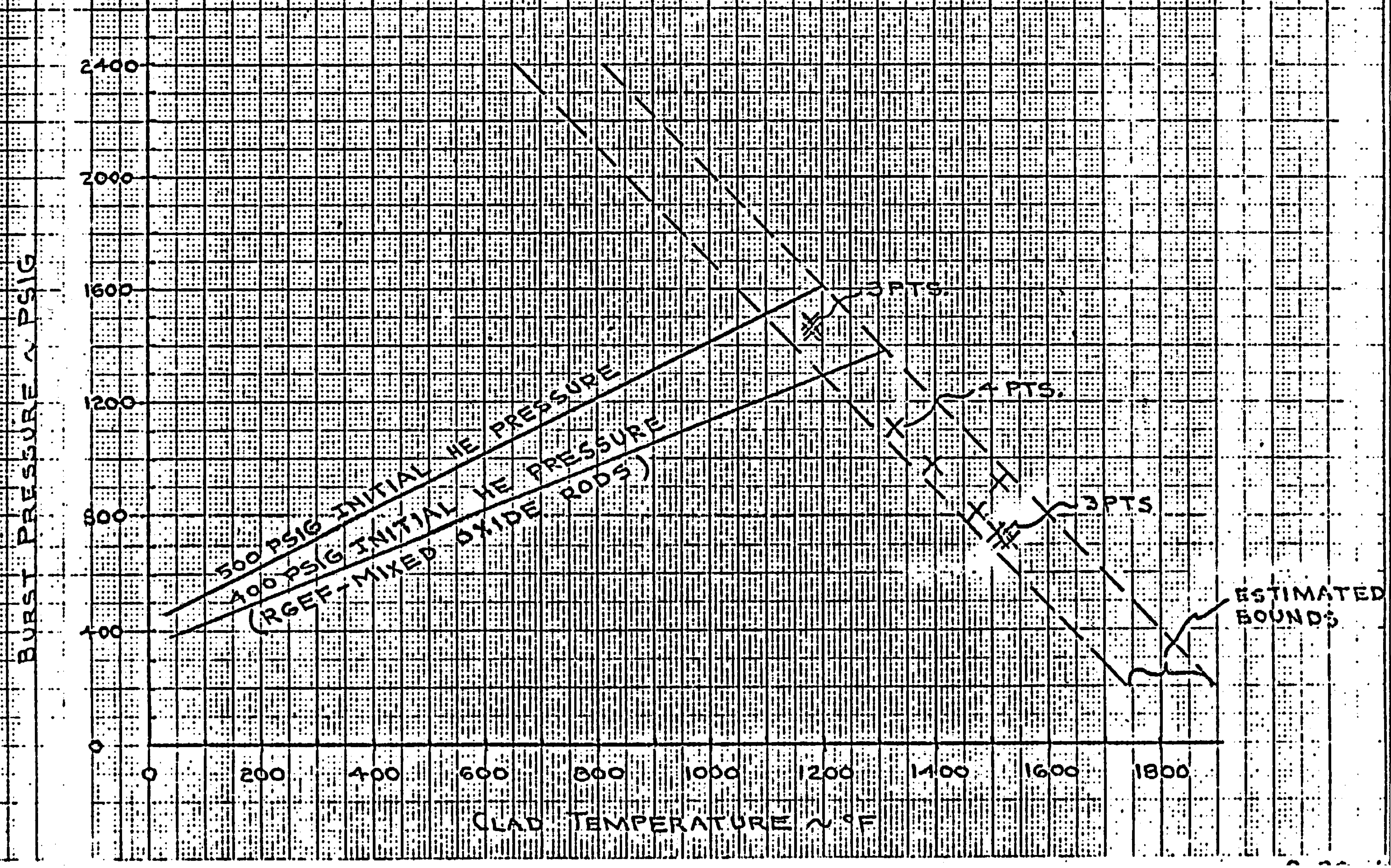
FIGURE 2 SIMULATED ROD RINGS FOR 14X14 ASSEMBLIES



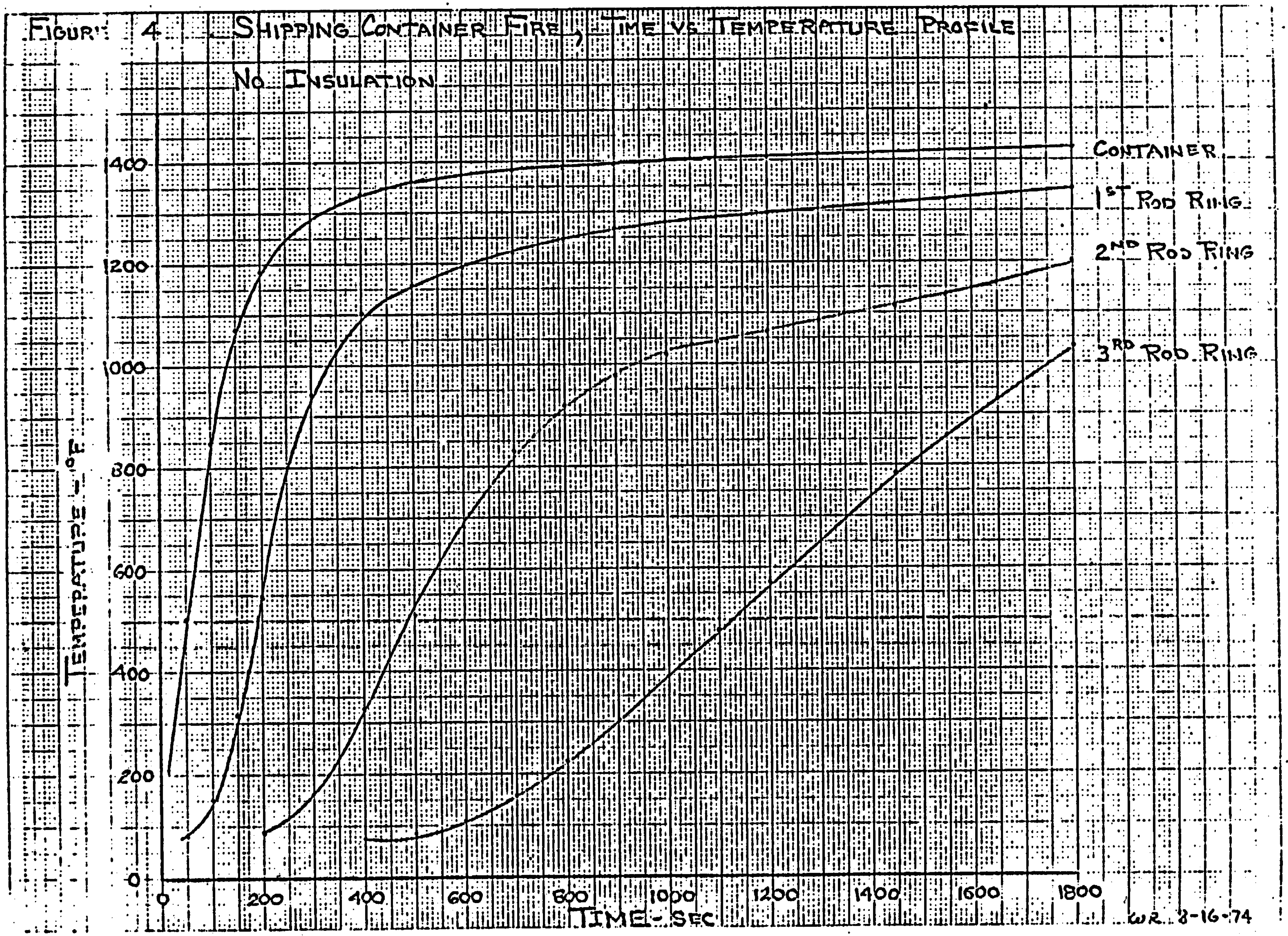
8-16-74

FIGURE 3

ZIRC-4 CLAD BURST CHARACTERISTICS DURING SHIPPING ACCIDENT FIRE



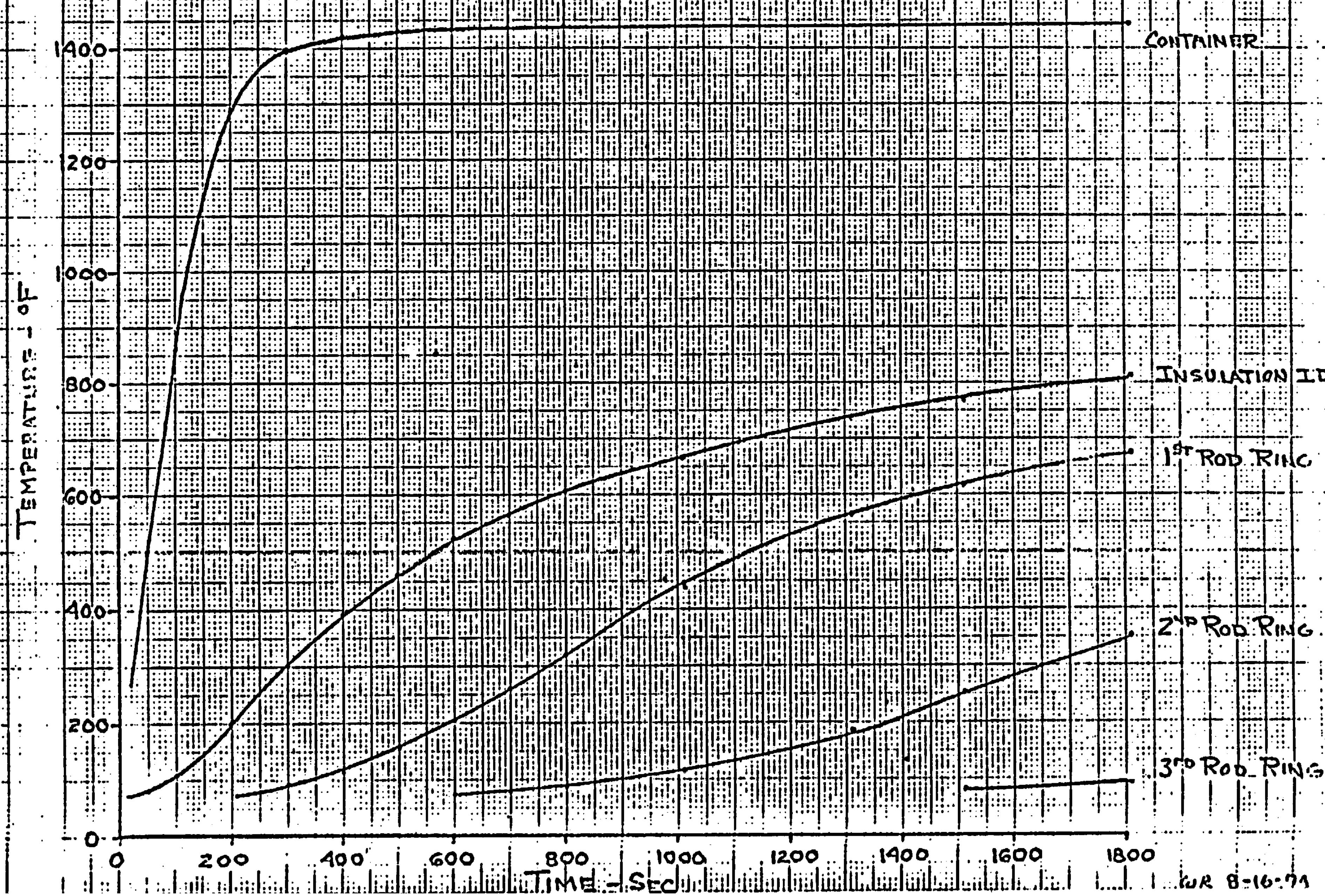
K&E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 461510



K·E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1510

FIGURE 5 . SHIPPING CONTAINER FIRE, TIME VS TEMPERATURE PROFILE

1/2 IN MARINITE INSULATION PLACED ON INSIDE WALL OF CONTAINER.



K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM. KEUFFEL & ESSER CO. MADE IN U.S.A. 46 1510

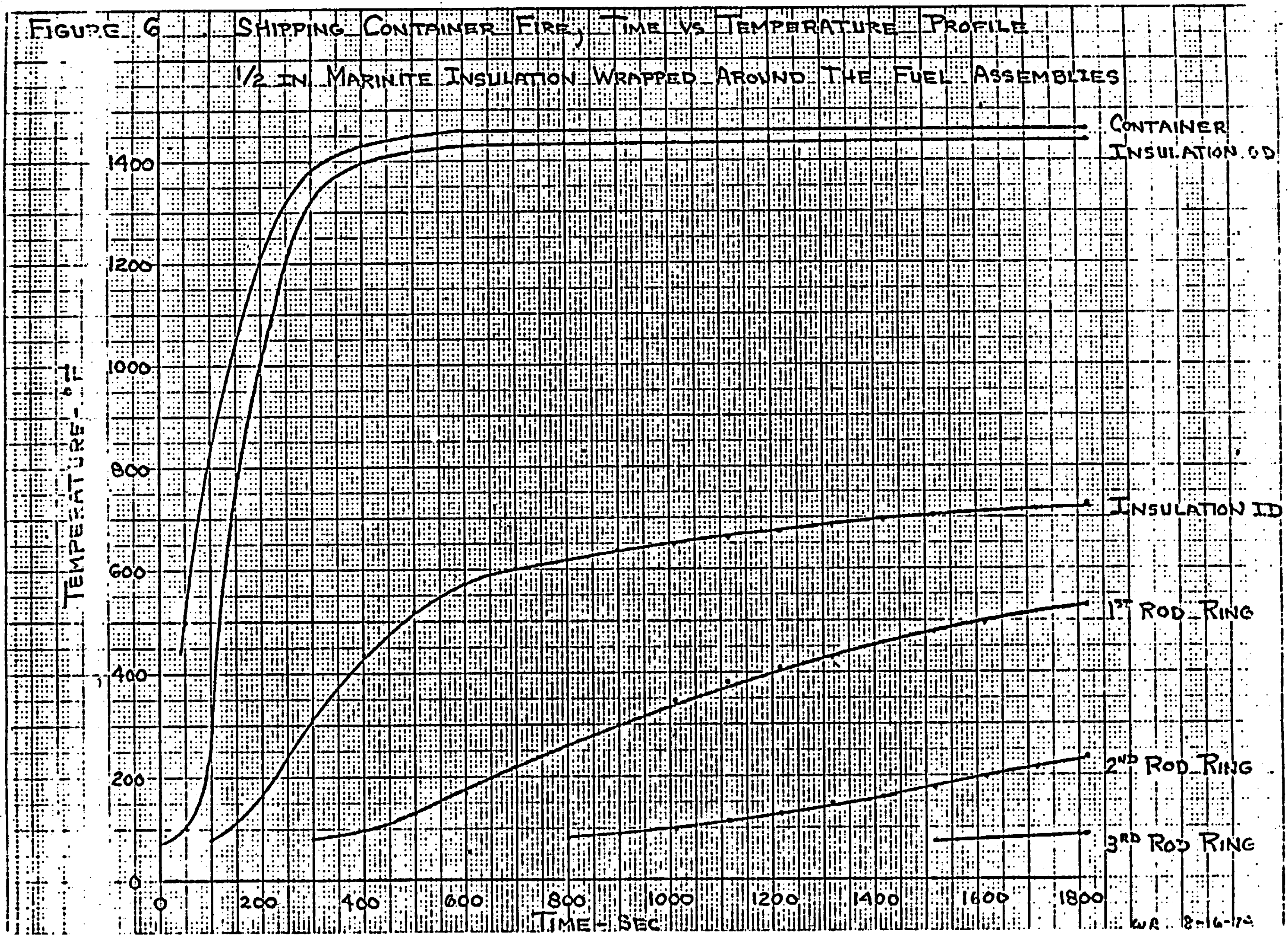
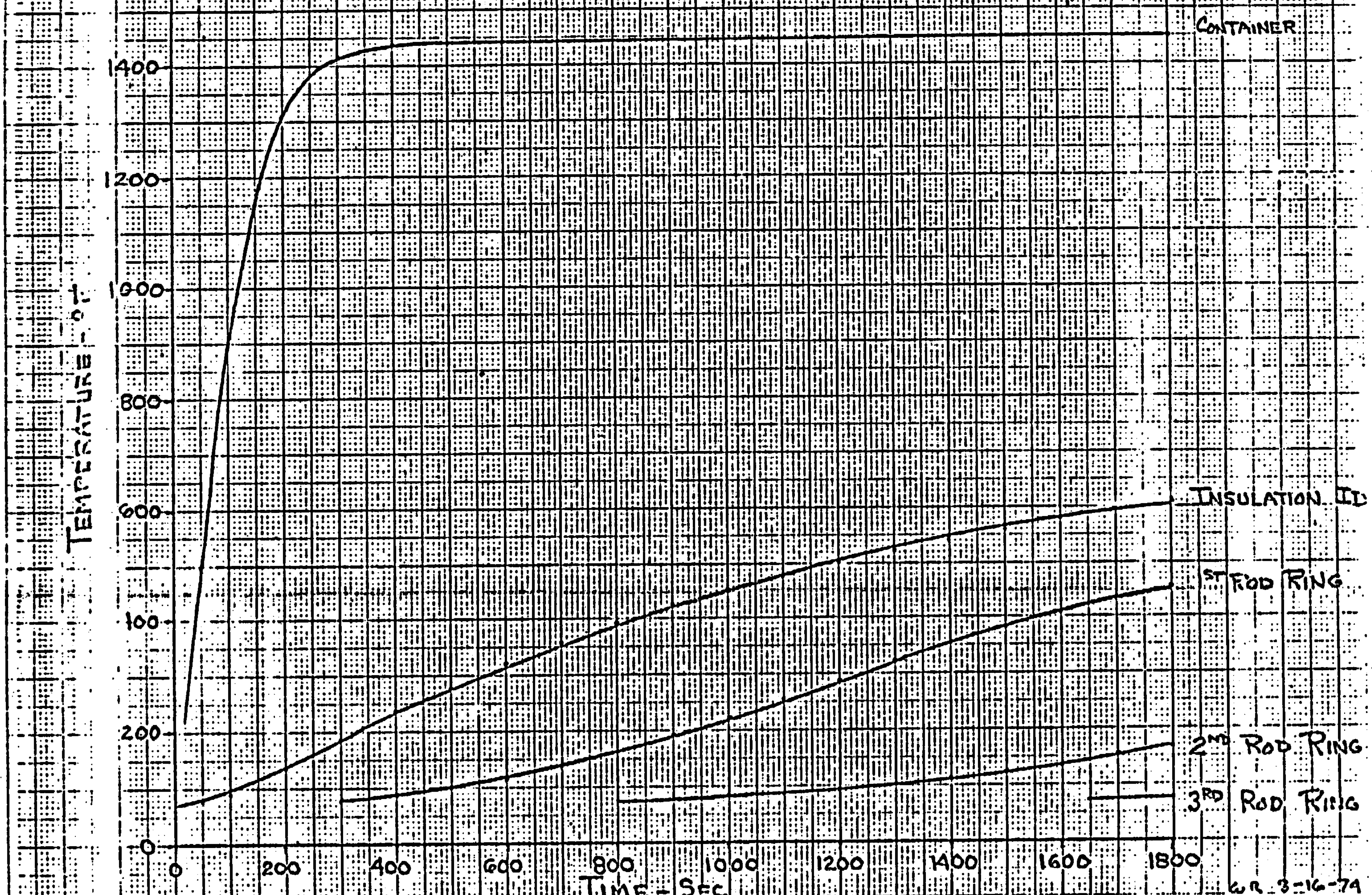
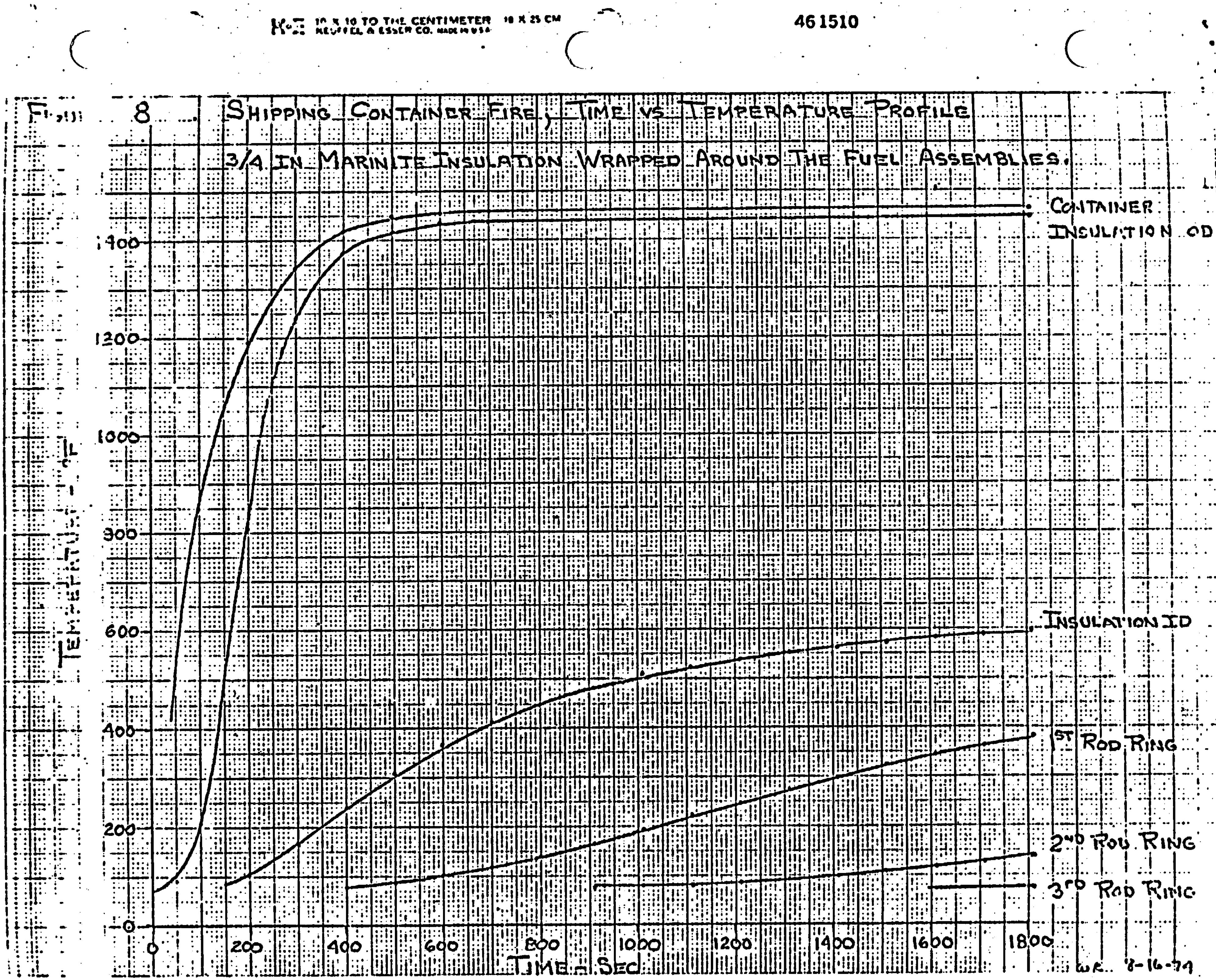


FIGURE 7   SHIPPING CONTAINER FIRE, TIME VS TEMPERATURE PROFILE

3/4 IN MARINITE INSULATION PLACED ON INSIDE WALL OF CONTAINER




K+E 10 X 10 TO THE CENTIMETER 18 X 25 CM
KEUFFEL & ESSER CO. MADE IN U.S.A.
461510
Fig. 8 Shipping Container Fire, Time vs Temperature Profile
3/4 IN Marinite Insulation Wrapped Around The Fuel Assemblies.
Container
Insulation OD
Insulation ID
1st Rod Ring
2nd Rod Ring
3rd Rod Ring
Temperature - °F
1400
1200
1000
600
400
200
0
200
400
600
800
1000
1200
1400
1600
1800
Time - Sec
WR 8-16-74

2.0 THERMAL EVALUATION

This chapter identifies and analyzes the principal thermal engineering design of the packaging and describes the system important to safety and to compliance with the performance requirements of 10 CFR 71. (Reference Section 1.7.3)

3.0 CONTAINMENT

This chapter identifies the package containment for the normal conditions of transport and the hypothetical accident conditions.

3.1 Containment Boundary

3.1.1 Containment Vessel

The containment vessel claimed for the Model MO-1 Package is the sealed zircaloy fuel rods as described in Section 1.9.

3.1.2 Containment Penetration

There are no penetrations into the containment vessel.

3.1.3 Seals and Welds

There are no seals which effect the package containment. The sealed zircaloy fuel rods are heliarc welded.

3.1.4 Closure

There are no closure devices used for the containment vessel.

3.2 Requirements for Normal Conditions of Transport

The following is an assessment of the package containment under normal conditions of transport as a result of the analysis performed in chapters 1.0 and 2.0, above. In summary, the containment vessel was not effected by these tests. (Refer to Section 1.6, above).

3.2.1 Release of Radioactive Material

There was no release of radioactive material from the containment vessel.

3.2.2 Pressurization of Containment Vessel

Normal conditions of transport will have no effect on the fuel rod pressurization.

3.2.3 Coolant Contamination

This section is not applicable since there are no coolants involved.

3.2.4 Coolant Loss

Not applicable.

3.3 Containment Requirements for the Hypothetical Accident Conditions

The following is an assessment of the packaging containment under the hypothetical accident conditions as a result of the analysis performed in Chapters 1.0 and 2.0, above. In summary, the containment vessel was not effected by these tests. (Refer to Section 1.7).

3.3.1 Fission Gas Products

The tests to demonstrate the Type "B" accident conditions have no detrimental effect on the containment vessel. It follows that there can be no release of Fission Gas Products to the containment vessel as a result of these tests.

3.3.2 Release of Contents

From the thermal analysis described in Section 1.7.3, above, it was determined that the fuel rods would reach a maximum temperature of approximately 275°F when the package was exposed to the 1475°F accident condition. Since rod burst occurs at temperatures exceeding 1200°F, it is safe to conclude that pressurization of the containment vessel represents no threat to the packaging integrity.

4.0 SHIELDING EVALUATION

4.1 Discussion and Results

The design and materials of construction for the Model MO-1 Packaging provide the necessary shielding effectiveness to meet applicable DOT requirements. Prior to each shipment, radiation readings will be taken based on individual loadings to assure compliance with applicable regualtions. Refer to Westinghouse shielding evaluation in Appendix 4.5

4.2 - 4.4 See Appendix 4.5.1

4.5 Appendix

4.5.1 Westinghouse letter Number ST-RES-SLA-1615 dated February 10, 1976. Subject: Shielding for PuO_2 Assembly Shipping Container.

APPENDIX 4.5.1

WRD-PWRSD Engineering
From Systems Technology
WIN :249-5154
Date :February 10, 1976
Subject: Shielding for PuO_2 Assembly Shipping Container

NUCLEAR ENERGY SYSTEMS
WATER REACTOR DIVISIONS

To: C. E. Palmer
K. R. Schendel

RECEIVED FEB 12 1976 STANDARD PRODUCT DESIGN

cc: F. J. Frank
D. Sperhac -572

Reference: HSS-043-75

The new fuel shipping container being designed by NuPaC for transport of KEP, RGE, and NOK plutonium assemblies has been analyzed to determine its overall shielding effectiveness and its ability to meet DOT shipping regulations. The isotopic composition of the MO_2 fuel was assumed to be that listed in the referenced transmittal.

The results of the analysis indicate that the materials of construction used in the container itself should be sufficient to reduce radiation levels on the surface of the container to less than 100 mrem/hr. However, without the use of auxiliary shielding, the DOT requirement of 10.0 mrem/hr at a distance of 6 feet from the external surface necessitates the use of a closed transport vehicle. Depending on the truck geometry and construction, it may also be necessary to insert up to 1 inch of borated polyethelene forward of the shipping containers to reduce neutron dose rates in the cab to levels less than 2 mrem/hr.

The dose rate calculations used in the analysis were performed using both Sn transport and point kernel techniques. The neutron and gamma ray source terms were derived from the isotopics listed in the referenced transmittal. Due to a lack of definitive information regarding truck geometry, rather broad conservative assumptions were used to estimate dose rates in the cab. A detailed analysis of the carrier may well indicate that the supplementary polyethelene shield is not required.

A copy of the calculations discussed above will be located in the Radiation and Environmental Systems files. If you have any further questions, please advise.

S. L. Anderson

S. L. Anderson, Engineer
Radiation and Environmental Systems

5.0 CRITICALITY EVALUATION

5.1 Discussion and Results

Criticality studies have demonstrated that the Model MO-1 Package can be safely shipped based upon the assumptions contained therein. Refer to Appendix 5.6.1 for Criticality Analysis and Review.

5.2 - 5.5 See Appendix 5.6.1

5.6 Appendix

5.6.1 Criticality Analysis and Review for Westinghouse Model MO-1 Packaging. (Fuel Assemblies)

5.6.2 Criticality Analysis and Review for Westinghouse Model MO-1 Packaging. (Fuel Rods)

5.6.3 Criticality analysis and Review for Westinghouse Model MO-1 Packaging for Copper Absorber Plates.

APPENDIX 5.6.1

CRITICALITY ANALYSIS AND REVIEW
W MODEL MO-1 PACKAGING

Introduction

In order to verify that plutonium fuel assemblies can be shipped without a nuclear safety hazard in plutonium fuel assembly shipping containers, nuclear criticality calculations were conservatively performed by modeling several accident situations.

The computed value of k_{eff} for the maximum credible accident (MCA) was considered to be the criteria for nuclear safety. The MCA configuration was defined as two flooded, maximally crushed, shipping containers each containing two assemblies aligned so as to effect the largest value of k_{eff}. Maximally crushed shipping cask dimensions have been determined by drop tests and conservative mechanical considerations.

The NRC guidelines require that k_{eff} for the MCA should not exceed 0.98. For undamaged, but flooded containers, the corresponding maximum value of k_{eff} should be no greater than 0.94. A simplistic diagram of the undamaged plutonium fuel assembly shipping container and internals are shown in Figures 1, 2 and 3.

Calculational Model

The plutonium fuel assemblies are composed of three enrichments arranged in a 14x14 fuel array (see Figure 4 and Table 1). These enrichments are nominally 4.20, 3.40, and 2.60 w/o total plutonium where enrichment is defined as

$$\text{Total Plutonium Enrichment} = \frac{\text{weight (Pu)}_2}{\text{weight }(PuO_2) + \text{weight }(UO_2)} .$$

Natural uranium is the constituent uranium with 0.711 w/o U-235. For calculational purposes, the assemblies were conservatively assumed to be of 4.4 w/o PuO_2 enrichment rather than the 3.82 w/o PuO_2 mean or the 4.2 w/o PuO_2 maximum enrichment. The plutonium isotopic distribution was measured in July, 1971 (Pu-241 decay was allowed to July 1974):

Isotope	w/o
PU-238	0.09
PU-239	78.13
PU-240	18.27
PU-241	3.05
PU-242	0.47

$$\frac{\text{Pu-239 + Pu-241}}{\text{Total Pu}} = 0.812$$

The 4.4 w/o - 81% fissile plutonium rods are nominally ten or twelve feet long, but were conservatively assumed to be of infinite length, i.e., the axial buckling was taken to be zero. In addition, the model neglects all structural material other than wall thickness and poison plates (1.3 w/o natural boron and 98.7 w/o SS-304). The assumption that the density of the flooding water is at its maximum value of 1.0 gm/cc represents another conservatism, since the 14x14 assembly design is under-moderated at ambient conditions.

Using Westinghouse versions of LEOPARD and PDQ, 2 group cross sections were generated (see Tables 2 and 3), calculations for k_{eff} were performed for three hypothetical accident situations.

Case 1 A single flooded assembly surrounded by an infinite water reflector.

Case 2 A single flooded shipping cask whose two assemblies are crushed to within a minimum credible distance of each other with borated SS poison plates, surrounded by an infinite reflector.

Case 3 Two flooded casks whose four assemblies are crushed together to within minimum credible distances of each other

a) accounting for SS cask walls and borated SS poison plates (MCA)

Figures 5 through 7 show the geometries of the three accident situations considered. The distances between assemblies represent minimum credible clearances during the hypothetical accident; the surrounding water reflector is effectively of infinite thickness.

Results

A table of k_{eff} values calculated for each case is shown below. These values may be taken as upper bounds on k_{eff} since in all cases they reflect numerous conservative assumptions.

Case	Configuration	Calculated k_{eff}
1	Single flooded 4.4 w/o Pu assembly surrounded by an infinite reflector	.8879
2	Two flooded, crushed, 4.4 w/o Pu assemblies with borated SS poison plates, surrounded by an infinite reflector	.8876
3	a) Four flooded, crushed, 4.4 w/o Pu assemblies, with cask wall, and borated SS poison plates (MCA)	.9729

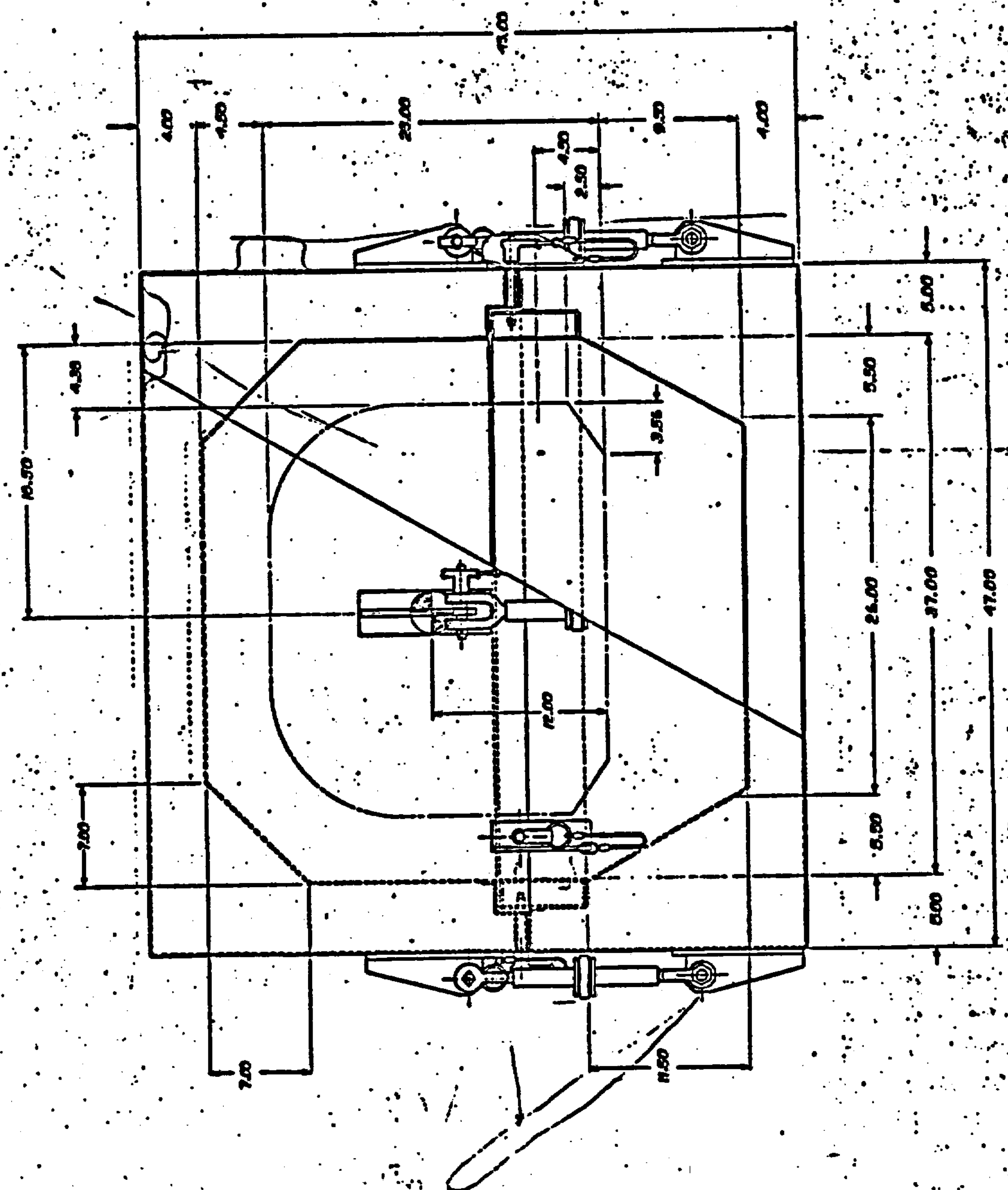
Conclusions

The calculational results shown above indicate that the plutonium assemblies may be safely shipped in shipping casks equipped with borated SS plates since the fuel assemblies can in no way become critical even under the severe conditions of the maximum credible accident, Case 3(a). (MCA $k_{eff} < 0.98$)

Figure 1

End View of NuPac Plutonium Fuel Assembly Shipping Container Overpak

PRELIMINARY COPY
FOR INFORMATION ONLY



Fi[illegible]e 2

Axial View of Plutonium Fuel Assembly Shipping Container Overpak

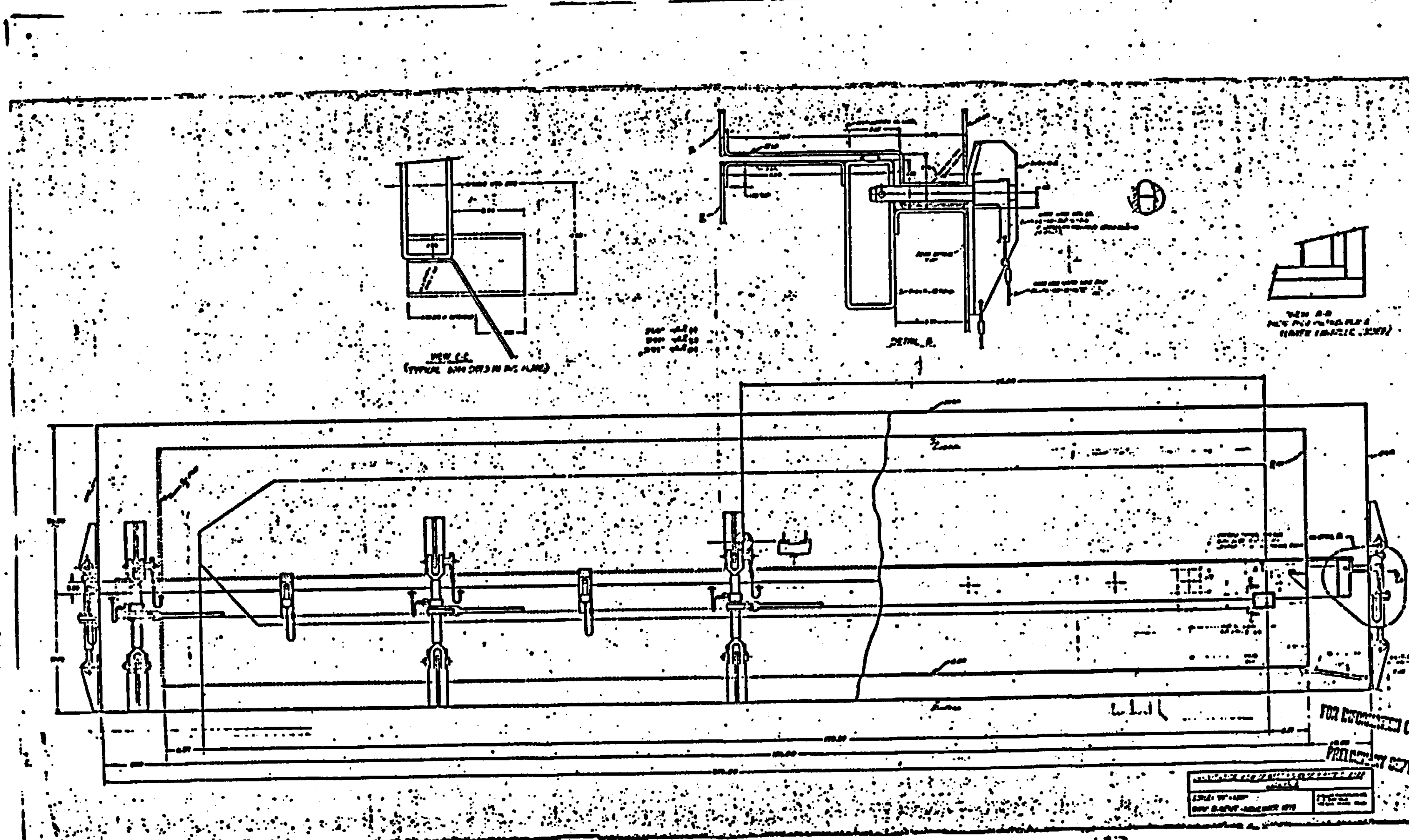
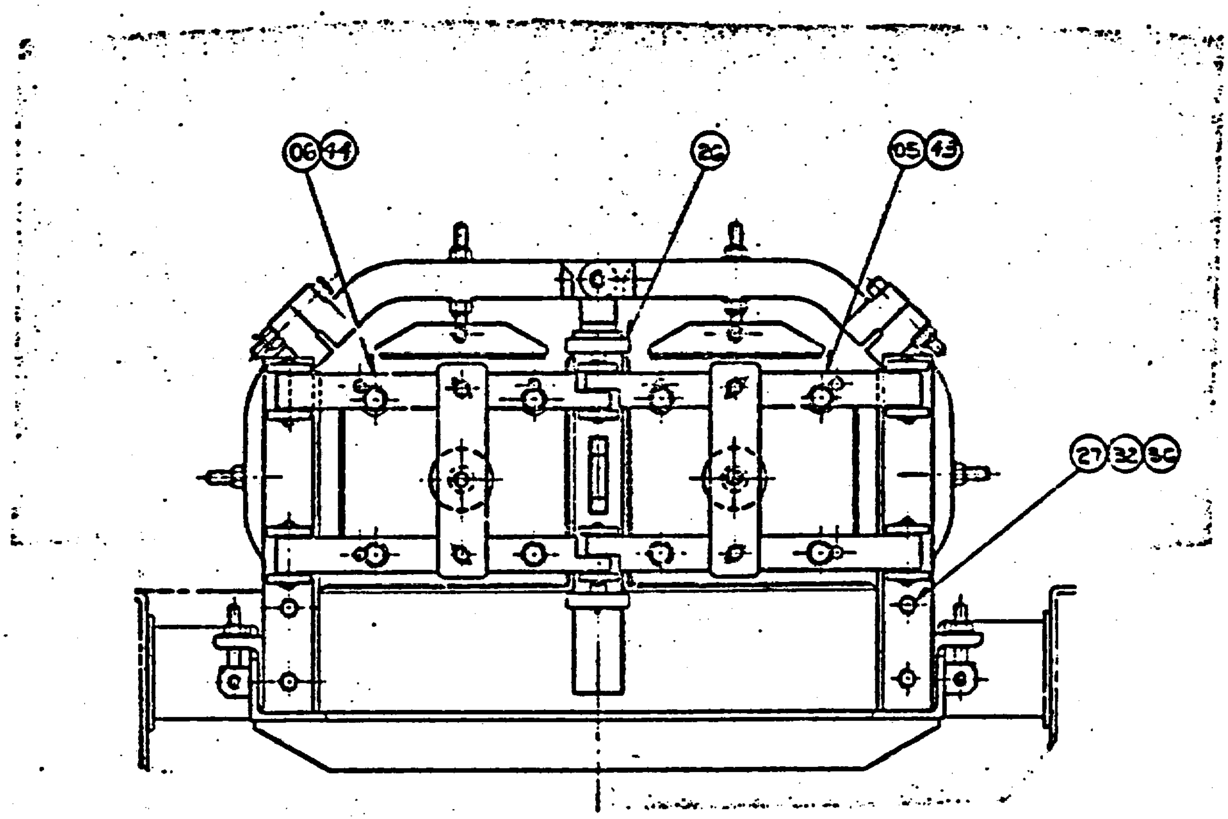
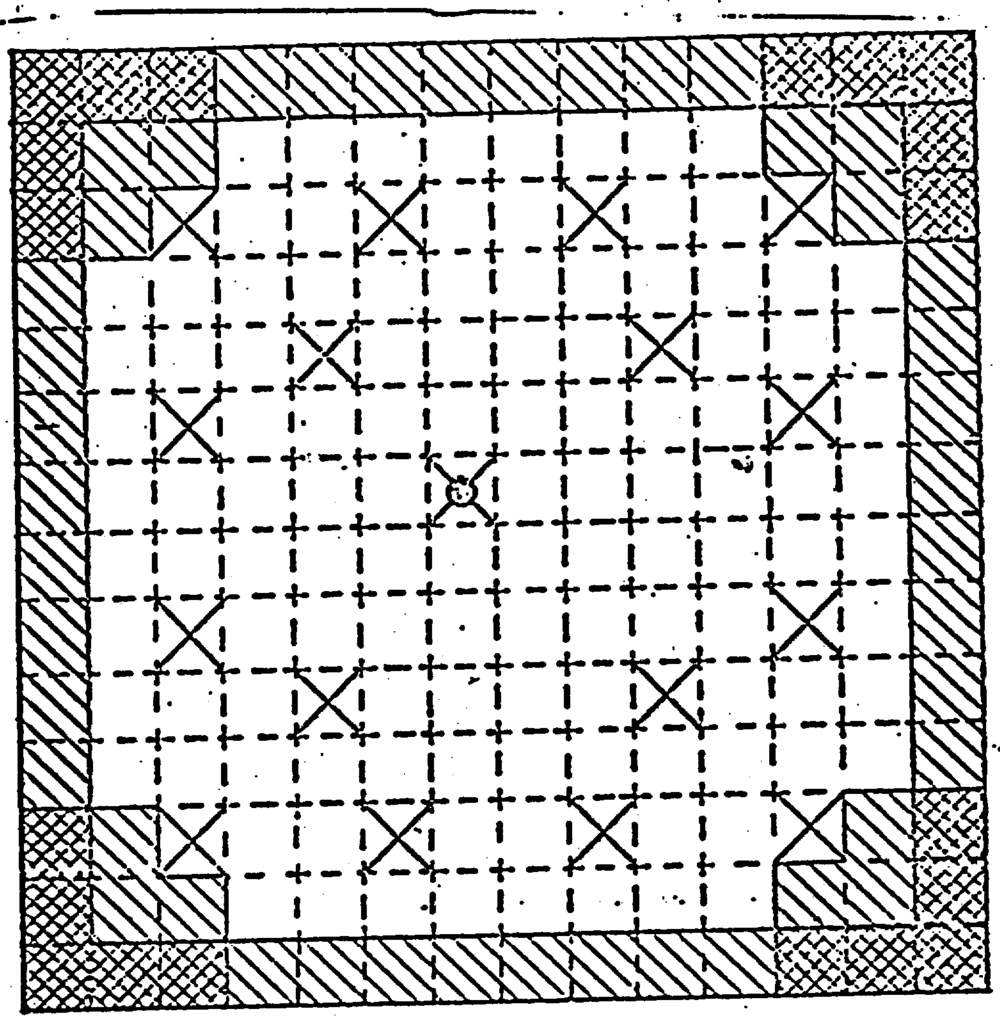


Figure 3

Assembly Support and Lifting Frames
(End View) of Current W Design



Enrichment Pattern for the 4-Pu Assemblies



LEGEND:

RCC GUIDE TUBES

INSTRUMENTATION TUBE

4.20 W/O Pu FUEL ROD (11.)

3.40 W/O Pu FUEL ROD (44)

2.60 W/O Pu FUEL ROD (20)

Avg enrich. = 3.92 w/o Pu (179)

Figure 4

TABLE I

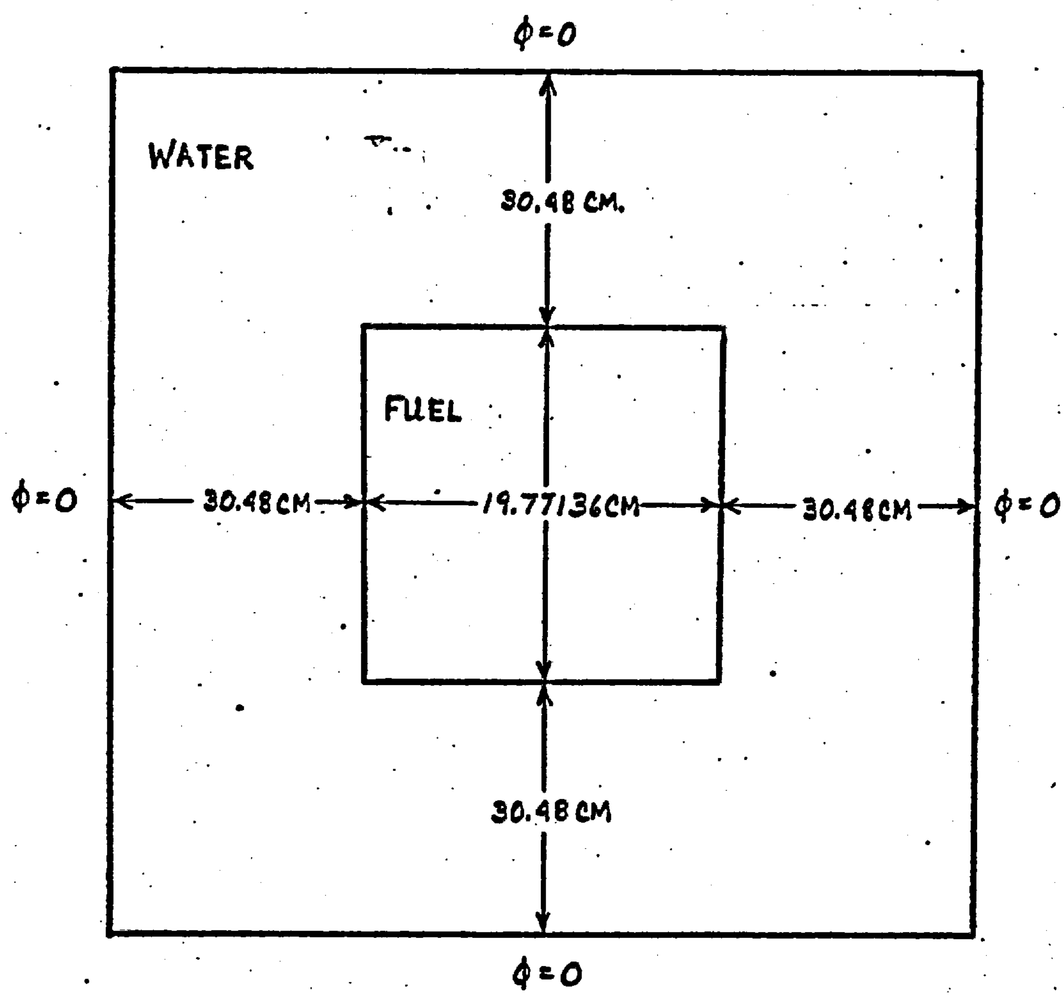
Plutonium Fuel Licensing Parameters

	14x14 Assembly	Loose Rods
Pellet Parameters		
Material	PuO_2	Same
Highest enrichment (PuO_2UO_2)	(See Note 1)	6.0 w/o (85% fissile), (.71 w/o U-235)
Diameter (NOM)	0.3659"	Same
Rod Parameters		
Cladding matl.	Zirc-4	Same
Clad O.D. (NOM)	.422"	Same
Clad thickness (NOM)	0.243"	Same
Fuel length	120" - 144"	Same
Array Parameters		
No. of rods (max)	179	
Pattern	14x14	NA
Fuel rod lattice pitch (NOM)	.556"	Touching square lattice (2)
Assembly envelope (NOM)	7.784" x 7.784"	8.072" x 8.072"
Licensing Criteria		
Total fissile (max)	< 20 kg/assembly	< 33 kg/box
K_{eff} (Max/ass'y)	< .90	Same
K_{eff} (Max/1 pkg)	< .94	Same
K_{eff} (Max/MCA)	< .98	Same
Poison Plates Required	2 borated stainless or OFHC copper	Not Required. Boxes per W drawing C5650D55.

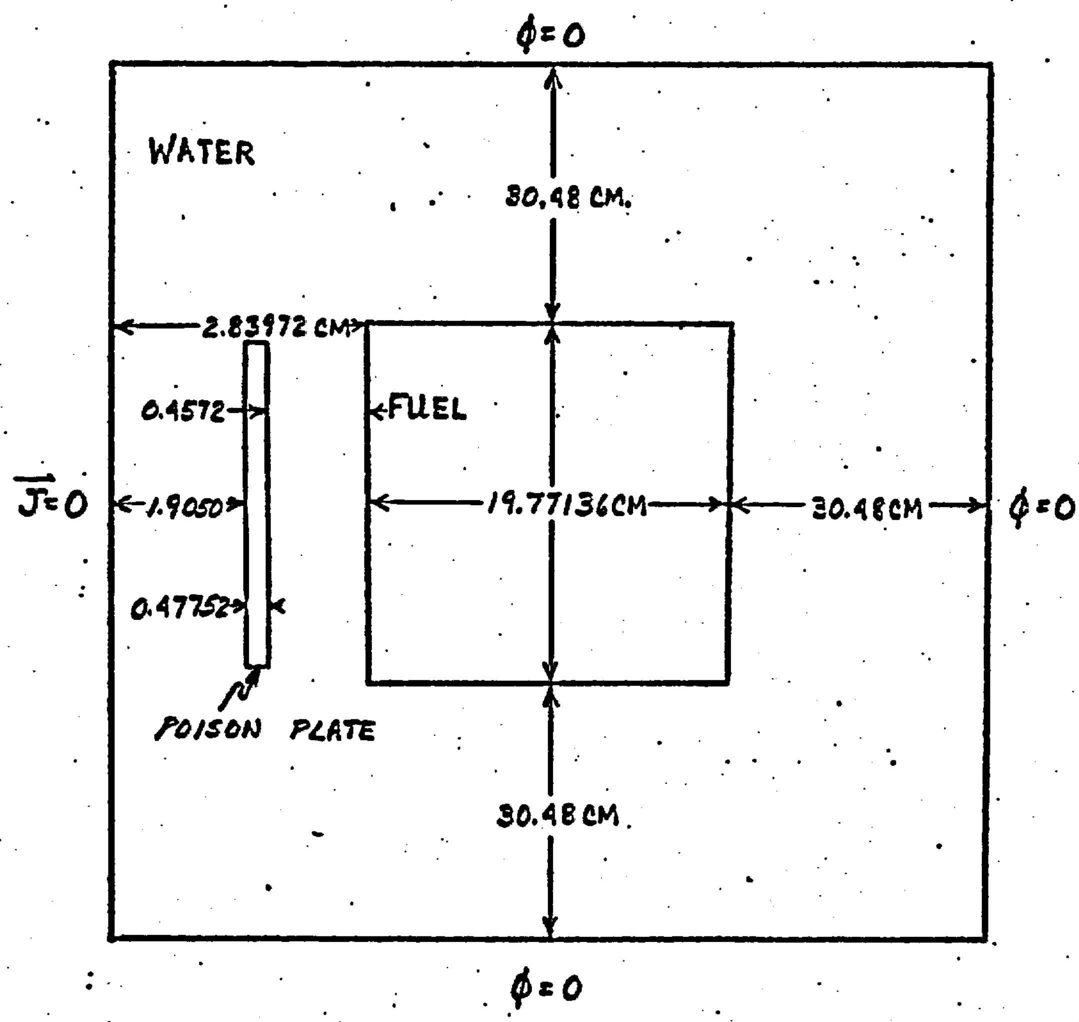
1. For various plutonium isotopics the PuO_2 enrichment is 6.0 w/o (71% fissile) 4.4 w/o (81% fissile) and 3.03 w/o (85% fissile). The U235 enrichment is the same for all cases at 0.71 w/o.

2. Fuel rods shall be closely packed in the fuel rod container on no more than an equivalent metal-to-metal square lattice. Partially loaded fuel rod container shall be fitted with a minimum of three, equally spaced blocks, of which the noncombustible portion of the blocks and the method by which they are secured shall assure that the rods are maintained on no more than an equivalent metal-to-metal square lattice within the fuel rod container.

Case 1: Single Assembly in Flooded Cask



Case 2: Two Assemblies in Flooded Casks



Case 3: Four Assemblies in Two Flooded Casks

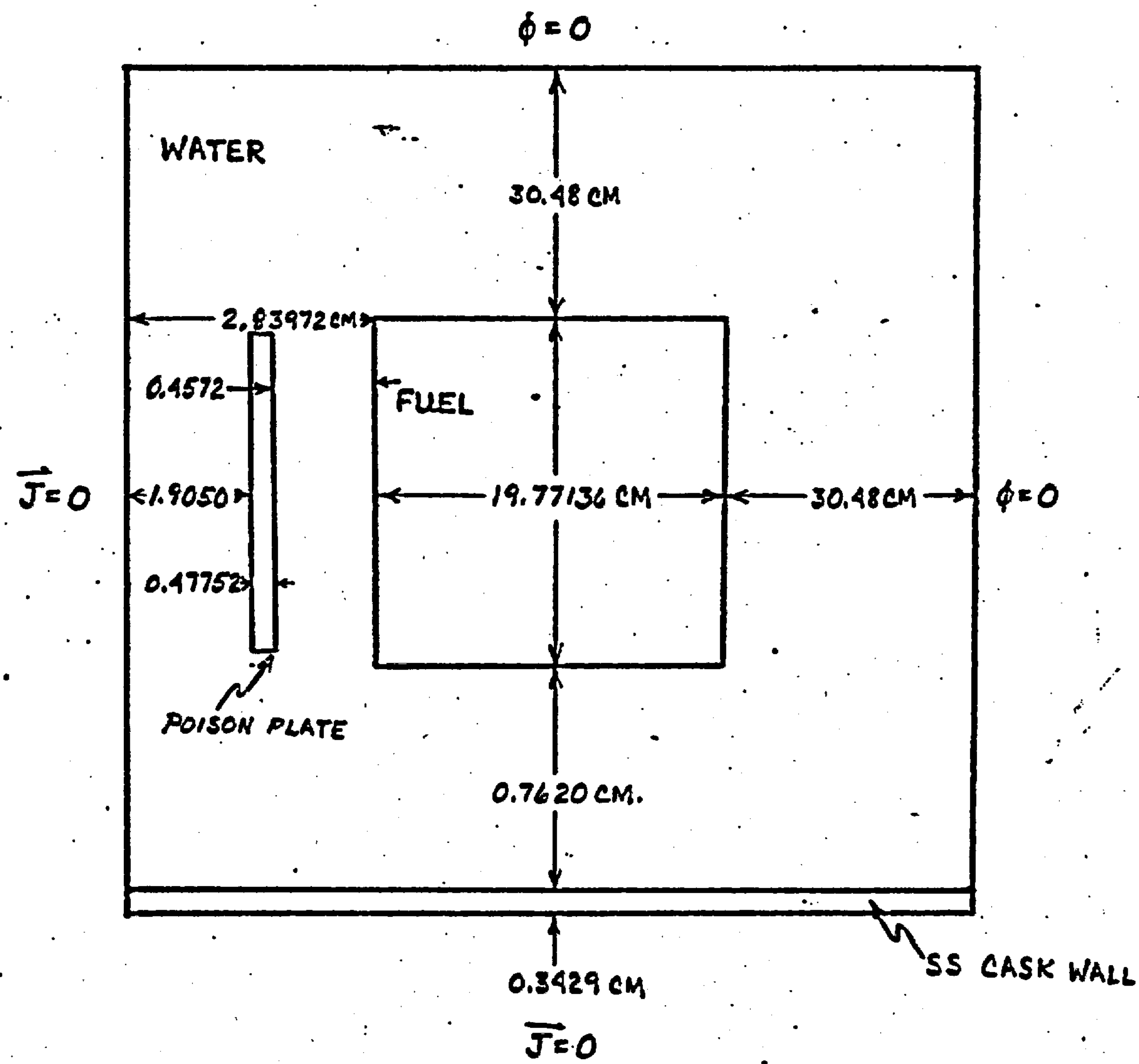


Table 2

Atom Densities

(10^{24} Atoms/CC)

Material	4.4 w/o Pu Assembly, Flooded	Reflector	Steel	Borated Steel	Cu Plate
Hydrogen	3.845502×10^{-2}	6.6880×10^{-2}	0	0	0
Oxygen	3.298293×10^{-2}	3.3440×10^{-2}	0	0	0
Zircaloy	4.221376×10^{-3}	0	0	0	0
Stainless Steel	4.888801×10^{-5}	0	8.65×10^{-2}	8.302×10^{-2}	0
Inconel	2.868596×10^{-4}	0	0	0	0
B-10	0	0	0	1.100×10^{-3}	0
Cu(natural)	0	0	0	0	8.47×10^{-2}
U-234	3.748388×10^{-5}	0	0	0	0
U-235	4.734856×10^{-5}	0	0	0	0
U-238	6.491287×10^{-3}	0	0	0	0
Pu-239	2.360837×10^{-4}	0	0	0	0
Pu-240	5.497964×10^{-5}	0	0	0	0
Pu-241	9.138146×10^{-6}	0	0	0	0
Pu-242	1.387309×10^{-6}	0	0	0	0

Table 3

Macroscopic Cross-Sections
(68°F, 1.0 gm/cc water)

Cross-Section	4.4 w/o Pu Assembly, Flooded	Reflector	Steel	Borated Steel	Cu
<u>Group 1</u>					
D(cm)	1.2085	1.2333	1.032	1.1088	1.2401
$\Sigma_a(cm^{-1})$	0.0128	0.0005	0.0006	0.0338	0.00907
$\Sigma_r(cm^{-1})$	0.0196	0.0476	0.00005	0	0
$\nu\Sigma_f(cm^{-1})$	0.0099	0	0	0	0
<u>Group 2</u>					
D(cm)	0.1960	0.1655	0.3360	0.0903	0.4872
$\Sigma_a(cm^{-1})$	0.3520	0.0222	0.2630	4.469	0.3502
$\nu\Sigma_f(cm^{-1})$	0.5962	0	0	0	0

APPENDIX 5.6.2

Introduction

In order to verify that mixed oxide (PuO_2, UO_2) fuel rods can be safely shipped in the Westinghouse Model MO-1 plutonium fuel assembly shipping container, nuclear criticality calculations were performed by conservatively modeling several accident situations. In modeling these accident situations, the loose fuel rods are assumed to be loaded into fuel rod boxes prior to their loading into the shipping container.

The computed value of k_{eff} for the maximum credible accident (MCA) was considered to be the criteria for nuclear safety. The MCA configuration was defined as two flooded, maximally crushed, shipping containers each containing two fuel rod boxes aligned so as to effect the largest value of k_{eff}. Maximally crushed shipping cask dimensions have been determined by conservative mechanical considerations.

The NRC guidelines require that k_{eff} for the MCA should not exceed 0.98. For undamaged, but flooded containers, the corresponding maximum value of k_{eff} should be no greater than 0.94.

Calculational Models and Geometry Considerations

For calculational purposes, the maximum expected fuel enrichment for mixed oxide fuel is conservatively set at 6 w/o PuO_2, where enrichment is defined as:

$$\text{Total } PuO_2 \text{ Enrichment (w/o)} = \frac{\text{weight of } PuO_2}{\text{weight of } PuO_2 + \text{weight of } UO_2} \times 100\%$$

Natural uranium is the constituent uranium with 0.711 w/o U-235 and the pellet density is taken to be 95% of theoretical.

Two sets of plutonium isotopic distributions were examined. The first is representative of 2.94 w/o PuO_2 fuel measured at the Westinghouse Plutonium Fuels Development Laboratory and backfitted to a zero Am-241 (reprocessing) date. This isotopic distribution was conservatively chosen due to its high fissile content (over 85%). These isotopics will be referred to as 85% fissile isotopics in this report. The second set of isotopics is representative of 1st recycle plutonium isotopics from a PWR and will be referred to as 1st recycle isotopics. Isotopic distributions are listed in Table I.

The updated Westinghouse versions of LEOPARD and PDQ were used in the criticality analysis. LEOPARD was used to generate 2 group macroscopic cross sections for input into the two dimensional PDQ model. Fuel cross sections include a post processing decay of Pu-241 for 10,000 hrs. The cross sections are representative of ambient (68°F) conditions with the flooding water density equal to 1 gm/cc.

It is intended that the licensing provision for the shipment of mixed oxide fuel rods contain the following statement which parallels our UO_2 shipping container authorized contents (per NRC Certificate of Compliance #5450):

> "Fuel rods shall be closely packed in the fuel rod container on no more than an equivalent metal-to-metal square lattice. Partially loaded fuel rod containers shall be fitted with a minimum of three, equally spaced blocks, of which the noncombustible portion of the blocks and the method by which they are secured shall assure that the rods are maintained on no more than an equivalent metal-to-metal square lattice within the fuel rod container."

With the above, the following assumptions were used for geometry considerations:

1) The rod box geometry specified in Westinghouse drawing C5650D55 remains intact.
2) The rod box inside dimension including manufacturing tolerances is 8.072" ± .0625."
3) The sponge rubber box liner decomposes subsequent to initial loading leaving a maximum inside box dimension of 8.072" + .1875" = 8.2595."
4) The fuel rods are packed in a square lattice. (Previous calculations have shown that fuel rods which are close packed in a square lattice are more reactive than in a hexagonal lattice. The true loading condition is expected to be some combination of the two.

Using these considerations as guidelines, four basic rod box geometries were examined:

1) A rod box loaded with an 18 x 18 array of fuel rods with a uniform rod pitch of .4523 in.
2) A rod box loaded with a 19 x 19 array of fuel rods with a uniform rod pitch of .4347 in.
3) A rod box loaded with a 18 x 18 array of fuel rods, close packed at .4220 in., with a vertical and horizontal gap of .545 in.
4) A rod box loaded with an 18 x 18 array of fuel rods, close packed at .4220 in., with 2 vertical and horizontal gaps equaling .545 in.

The above geometries are shown in Figure I. The geometries with gaps have been considered, in order to include reactivity effects of any gaps which could occur where fuel rods are packed in a square array.

The four basic rod box geometries were examined with the PDQ 2-D model for the following hypothetical accident configurations:

Case 1: A single flooded rod box surrounded by an infinite water water reflector (Criterion: k_{eff} not to exceed 0.90).

Case 2: A single flooded shipping container whose two rod boxes are crushed to within a minimum credible distance of each other, and surrounded by an infinite water reflector. (Criterion: k_{eff} not to exceed 0.94).

Case 3: The maximum credible accident (MCA). Two flooded containers whose four rod boxes are crushed together to within minimum credible distances of each other. (Criterion: k_{eff} not to exceed 0.98).

The fuel rods were assumed infinitely long ($B_z^2 = 0$), the flooding water is assumed pure at 1 gm/cc, and no credit was taken for the rod box as an absorber material. In addition, both sets of plutonium isotopic distributions were used.

The 2-D model hypothetical accident configurations are shown in Figure II.

Results

The maximum calculated k_{eff} values for each Case defined above are less than the allowable values specified as criteria. The calculated values may be taken as upper bounds on k_{eff} since in all cases they reflect numerous conservative assumptions.

Tables II and III give the required criticality model atom densities and cross sections used in the MCA analysis. Geometry 4 above was found to be the most reactive configuration for the MCA analysis.

Conclusions

The calculational results shown above indicate that zirconium clad fuel rods of the following specifications can be safely shipped in rod boxe[s] loaded into the Westinghouse Model MO-1 shipping container since the r[o] boxes can in no way become critical even under the severe conditions of the maximum credible accident, Case 3 (MCA k_{eff} < 0.98).

Fuel Rod O.D. (NOM)	.4220 in.
Pellet O.D. (NOM)	.3659 in.
Clad Thickness (NOM)	0.243 in.
Maximum Enrichment	6.0 w/o PuO_2
Maximum Fissile Content	85%

TABLE I

Plutonium Isotopic Distributions Used In Criticality Analysis

(Distributions Assumed At Completion Of Reprocessing)

ISOTOPE	85% FISSILE ISOTOPICS W/O	1ST RECYCLE ISOTOPICS W/O
Pu-238	.228	1.53
Pu-239	81.839	57.43
Pu-240	13.575	22.45
Pu-241	3.768	13.54
Pu-242	.590	5.05
$\frac{\text{Pu-239 + Pu-241}}{\text{Total Pu}}$ =	85.607%	70.97%

TABLE II

MCA CRITICALITY MODEL
ATOM DENSITIES PRIOR TO POST PROCESSING
DECAY OF PU-241 FOR 10,000 HOURS
(10^{24} ATOMS/CC)

ELEMENT	FUEL IN FLOODED ROD BOX (.422" ROD PITCH)	
	6 w/o PuO_2 85% Fissile Isotopics	6 w/o PuO_2 1st Recycle Isotopics
HYDROGEN	1.4353-2	1.4353-2
OXYGEN	3.4339-2	3.4339-2
ZIRCONIUM	7.3752-3	7.3752-3
U-234	3.6779-7	3.6779-7
U-235	9.1948-5	9.1948-5
U-236	5.8233-7	5.8233-7
U-238	1.2678-2	1.2678-2
Pu-239	6.6612-4	4.7942-4
Pu-240	1.0972-4	1.8176-4
Pu-241	3.0328-5	1.0917-4
Pu-242	4.7357-6	4.0545-5

	H_2O
HYDROGEN	6.688-2
OXYGEN	3.344-2

	SAE 1010-1020 LOW CARBON STEEL
STEEL	8.5239-2

(1.000-2 = 1.000E-2)

TABLE III

MCA CRITICALITY MODEL

MACROSCOPIC CROSS SECTIONS

(68°F, $H_2O\rho$ = 1 gm/cc)

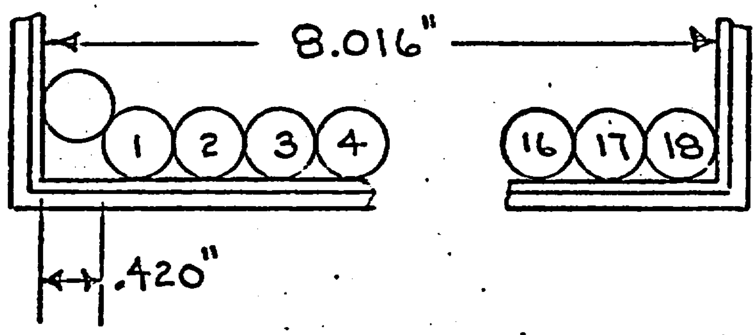
(6 w/o PuO_2)

FUEL IN FLOODED ROD BOX (.422" ROD PITCH)

	85% Fissile Isotopics	1st Recycle Isotopics	Water	Carbon Steel
Group 1 (0.625 ev to 10 Mev)				
D (cm)	1.16715	1.16551	1.3085	1.125
Σa (cm^{-1})	.01763	.01816	.00045	.00330
Σr (cm^{-1})	.00260	.00229	.04826	.00014
$\nu\Sigma f$ (cm^{-1})	.01755	.01746	0	0
Group 2 (0.0 to 0.625 ev)				
D (cm)	.25443	.25902	.1666	.3302
Σa (cm^{-1})	1.3644	1.2361	.0222	.2208
$\nu\Sigma f$ (cm^{-1})	2.3843	2.0929	0	0

FIGURE 1
ROD BOX GEOMETRIES

I a. ASSUME INSIDE DIMENSION OF ROD BOX W/LINER IS SUCH THAT 19 RODS CANNOT CLOSE PACK FILL A ROW



b. FROM ABOVE ASSUME 18 FUEL RODS (.422") + .420" GAP = 8.01

c. ASSUME DECOMPOSITION OF ROD BOX LINER SUBSEQUENT TO LOADING, LEAVING INSIDE BOX DIMENSION OF

8.016" + .125" = 8.141"

II a. ASSUME INSIDE DIMENSION WITH LARGEST MANUFACTURING TOLERANCE

8.072" + .0625" = 8.1345"

b. ASSUME DECOMPOSITION OF ROD BOX LINER SUBSEQUENT TO LOADING, LEAVING MAXIMUM INSIDE BOX DIMENSION OF

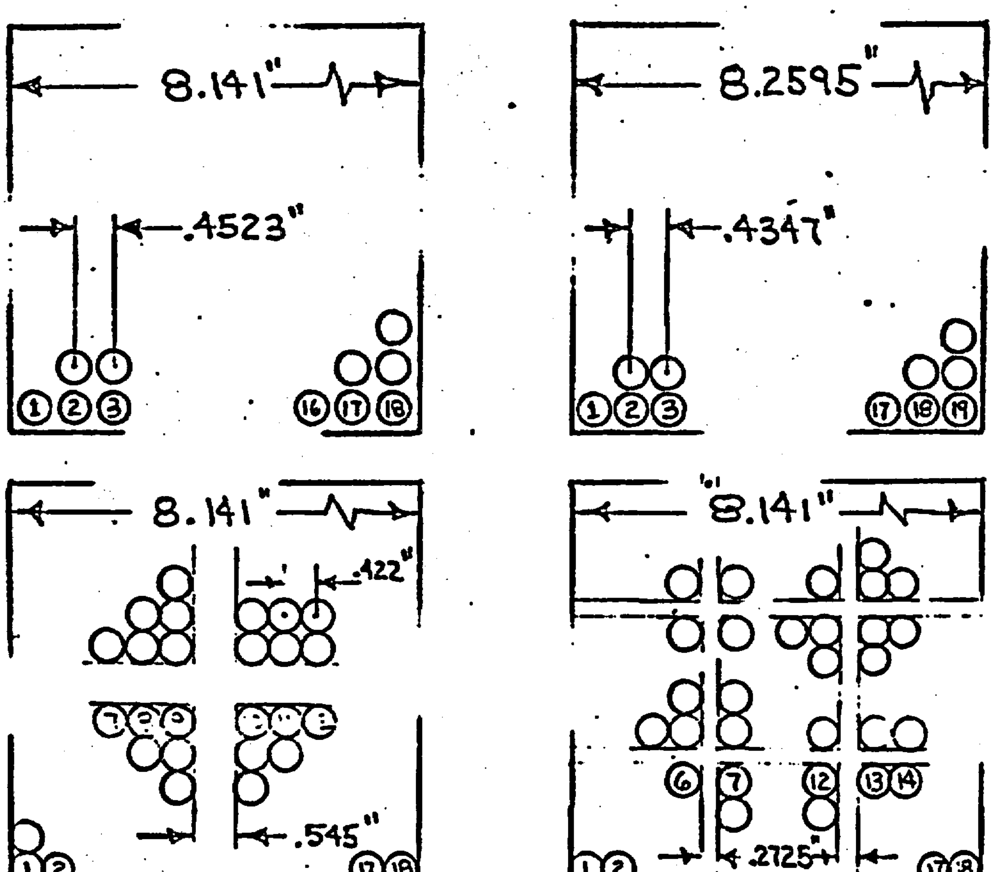
8.1345" + .125" = 8.2595"

18x18 UNIFORM PITCH

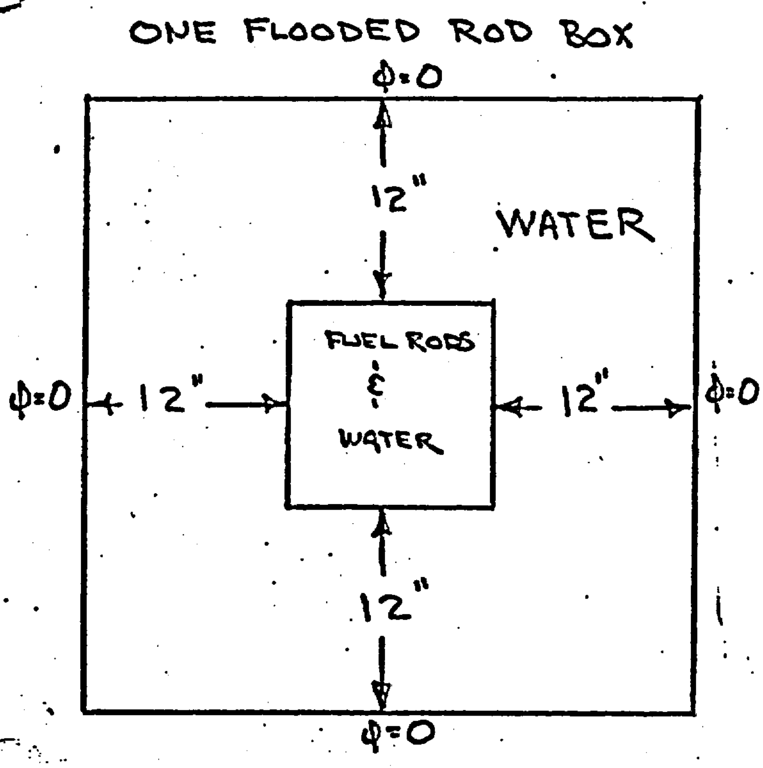
19x19 UNIFORM PITCH

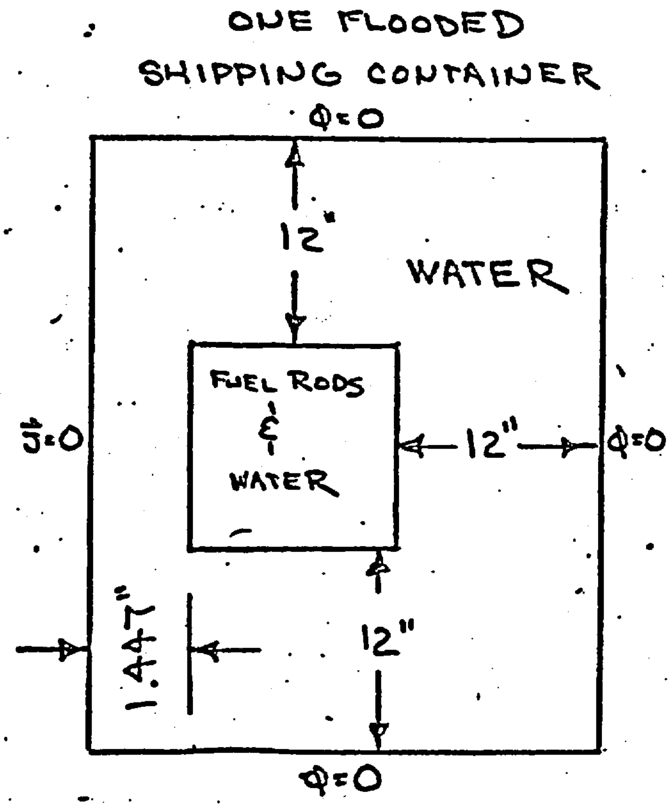
18x18 CLOSE PACKED 1 VERTICAL & HORIZ. GAP

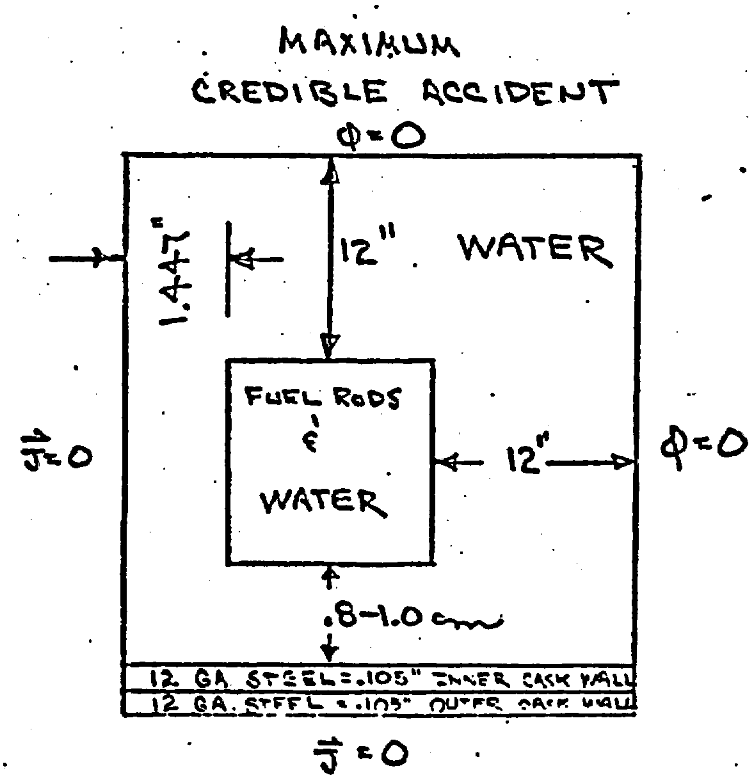
18x18 CLOSE PACKED 2 VERTICAL & HORIZ GAPS



2-D GEOMETRIC CONFIGURATIONS AND BOUNDARY CONDITIONS







CRITICALITY ANALYSIS AND REVIEW

W MODEL MO-1 PACKAGING FOR COPPER ABSORBER PLATES

An evaluation was made, for the MO-1 Plutonium Fuel Assembly Shipping Container, of the conditions which would justify the use of copper absorber plates instead of borated stainless steel. A previous study concluded that borated steel plates would be required to meet NRC guidelines on criticality for the maximu credible accident ($k_{eff} \leq 0.98$). This conclusion was reached with the ultra-conservative assumption that the polyurethane foam between the inner and outer container liners was absent, that the inner and outer liners were crushed to contact, and that the assemblies in the containers were free to move any vertical distance relative to the liners such that the greatest k_{eff} resulted. If assumptions are made which limit the degree of container crushing or vertical fuel assembly movement to a more realistic (although still very conservative) dimension, copper is found to be a suitable poison material.

In this reevaluation, the effects on reactivity of vertical movement and separation of assemblies in the maximum credible accident are investigated. The methods, geometry, and models used are essentially those used in the previous study.

The maximum credible accident was considered to be two flooded, crushed containers in contact, whose assemblies are uniformly loaded with 6 w/o PuO_2 and first recycle isotopics, as described in Appendix 5.6.1. The polyurethane between the inner and outer carbon steel walls is missing and the walls are crushed into contact. Copper plates are used for a poison material. The vertical distance between the assemblies in the assembly support frame and the crushed walls is variable. The geometry is shown in Figure 1.

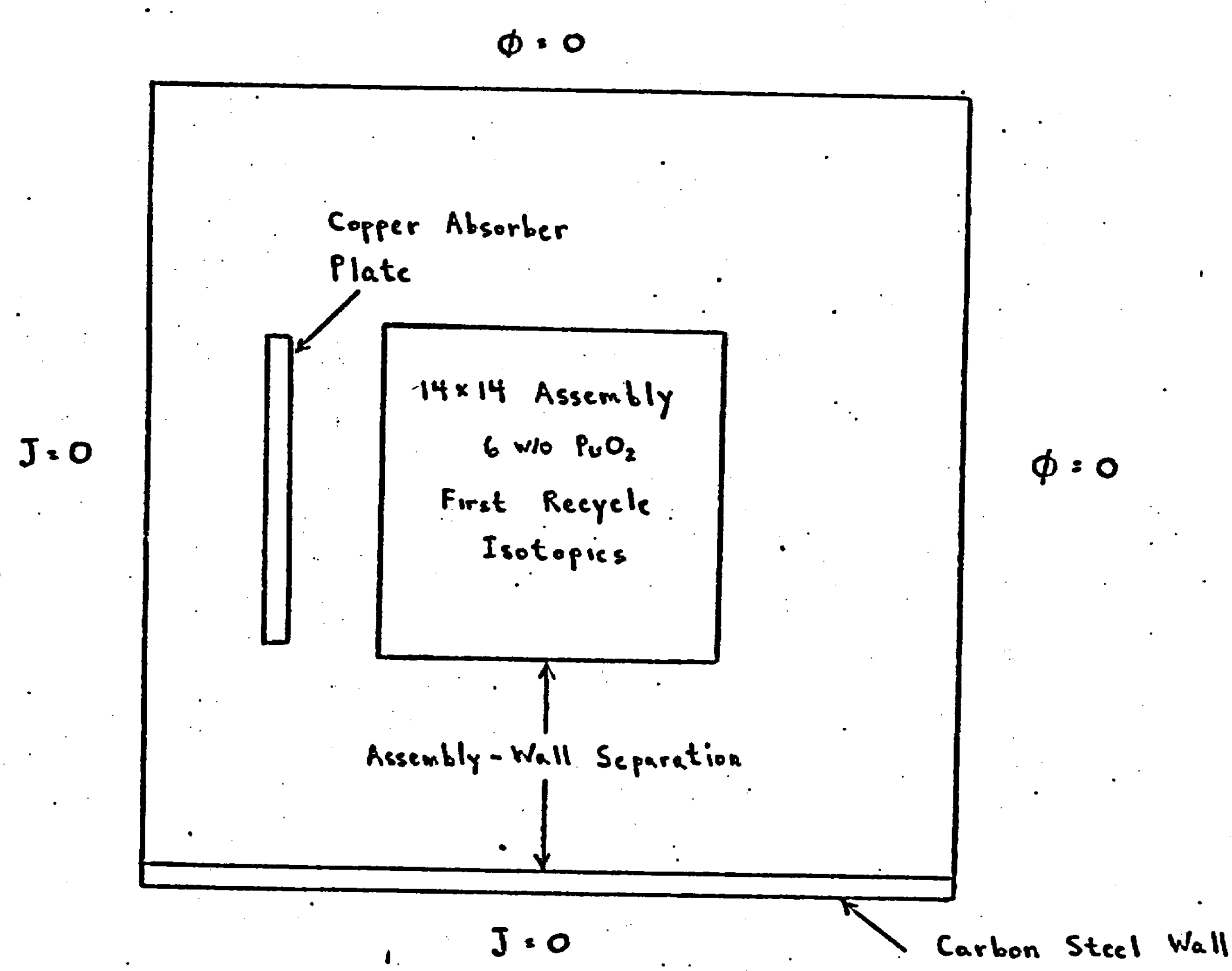
The results of the calculations show that for separations between the pairs of assemblies of four inches (4") or more, the k_{eff} for 6 w/o first recycle isotopic assemblies using copper absorber plates is less than the MCA criterion of 0.98 maximum. Considering the physical construction of these packages, a separation of 4" is readily credible as a revised assumed parameter of the MCA.

In addition, similar calculations were performed using 3.03 w/o PuO_2 fuel with 83.5% fissile content. The results showed that K_{eff} was 0.03 ΔK lower than the 6.0 w/o Pu (71% fissile) case discussed above. This 0.03 ΔK margin means that assemblies with average PuO_2 enrichments up to 3.03 w/o and fissile content up to 85% can be shipped.

NRC criticality guidelines are met for a single flooded assembly and for two flooded assemblies with copper absorber plates. When it is assumed that in the maximum credible accident the fuel assemblies, after crushing, are separated by greater than 4 inches from each other, then copper absorber plates will meet NRC requirements.

Figure 1

Problem Geometry



6.0 OPERATING PROCEDURES

This chapter generally describes the procedures to be used for loading and unloading the Model MO-1 Package. In addition, detailed Westinghouse operating procedures and forms should be used when performing these operations.

6.1 PROCEDURES FOR LOADING THE PACKAGE

1) Equalize the pressure inside the package by releasing the air filling valve located on the forward end of the container.

2) Remove the latch pins located near the separation plane of the lid and body. A small cable is attached to each pin to prevent loss of the latch pins during the lid removal operation.

3) Loosen and remove the ratchet binders which secure the lid to the body of the package.

4) Remove the overpack lid by attaching suitable hooks or shackles to the lifting ears provided on the lid. (Refer to drawing, Appendix 1.10) Care should be taken during this operation so as not to damage the lid to body interface seal. Set the lid on wood cribbing to protect this interface.

4a) Check for the presence of or install appropriate neutron absorbers. (Refer to Section 5.0, Criticality Evaluation)

5) Loosen swing bolt clamps of the shock mount support frame and swing free of the fuel assembly support frame.

6) Attach crane to lifting lug at the forward end of the fuel assembly support frame.

7) Pivot fuel assembly support frame to vertical position.

8) While holding the fuel assembly support frame with crane in the vertical position, install two supports which are used to hold the uprighted fuel assemblies in the vertical position.

9) Remove pins securing top end support assembly and swing supports free of the top opening.

10) Open the fuel assembly clamping frames for the fuel assembly position being loaded.

11) Attach the crane using the fuel assembly handling fixture, to the top nozzle of the fuel assembly to be loaded.

12) Lift the fuel assembly until the bottom end is at an elevation slightly higher than the bottom end support of the cradle assembly and then carefully move the fuel assembly horizontally into the container support frame. Position the fuel assembly against the support frame

and lower it until the bottom nozzle contacts the bottom support plate.

13) While supporting the weight of the fuel assembly with the crane, close the clamping frames onto the fuel assembly grid and tighten clamp fasteners.

14) Repeat steps 10 through 13, above, to load the second fuel assembly.

15) Swing closed the top end support assembly and insert locking pins.

16) Attach crane to lifting eye at the top end of the fuel assembly support frame in preparation for lowering to the horizontal position.

17) Remove two vertical support bars.

18) Lower fuel assembly support frame to the horizontal position.

19) Engage and tighten swing bolt clamps to secure the fuel assembly support frame to the shock mount support frame.

20) Check tightness of all fastener hardware.

21) Install accelerometers on the internal support mechanism.

22) Inspect the inside of the base and lid to assure that there are no loose articles within the packaging.

23) Place the overpack lid on the body using the alignment pins on the body assembly to guide the lid assembly.

24) Install the latch pins through the lid into the body.

25) Inspect the package for proper labeling necessary to meet federal regulations. Correct any labeling deficiencies.

26) Install an approved security seal.

27) Using an overhead crane with slings, transfer the package to the bed of the transport vehicle.

28) After all packages are on the transport vehicle, secure them to the vehicle using appropriate tiedown devices.

6.2 Procedures for Unloading the Package

1) Move the unopened package to the appropriate unloading area. Place it in a suitable unloading attitude.

2) Perform an external inspection of the unopened package

as required in appropriate Westinghouse Procedures. Record any significant or potentially significant observations in addition to the standard information.

3) Equalize internal container pressure with atmospheric Pressure by pressing or removing the air valve stem located at the aft end of the container. Reinsert the air valve stem if it has been removed.

4) Remove the security seal.

5) Repeat steps 2 through 10 in Section 6.1 above for removing the overpack lid and raising the fuel assembly support frame to the vertical position.

6) Loosen and swing back all clamping frames so that they do not interfer with removal of the fuel assembly.

7) Remove the fuel assemblies.

7.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

7.1 Acceptance Tests

The Model MO-1 Packaging shall be inspected and released for use by a responsible Westinghouse employee prior to loading fuel assemblies. The following items will be included in such inspections:

1) The entire package, both inside and out, shall be visually inspected and assured that it has not been significantly damaged (no cracks, punctures, holes, nor broken welds).

2) The exterior stencils must be in place and legible.

3) Latch pins, ratchet binders, and gaskets must be present and free of defects.

4) The internal shock mounted support mechanism should be visually inspected and assured that it has not been significantly damaged (no broken welds, no broken nor bent members, and the assembly must be properly orientated within the body of the overpack).

5) The shock mounts shall be visually inspected and assured to be in place and properly secured to the mounting brackets and to the support mechanism.

5a) The appropriate neutron absorbing poison plates must be in position between the fuel assemblies prior to release of the Model MO-1 Packaging.

6) Follow all Westinghouse operating procedures and complete all necessary records for the handling and operation of the Model MO-1 Packaging.

7.2 Maintenance Program

A good sound industrial maintenance program should be followed to assure the integrity of the Model MO-1 Packaging. Components such as gaskets, latch pins, ratchet binders, poison plates, and components necessary for the safe and easy operation of the packaging should be given regular inspection and repaired or replaced as necessary.

THIS PAGE IS AN OVERSIZED DRAWING OR FIGURE,

THAT CAN BE VIEWED AT THE RECORD TITLED: DWG. NO. C5650D55 FUEL ROD SHIPPING CONTAINER WITHIN THIS PACKAGE...OR, BY SEARCHING USING THE DRAWING NUMBER: C5650D55

NOTE: Because of this page's large file size, it may be more convenient to copy the file to a local drive and use the Imaging (Wang) viewer, which can be accessed from the Programs/Accessories menu.