June 30, 1975

TR-466

USA/5705/AF (ERDA-ID)

ATR FUEL ELEMENT SHIPPING CONTAINER SAFETY ANALYSIS

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0.0 GENERAL INFORMATION

0.1 Introduction

The ATR Fuel Element Shipping Container, USA/5705/AF (ERDA-ID), is used for the transport of fuel elements for the Advanced Test Reactor (ATR) operated by Aerojet Nuclear Company (ANC) at the Idaho National Engineering Laboratory (INEL). The container was analytically evaluated to determine its compliance with ERDA 0529 and 10 CFR 71 governing containers in which fissile materials are transported, and those tests and evaluations are reported herein (ATR Fuel Element Shipping Container Safety Analysis, June 30 , 1975). The results show that the container complies with the applicable regulations.

When fissile or radioactive materials are transported, the packaging and contents must meet standards [specified in ERDA Manual Chapter 0529, "Safety Standards for the Packaging of Fissile and Other Radioactive Materials", its Appendix, and also in Title 10, Part 71 of the Code of Federal Regulations, Packaging of Radioactive Material for Transport,] to assure protection of the public health and safety. These standards state the requirements for criticality safety, structural integrity, thermal and shielding capabilities, quality assurance, and maintenance and operating instructions. Any package used for the transport of fissile material must be shown to meet these standards, by test or computational methods, before issuance of a Certificate of Compliance. The tests and computational analyses of the ATR Fuel Element Shipping Container to determine compliance with the above standards, as a Type A quantity, Fissile Class 1 container, are reported herein.

It should be noted that the ATR Fuel Element Shipping Container has been in use since 1968 under DOT Special Permit No. 5705. The primary document supporting this Certificate of Compliance is ANCR-1100, "Protective Shipping Packages for Radioactive and Fissile Material Containers", D. A. Tobias, March 1968. The purpose of this report is to upgrade ANCR-1100 to current documentation requirements.

0.2 Package Description

The ATR Fuel Element Shipping Container is used for shipping new, unirradiated fuel elements from the supplier to the Advanced Test Reactor at the Idaho National Engineering Laboratory (INEL) in Idaho. Each container (Nos. 1 through 24) is designed to transport, in a horizontal position, four ATR fuel elements, which contain approximately 1100 grams of U-235 each. Other fissile material may be transported in the container within the limits specified in Section 0.3. The container, as shown in Figure 0.1, actually consists of two containers, one inside the other.

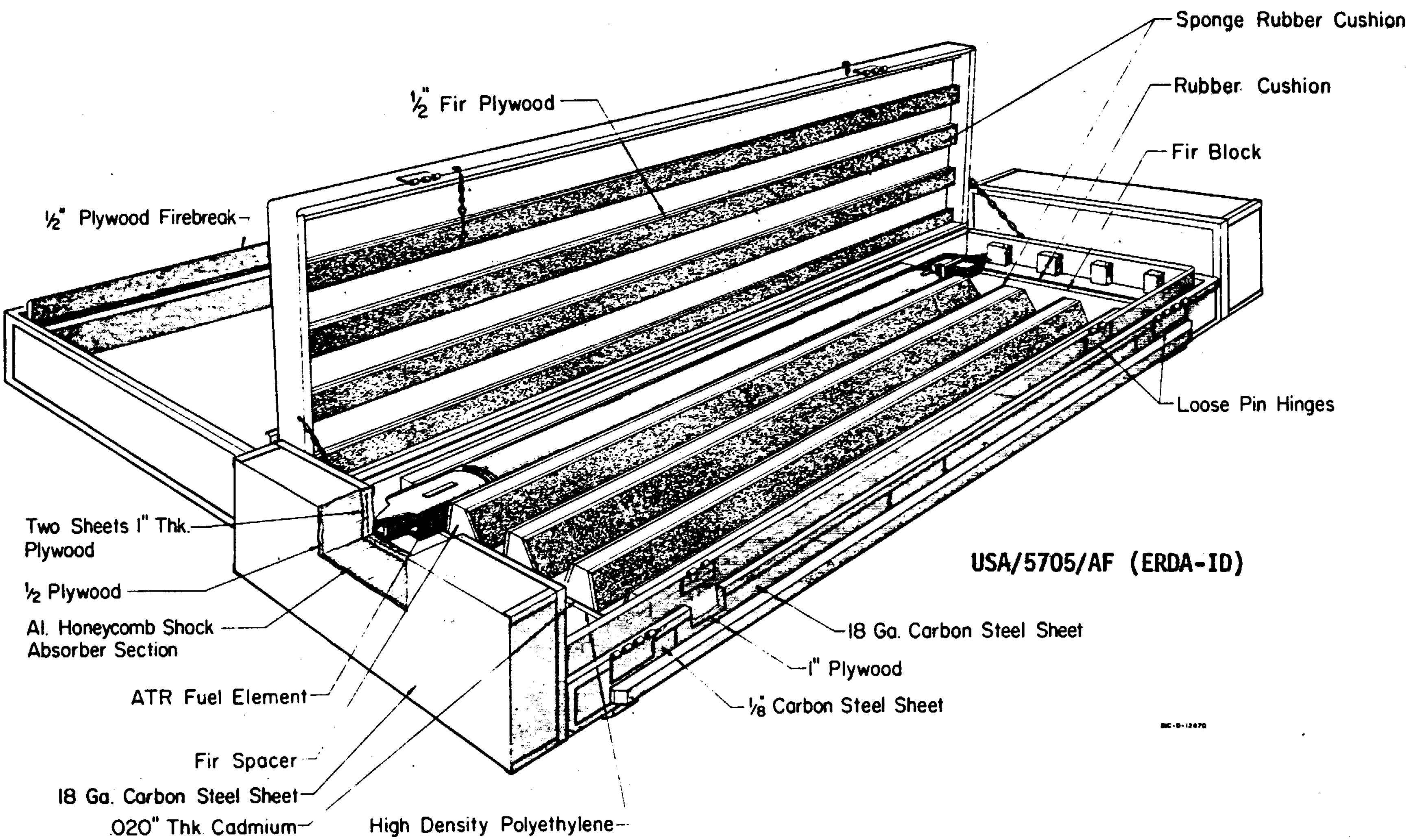


Figure 0.1 ATR Fuel Element Shipping Container

The inner container, drawing ATR-E-1052, is the container originally designed for the transportation of ATR fuel elements. It is constructed mainly of 16 gauge steel-covered, 3/4-inch plywood which has been pressure impregnated with the fire retardant. There are 0.020-inch cadmium sheets located above, below, and along both sides of the container for neutron absorption. One-half inch polyethylene sheets are located external to the upper and lower cadmium sheets for neutron moderation. The external dimensions of the shipping container are 69.1 inches long by 26.8 inches wide by 7.7 inches high. The cavity is 68.5 inches long by 25.0 inches wide by 4.0 inches high, and contains triangular wood spacers covered with sponge rubber which divide the cavity into four compartments. Each compartment is trapazoidal and measures approximately 2 inches and 3-1/2 inches in width on the bottom and top, respectively, and 4 inches high (note drawing ATR-E-1053). The lid is held shut by pinned steel hinges.

As shown in drawing ATR-E-1053, there are approximately 8-1/2 inches at each end of the container which is used to accommodate ATR fuel element end boxes, and which does not contain polyethylene and cadmium sheeting. Between the inner and outer containers is a region approximately 1-inch thick which contains an estimated 20% volume of wood and 80% air.

The outer container, drawing 533-0670-47-400-035929, was designed to enable the complete package to meet the requirements of ERDA Appendix 0529. It is constructed using 18 gauge steel-covered, 1-inch plywood, which has been pressure impregnated with fire retardant, with a steel-sheathed, 4-inch thick aluminum honeycomb shock absorber at each end. The dimensions of the outer container are 88 inches long, 32 inches wide, and 11 inches high. The cavity is 71.8 inches long, 27.6 inches wide, and 8.9 inches deep. The lid is secured to the body by four carbon steel hinges, the leaves of which are welded to the sides of the lid and body near the ends of the lid.

For lid lifting purposes there are four 26-inch, 60° sections of 4-inch, schedule 40 steel pipe welded to the lid of the outer container. Each pipe section has four 0.19-inch gusset plates welded between the pipe section and the lid at even spaces. Figure 0.1 shows the shipping container inside the outer container.

0.3 Authorized Contents of Packaging

The authorized contents and limits are as follows:

0.3.1 Fissile Material Limits

The ATR shipping containers are authorized for Fissile Class I transport with the following limits:

a. Solid material containing no more than 12,000 grams of U-235 total, provided that not more than 700 grams of U-235 is contained in any linear foot in each of the four compartments.

b. The uranium must be confined to the longitudinal region of the container containing cadmium. For other than ATR fuel elements, the end region normally containing the fuel element end boxes must be securely blocked off with solid wood blocks.

0.3.2 Radioactivity Limits

The contents shall not exceed Type A quantities of special or normal form radioactive material. For example, uranium curie content shall not exceed 3.0 curies. However, the 12,000 gram limit for U-235 effectively restricts the various isotopes of uranium to less than 1.0 curie in the unirradiated condition.

0.3.3 Physical and Chemical Form

The contents may be special or normal form but must be in solid form and either clad (as in fuel plates or rods) or enclosed in a container which will prevent the spread of contamination. In addition the contents must be of a configuration to preclude the redistribution of material beyond the 700 grams of U-235 per linear foot limit. The chemical composition and form of the contents may be any that are not chemically reactive with the packaging, explosive, or have a hydrogen atom density, when averaged over the volume of the contents, greater than that of water at one gram per cubic centimeter.

0.3.4 Heat Generation

Heat generation of the shipping container contents shall not exceed 0.1 watt. (Note: The heat generated by enriched uranium containing 12,000 grams of U-235 is less than 0.1 watt.)

0.4 Administrative Controls

ANC personnel, who load fissile material shipping containers, must have received criticality safety training and be qualified as an authorized loader of fissile material. In addition, prior to loading or unloading the container, the operator must, as required by ANC procedures, have direct knowledge of shipping container limits as specified in a Certificate of Compliance. He must also verify compliance with these limits and document verification on shipping forms which, in turn, must be approved by the ANC Radioactive Shipping Coordinator.

Prior to shipment, a survey must be made for contamination and direct radiation levels to assure compliance with applicable shipping regulations.

In addition, when shipping fissile material other than complete fuel elements, an independent verification (visual inspection) must be made and documented to assure that the end regions have been blocked off, as required in 0.3.1.b, above, and unclad material, if any, is confined to an inner container.

The ATR Fuel Element Shipping Container is designed to be lifted and/or moved using a fork lift. The handles are not to be used in lifting the container. The handles are designed for hand use only when removing the top half of the outer container.

1.0 STRUCTURE EVALUATION

The ATR Fuel Element Shipping Container was analyzed by computational methods, which were verified by actual testing of similar containers, to determine whether it meets the standards regulating the shipment of fissile materials. It has been found that the container does meet the requirements.

The container meets the requirements for chemical reactions and positive closure specified in the general standards. The lid lifting handles are not intended for use in lifting the container, but they do meet the requirement of lifting devices. The hinges have been modified by welding the metal, which forms the eyes into a continuous ring, enabling the container to fully meet the requirements of the general standards.

The free drop, puncture, thermal, and immersion conditions of the hypothetical accident will not adversely affect the structural integrity of the container.

1.1 Structural Design

The structural design of the total package consists of two steel-covered plywood constructed containers assembled one inside the other. The inner container provides the primary containment of the contents and considerable structural strength. The outer container is of similar construction and provides protection for the inner container. This container, when fitted with the steel-sheathed aluminum honeycomb shock absorbers at each end, provides the total package with the required structural rigidity, energy absorption, and heat transfer resistance to comply with the performance requirements of ERDA 0529 and 10 CFR 71. Additional information regarding structure is given in Section 0.2. Adequacy of the structural design is discussed in the appropriate sections of this report.

1.2 Weights and Centers of Gravity

The total calculated weights of the packaging and contents is 853 pounds. The weights of the individual components of the package are as follows:

Inner Container	315 pounds
Outer Container	450 pounds
(Four ATR Fuel Elements)	88 pounds
Total	853 pounds

This weight is rounded to 850 pounds when used in calculations. The weight assumed for the hypothetical accident conditions was 853 pounds. The weight of the contents for fissile shipment, other than ATR fuel elements, is unknown. However, the space available for the contents is sufficiently small that gross weight variations will not be large enough to invalidate the stress analyses. The center of gravity is essentially the geometric center of the package, excluding the skids.

1.3 Codes and Standards

Codes and standards used in the manufacture of the container are listed in the drawings and included below.

Cadmium	Inner Container - .020-inch thick sheeting
Paint	Outer Container - Federal Specifications TT-P-636, TT-P-25, and TT-E-529 Inner Container - Gray rust-oleum
Polyethylene	Inner Container - 1/2-inch high density polyethylene, .095 gm/cc minimum
Plywood	Outer Container - Fir exterior A-A grade and fire retardant treated per MIL-L-19140 Inner Container - Fire protected with Underwriter's Laboratories, Inc.; approval Issue No. 6101, Fire Hazard Classification
Sponge Rubber	Inner Container - ASTM-D-1056-59T RO-10-CF
Steel Sheeting	Outer Container - 18 gauge steel sheeting, ASTM A366 Inner Container - 16 gauge steel sheeting
Wood Glue	Outer and Inner Container - Adhesive caseine-type water resistant per Federal Specification MMM-125
Wood Screws	Outer and Inner Container - Wood screws to comply with Federal Specification FF-S-111

1.3.1 Mechanical Properties

Mechanical properties of materials used in the structural evaluation are referenced in the text to the reference list that appears in Appendix 1.8.4.

1.4 Compliance with General Standards for All Packaging

The general standards for all packaging, as specified in Part II, A of ERDA Appendix 0529, cover chemical and galvanic reactions, closure of the package, lifting devices, and tie-down devices.

1.4.1 Chemical and Galvanic Reactions

The ATR Fuel Element Shipping Container is constructed of the following materials: plywood, steel, aluminum, cadmium, rubber, wood, polyethylene, primer, paint, 3M super adhesive, and a caseine-type adhesive. No chemical or galvanic reactions are possible between any of these materials or between these materials and the intended contents of the container.

1.4.2 Positive Closure

Both lids are secured with hinge pins which are retained in their hinges by cotter pins, thus insuring positive closure which will prevent inadvertent opening of the container. The cotter pin holes provide the capability for security sealing, as per DOT Regulation 173.393 (b).

1.4.3 Lifting Devices

The regulations require that any structural part of the packaging, which could be used to lift the entire package, shall be capable of supporting three times the weight of the package without generating stress in any of the packaging material in excess of its yield strength. The ATR container is intended to be lifted from below, as with a fork lift. The handles on the outer container are designed only for hand use in removing the upper half of the container.

In addition, they are so designed that it is extremely unlikely that they would be used for lifting the entire container. Though the tip of a hook could be inserted underneath the "flange" handle, this would be a violation of safe lifting procedures. Nevertheless, this handle could conceivably be used to lift the entire container. Therefore, analyses were made and are included in Appendix 1.8.3, demonstrating the fact that the handles will support three times the weight of the container by a large margin.

1.4.4 Tie-Down Devices

There are no tie-down devices which are a structural part of the ATR Fuel Element Shipping Container. Exterior handles, which are a part of the outer container lid are designed so that they cannot be used as tie-downs.

1.5 Standards for Type B and Large Quantity Packaging

The structural standards for packaging are specified in Part II, B of ERDA Appendix 0529. This part applies only to shipments of Type B or a large quantity of radioactive material. Since the ATR Fuel Element Shipping Container is to be used only for Type A quantities of radioactive materials, these structural standards are not applicable.

1.6 Compliance with Standards for Normal Conditions of Transport

The regulations for normal conditions, as specified in Part II, E of ERDA Appendix 0529, are in three parts. The first part applies to packages used for the shipment of fissile material or more than Type A quantity of radioactive material, and thus applies to the ATR Fuel Element Shipping Container. This part covers release of radioactive materials, effectiveness of the packaging, increases of pressure or an explosion of gases or vapors within the package, radioactive contamination, and loss of coolant or loss of operation of any mechanical cooling device.

The container is not adversely affected by the extremes of normal transport conditions. Each condition is discussed in separate subsections below. Also, no buildup of pressure (the container is not airtight) or release of radioactive material can occur, as a result of conditions within the package. This is because shipping of explosives, liquids, gases, or chemically reactive material is not permitted and additional containment is required for unclad, solid uranium. In addition, no cooling devices are provided or required since heat generation within the entire package must be no greater than 0.1 watt.

The second part applies to packages used for the shipment of fissile material, and thus also to the ATR container. As discussed in Section 5.0, Criticality Evaluation, a safe margin of subcriticality exists for an infinite array of packages containing uranium at the specified limits, assuming the optimum reactive form and distribution of uranium and water moderation.

The third part applies only to packages used for the shipment of more than Type A quantities of radioactive material, and thus <u>not</u> to the ATR container.

The normal conditions, specified in Annex 1 of the ERDA Appendix 0529, include the effects of heat, cold, pressure, vibration, water spray, free drop, penetration, and compression, and are discussed below.

1.6.1 Heat

The thermal evaluation for the normal condition heat test is reported in Section 2.4. It is concluded that the ATR Shipping Container will withstand the heat test for normal conditions with no detrimental effects.

1.6.2 Cold

The regulations require that a package withstand an ambient temperature of -40°F in still air and shade. This temperature will not cause any adverse effects, including a decrease in internal pressure, since the container is not sealed to air.

1.6.3 Pressure

The ATR fuel container is required to withstand an atmospheric pressure of 0.5 times standard atmospheric pressure. Again, this condition will not cause adverse effects, since the container is not sealed to air.

1.6.4 Vibration

The regulations require that a package withstand vibration normally incident to transport. Vertical vibrations will result in compressive forces between lid and body of the container, but not tensile forces since only gravity holds the boxes down. The interface between the lid and body has a large area (230 in^2) to resist forces and fretting.

Similarly, for horizontal vibrations in the longitudinal direction, the ends of the container body will constrain the lid with a large area to resist compressive forces and fretting. The outer container has a 57 inches x 0.75 inch by 0.125 inch carbon steel strip along each side of the lid interface to resist transverse vibrations of the lid relative to the body.

The ATR shipping containers have been in use for approximately five years. In this period, there have been no failures of the kind specified above, due to vibration. It is reasonable to assume that the container will continue to operate satisfactorily in this respect.

1.6.5 Water Spray

The regulations require a package to withstand water spray sufficiently heavy to keep the entire exposed surface of the package, except the bottom, continuously wet for 30 minutes. Since the containers are sheathed in steel, the plywood is of exterior grade, and water resistant glue is used, no adverse effects, such as delamination of plywood, would occur. Minor leakage of water to the interior could possibly occur. However, the criticality analysis shows that with water fractions and fuel configuration in the most reactive configuration possible, an infinite number of the containers in close geometric arrangement will remain subcritical. Thus, it can be concluded that a water spray, as described, will not cause significant adverse effects.

1.6.6 Free Drop

The regulations require a package of less than 10,000 pounds to withstand a free drop of four feet onto a flat, unyielding horizontal surface. This test must be made between 1.5 hours and 2.5 hours after the conclusion of the water spray test. The package must strike the surface in a position for which maximum damage is expected. This test is much less severe than the 30-foot free drop specified under the hypothetical accident conditions of ERDAM 0529, Annex 2. Section 1.7 shows that the ATR container will survive the 30-foot drop with damage limited to crushing the aluminum honeycomb shock absorber. Although this test was not done after a water spray test, as required by the normal conditions, water will in no way affect the shock absorber or any of the steel structure of the container. A drop, as specified by the standards for normal conditions, will not result in significant damage to the container.

1.6.7 Corner Drop

The corner drop test applies only to packages not exceeding 110 pounds gross weight and to Fissile Class II packages, and is thus not applicable to the ATR fuel element container which is not Fissile Class II and does not weigh less than 110 pounds.

1.6.8 Penetration

The standards require that a package withstand the impact of the hemispherical end of a 13-pound steel cylinder, 1.25 inches in diameter, dropped 40 inches onto the surface most vulnerable to puncture without sustaining any of the specified damage. One-inch plywood covered with 18 gauge steel sheeting will withstand such an impact. This is demonstrated by the following calculations.

The kinetic energy of an object after a free fall is expressed as the product of its weight and the distance of free fall,

$$\begin{aligned} U &= W \cdot h \\ &= 13 \text{ lb} \cdot 40 \text{ in} \\ U &= 520 \text{ in} \cdot \text{lb} \end{aligned}$$

in the case of a 13-pound cylinder falling 40 inches.

The most vulnerable surfaces on the ATR container are any of those consisting of 18 gauge carbon steel sheet backed by 1-inch plywood. The energy required to punch a 1.25-inch hole through the plywood in a punch-and-die operation is:

$$E = S_s A_s \frac{t}{2}$$

where S_s = the shear strength of the plywood; 315 lb/in^2*

A_s = πdt is the area of shear; 3.93 in^2

t = the thickness of the plywood; 1 inch

d = the diameter of the hole; 1.25 inches

Substituting,

$$E = 315 \times 3.93 \times 1/2 = 618 \text{ in} \cdot \text{lb} > U$$

Actually, the plywood will yield along the lines of least resistance; that is, parallel and perpendicular to the grain. Thus, approximating a square hole, the area of shear would be:

$$A_s = 4\, dt$$

where d = the diameter of the cylinder.

Substituting,

$$E = 210 \text{ lb/in}^2 \cdot 4 \cdot 1.25 \cdot \frac{1^2 \text{in}^2}{2}$$

$$E = 525 \text{ in} \cdot \text{lb} > U$$

It is concluded that the cylinder would not have enough energy after a 40-inch drop to punch a hole through the plywood in a punch-and-die operation. In the actual case, there is no die, so the actual energy required would be larger due to bending of the plywood. In addition, the steel sheathing would absorb part of the energy. It can be safely concluded that the ATR container will withstand this test successfully.

1.6.9 <u>Compression</u>

Finally, the standards for normal conditions require a package to endure for 24 hours a compressive load of 5 times the weight of the package, or 2 lb/in^2 times the maximum horizontal area of the package, whichever is greater. The load is to be applied uniformly against the top and bottom of the package in the position in which the package would normally be transported.

*The shear strength of fir plywood depends upon the direction. It is 210 lb/in^2 if the shear is parallel to or perpendicular to the face grain and 420 lb/in^2 if the shear is at 45° to the face grain[1]. An average figure, 315 lb/in^2 is assumed for a circular hole

The ATR container weights 850 pounds. Five times its weight is 5 · 850 pounds = 4250 pounds. The container has a horizontal area:

$$A = 87.75 \text{ in} \cdot 31.25 \text{ in} = 2742 \text{ in}^2$$

The load required on the basis of 2 lb/in^2 is:

$$P = 2 \text{ lb/in}^2 \cdot 2742 \text{ in}^2$$

$$P = 5484 \text{ lb}$$

Since 5484 lb is greater than five times the weight of the container, this load was used in a test performed on January 14, 1974. An ATR container was loaded with lead bricks weighing 26.2 lb each. The number of bricks required is P/26.2 lb = 209.4. The bricks are of such a size that only 88 bricks can be placed in one layer on the container. Therefore, two layers of 88 bricks each and one layer of 36 bricks, for a total of 212 bricks, were placed on top of the container and left for 24+ hours. During and after the test, there were no changes in the container. The test and results were certified by ANC Quality Division. This division meets the requirement of RDT F 2-2, "Quality Assurance Program Requirements".

1.7 Compliance with Standards for Hypothetical Accident Conditions

The applicable standards for hypothetical accident conditions are specified in ERDA Appendix 0529, Part II, F.2. These standards require that a package used for the shipment of fissile material shall be so designed and constructed and its contents so limited that if it is subjected to the sequence of free drop, puncture, thermal, and immersion conditions, the package would be subcritical.

The content of this section consists of applicable material from ANCR-1100, an Aerojet Nuclear Company Report, issued March 1968, titled, "Protective Shipping Packages for Radioactive and Fissile Containers", which was the primary supporting document submitted to obtain DOT Special Permit No. 5705. Supporting analysis for the design of the ATR fuel shipping outer container, taken from a supplement to the above report, is included in this report as Appendix 1.8.2.

It should be noted that the above referenced report and supplement were prepared in support of four different fuel element (SPERT, MTR, ETR, and ATR) shipping containers. The ability of these containers to meet the specified tests were based on engineering analysis. The analytical methods were verified by experimental data obtained by tests on one of the four containers. Thus, the data obtained from the testing of one container verified the accuracy of the engineering analysis for the other containers. It is noted that the discussion of analytical methods was provided in greater detail for the MTR and ETR containers than for the ATR container. These discussions are repeated in this report to demonstrate the adequacy of the analytical methods, even though there may be minor differences in the actual analysis of the containers.

1.7.1 Free Drop

The engineering analysis for the protective package design was based upon the knowledge that whenever a ductile material yields under high strain, the reactive force is considerably reduced. The dynamic and static stress analysis of the containers and packages utilized equations involving impact velocity, stress wave velocity, conservation of momentum and kinetic energy, and elastic deformation.

Inasmuch as only elastic stress waves can be propagated at the velocity of sound through an object, the plastic strain is localized at the impact end. The plastic stress wave will move at a velocity considerably lower than the elastic stress wave, and the extent of plastic deformation may be estimated by utilizing the theoretical contact time. Primary contact time is calculated by determining the velocity of the elastic stress wave and reflected wave distance.

Average impact force and consequent "g" level were determined by using the conservation of momentum equation, after the container mass, velocity, and impact time had been calculated.

The kinetic energy equation and stopping distance required to produce a tolerable "g" loading on the container package structures were utilized in determining the design of the shock absorber medium. Calculations of the coefficient of restitution indicated the drop test collisions to be partially elastic and partially inelastic.

All container modifications and shock attenuation designs are the result of extensive engineering analysis. The drop tests conducted at the conclusion of the design phase verified the accuracy of the analysis and demonstrated the feasibility of the designs.

The package must withstand a 30-foot free drop in any attitude onto a flat, unyielding surface. Maximum damage will occur in an end impact in which the longitudinal axis of the container is nearly vertical. It is obvious that a smaller impact area will result in a greater deformation. Calculations for such an impact are given in Appendix 1.8.2. These calculations were verified by an actual drop test conducted on an ETR fuel element shipping container, utilizing six dummy fuel elements, which weighed a total of 96 pounds, as the simulated load.

A 5.5-inch thick honeycomb prototype shock absorber, encased in 18 gauge sheet steel, was installed on one end of a container to verify the shock absorption qualities of this type of shock absorber design (Figure 1.1).

Instrumentation mounted on the inner container consisted of three accelerometers and two strain gauges. The axis of one of the accelerometers was parallel to the direction of failure and directly above the point of impact. The remaining two were mounted normal to the vertical axis 90° apart. The accelerometers were double ranged for 2000 and 200 "g" loadings. The strain gauges were ranged for 3000 microinches per inch and 30,000 microinches per inch, and were mounted on a brace above the impact area.

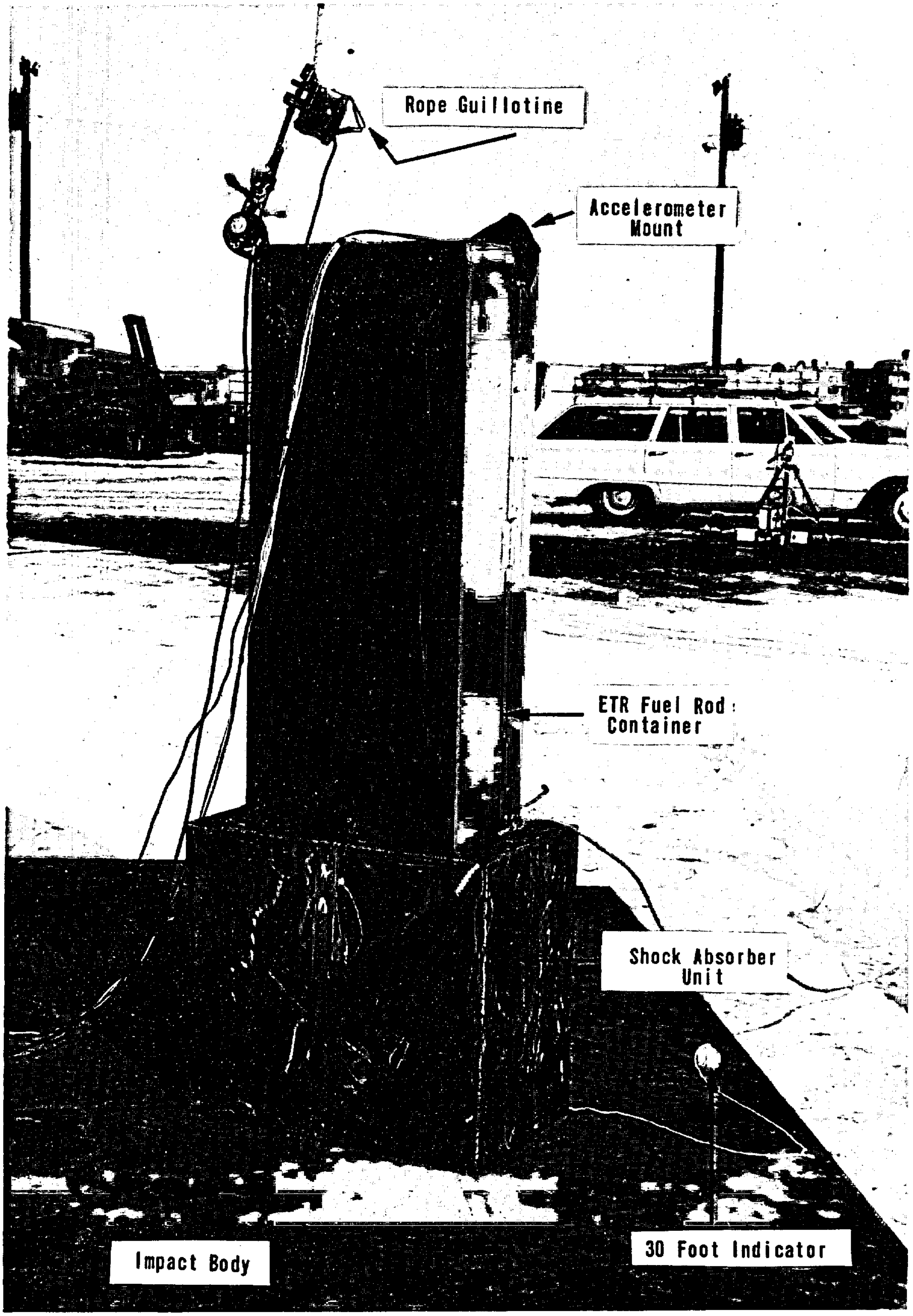
In order to simulate a flat, essentially unyielding surface, a steel plate, 12 feet by 7 feet by 1.75 inches thick, placed horizontally on frozen ground, was used as the impact body.

The container, dropped from a height of 30 feet and with the shock absorber attached, impacted on a corner of the structure at an angle approximately 20° from the horizontal plane. Maximum indicated vertical deceleration rate was 293 "g's" with an average deceleration rate of 114 "g's". Plotted traces of the accelerometer output for this test and a previous test are shown in Figure 1.2. Maximum stress measured by the strain gauges was 11,600 psi which is well below the yield value of steel, 32,000 psi. The honeycomb structure was crushed appreciably (Figures 1.3 and 1.4), but withstood the impact as calculated. No damage to the inner container was sustained (Figure 1.5).

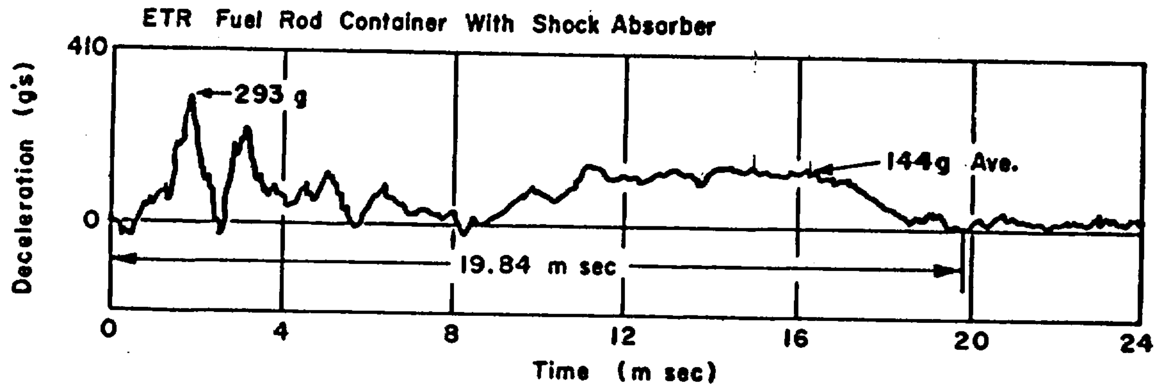
Therefore, the drop test with the ETR container and prototype shock absorber verified the analytical method for the ETR container. This same analytical method was then used on the ATR container to arrive at a required honeycomb thickness of 3.8 inches versus the 4 inches actually used in construction. The calculations are shown in Appendix 1.8.2.

1.7.2 Puncture

The package must withstand a 40-inch free drop striking, in any position, a 6-inch diameter, vertical steel bar mounted perpendicular to an unyielding surface.



<u>Figure 1.1</u> ETR Container with Honeycomb Shock Absorber



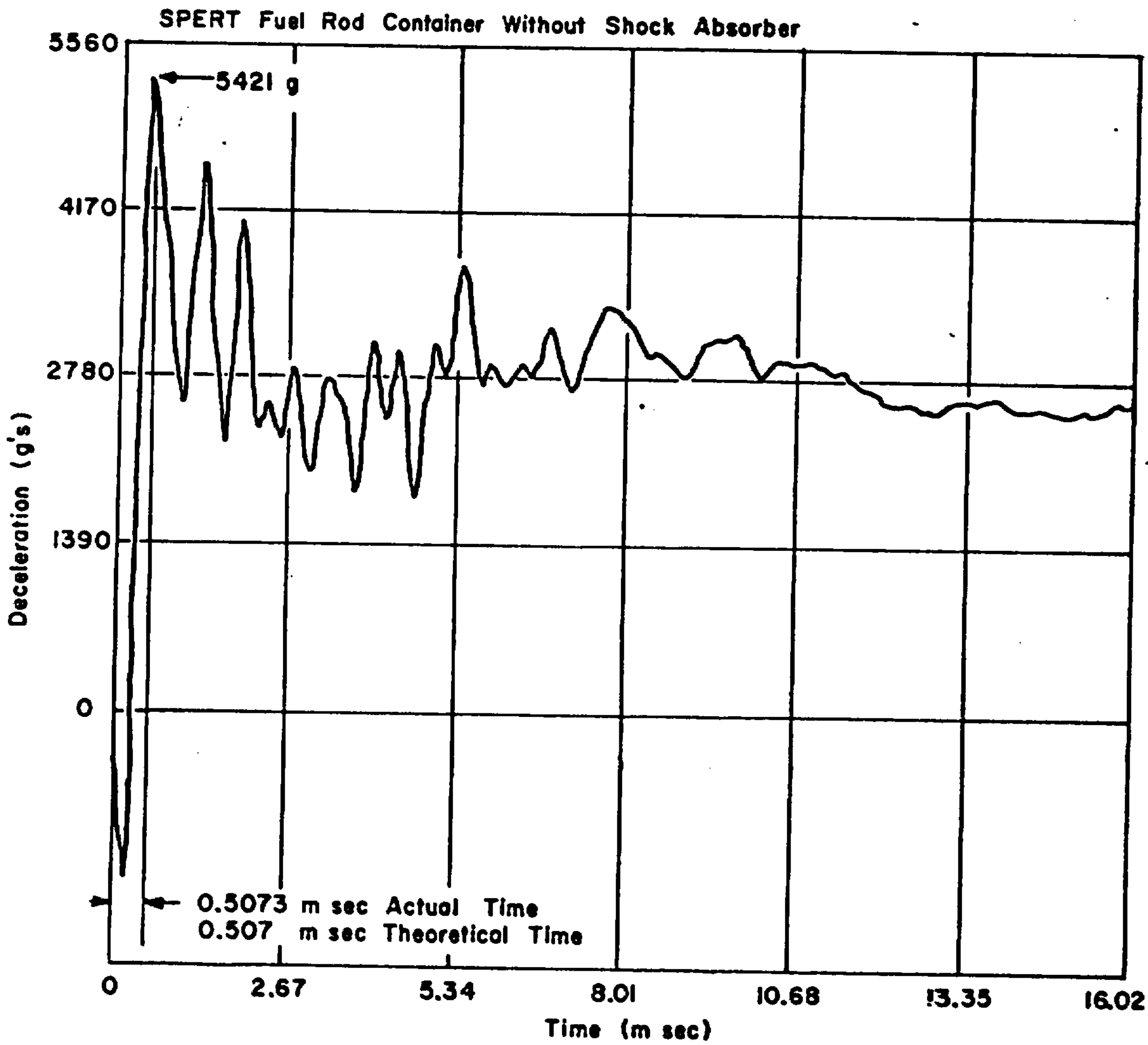


Figure 1.2 Accelerometer Traces - Vertical Axix

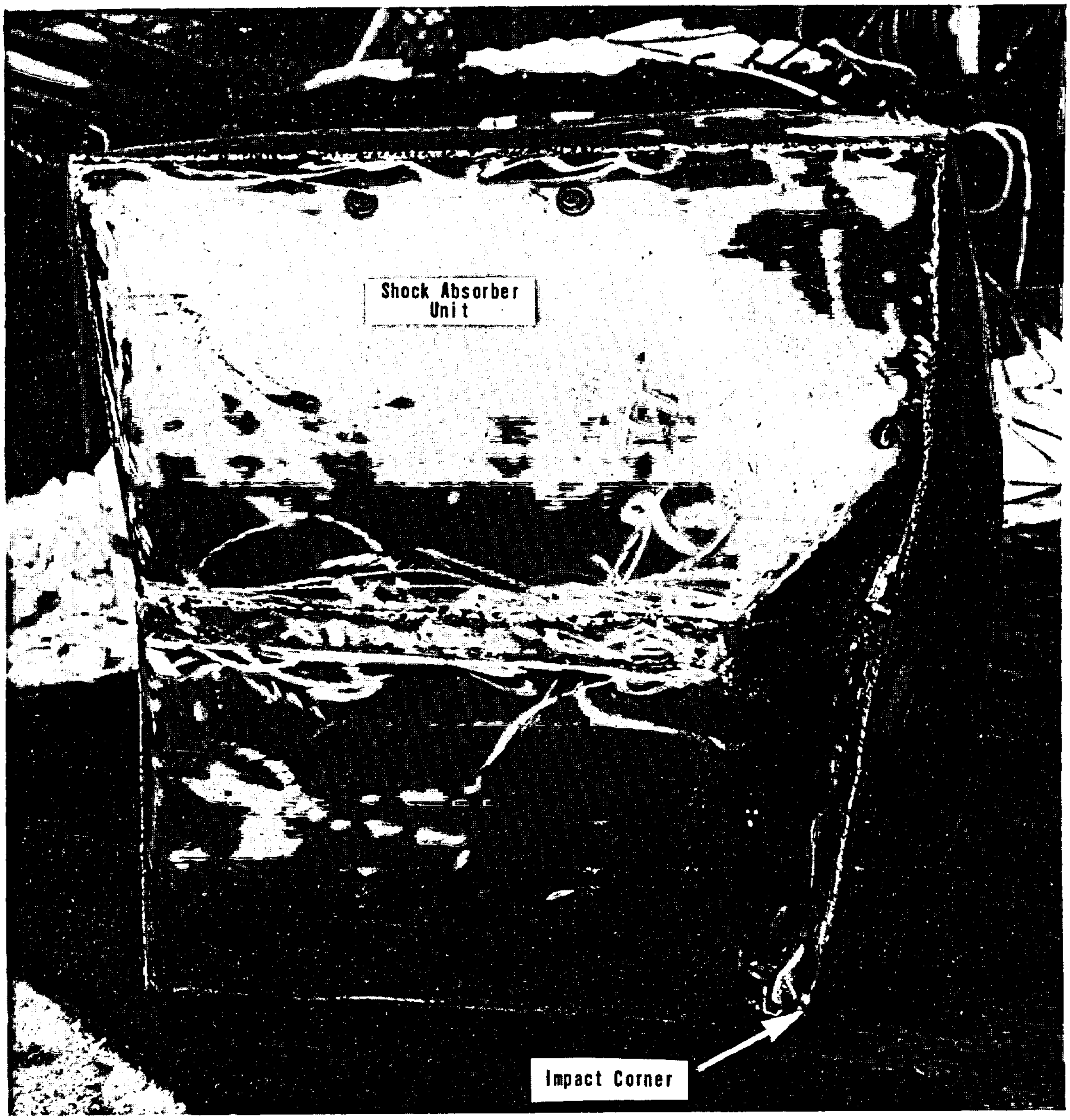


Figure 1.3 Damaged Honeycomb Shock Absorber

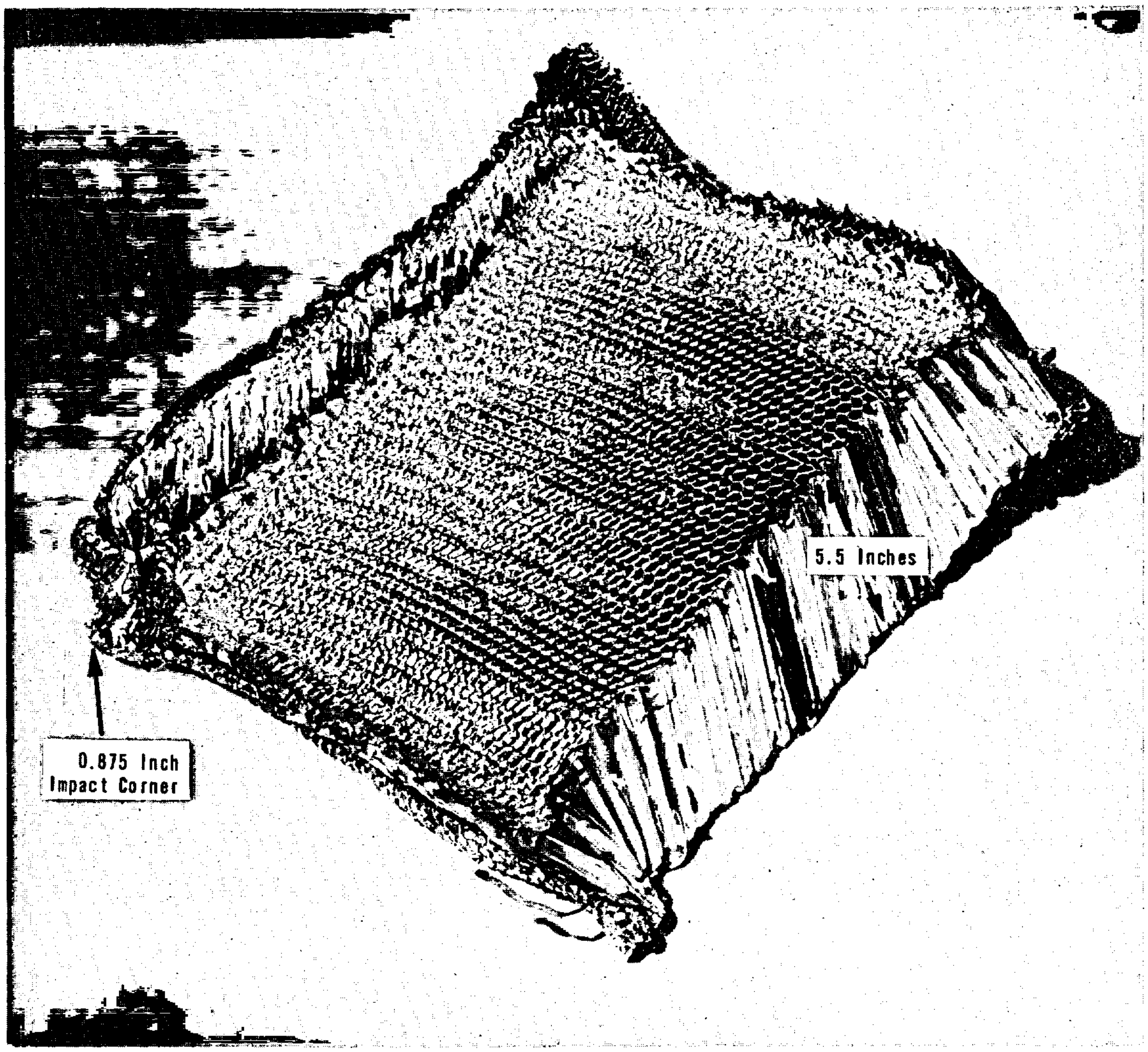


Figure 1.4 5.5 Inch Thick Honeycomb Panel After Impact

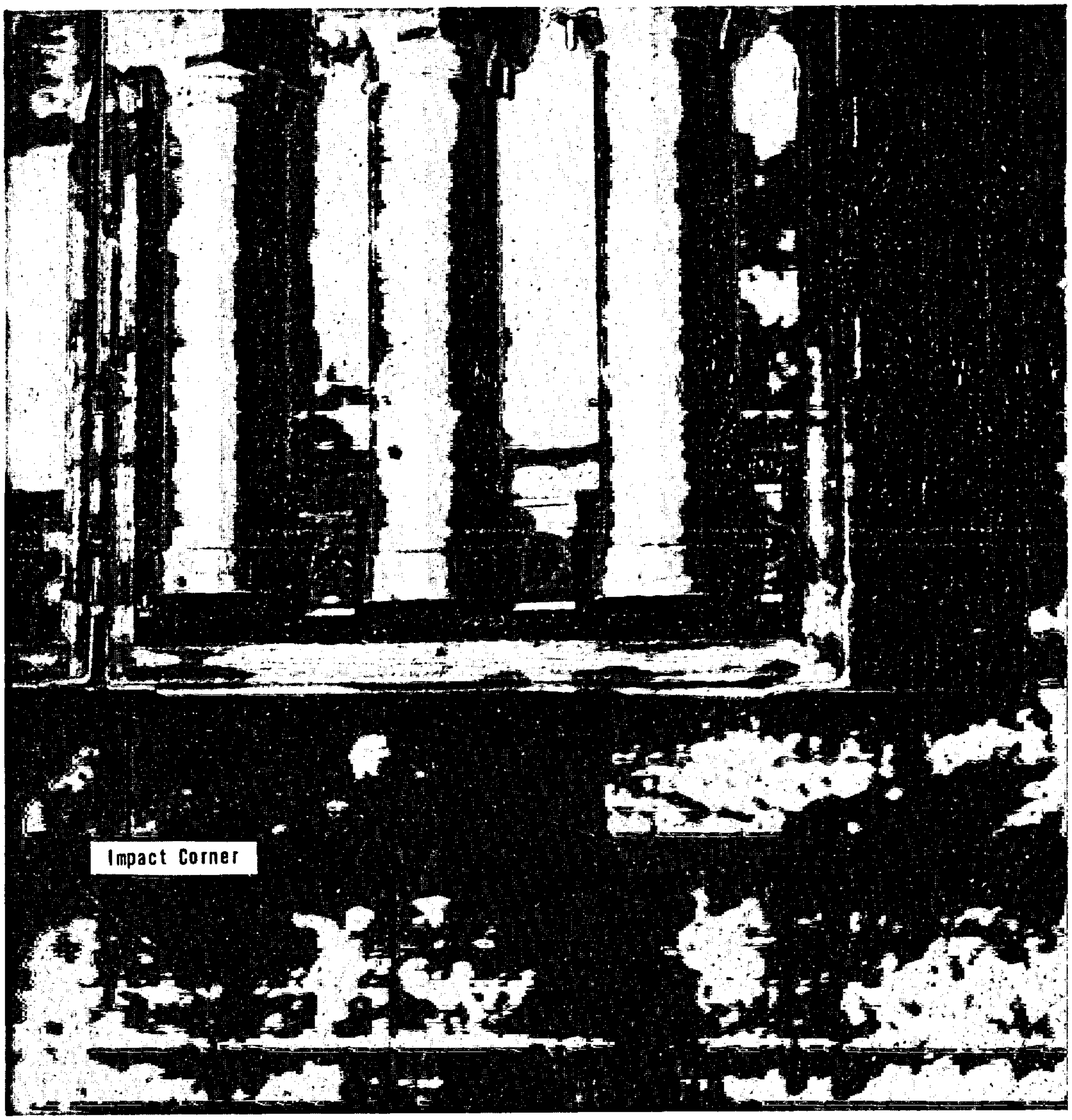


Figure 1.5 ETR Container After Drop Test with Honeycomb Shock Absorber

Two equivalent forty-inch free fall drop tests were conducted utilizing a SPERT inner container which, like the ATR inner container, is constructed of steel-covered plywood. This inner container was utilized because the upper plywood panel of the lid had been shattered transversely and would provide conditions for a severe test. The SPERT inner container was raised to a height which would simulate the kinetic energy that would be obtained from forty inches with the ATR container.

The container was dropped once on the undamaged lower side and then secondly on the damaged lid to note what additional damage would be incurred. Damage sustained to the container was not considered critical to the integrity of the structure. A 0.35-inch deep depression was made in the lower side (Figure 1.6), and a depression of less depth was made on the lid due to impact occurring on the name plate affixed there. Internal damage was noted to be a bending failure on both the lower side and lid members, and was indicated by a visible transverse crack in the wood. No splintering or crushing of wood was noted in the impact area. The lid member that had previously been damaged was slightly more cracked than the lower member and had experienced some separation of the panel laminations. The additional damage was attributed to the lack of support at the impact end of the container. Two of the tack welds holding the 18 gauge steel sheet to the side angles were broken on both the lower and upper sides of the container. This type of opening or rupture will not occur with the ATR container, since it is welded continuously over the full length of the sheet metal. The test verified the need of exterior steel sheeting to maintain container integrity.

1.7.3 Thermal

The thermal test for the hypothetical accident conditions is reported in Section 2.5. Experimental and analytical results show that the ATR shipping container will survive this test without compromising the ability of the container to withstand any of the other hypothetical accidents.

1.7.4 Water Immersion

The package must withstand immersion in water to the extent that all portions of the package are under at least three feet of water for a period of not less than eight hours.

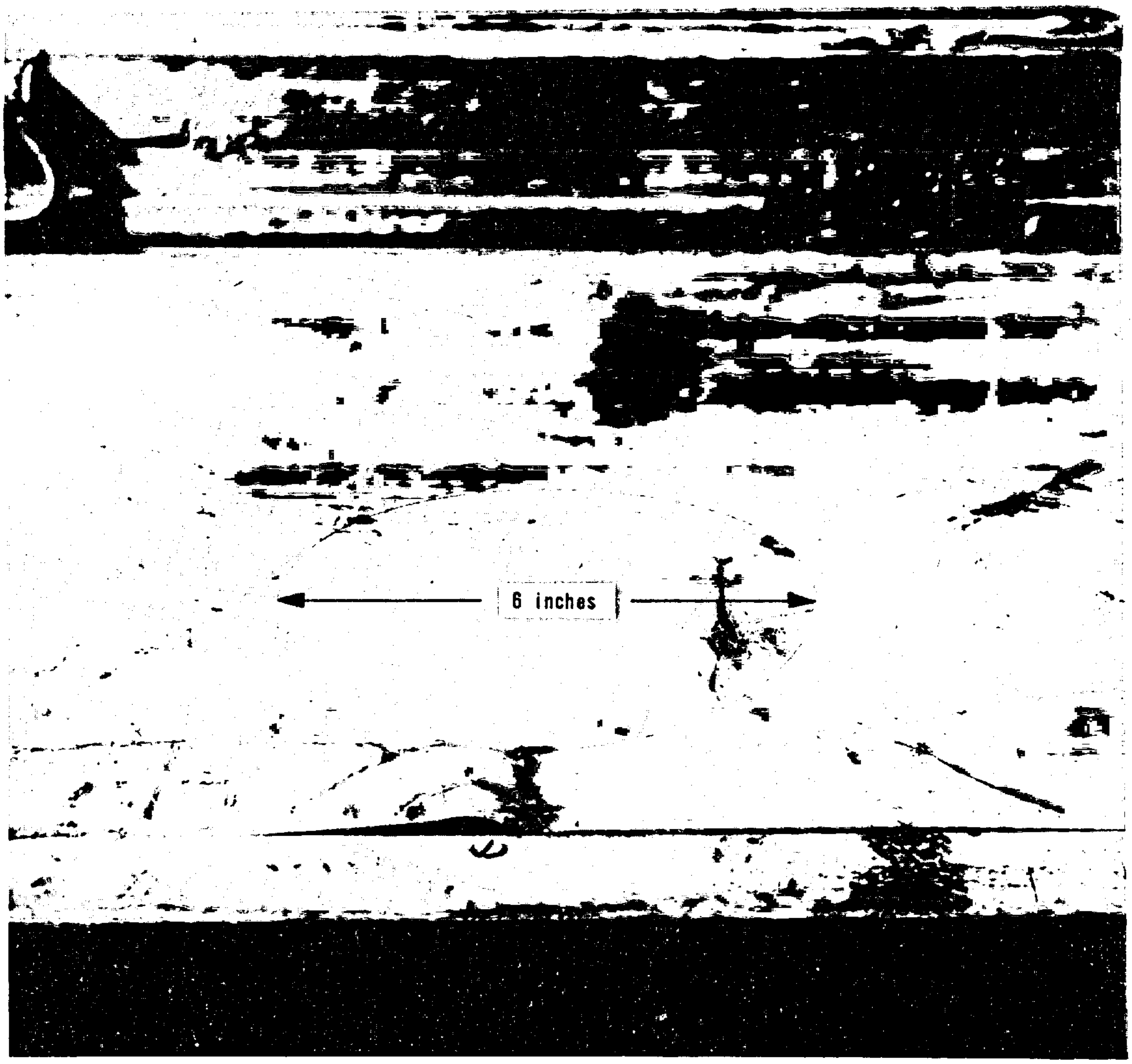


Figure 1.6 Damage to Bottom of SPERT Container

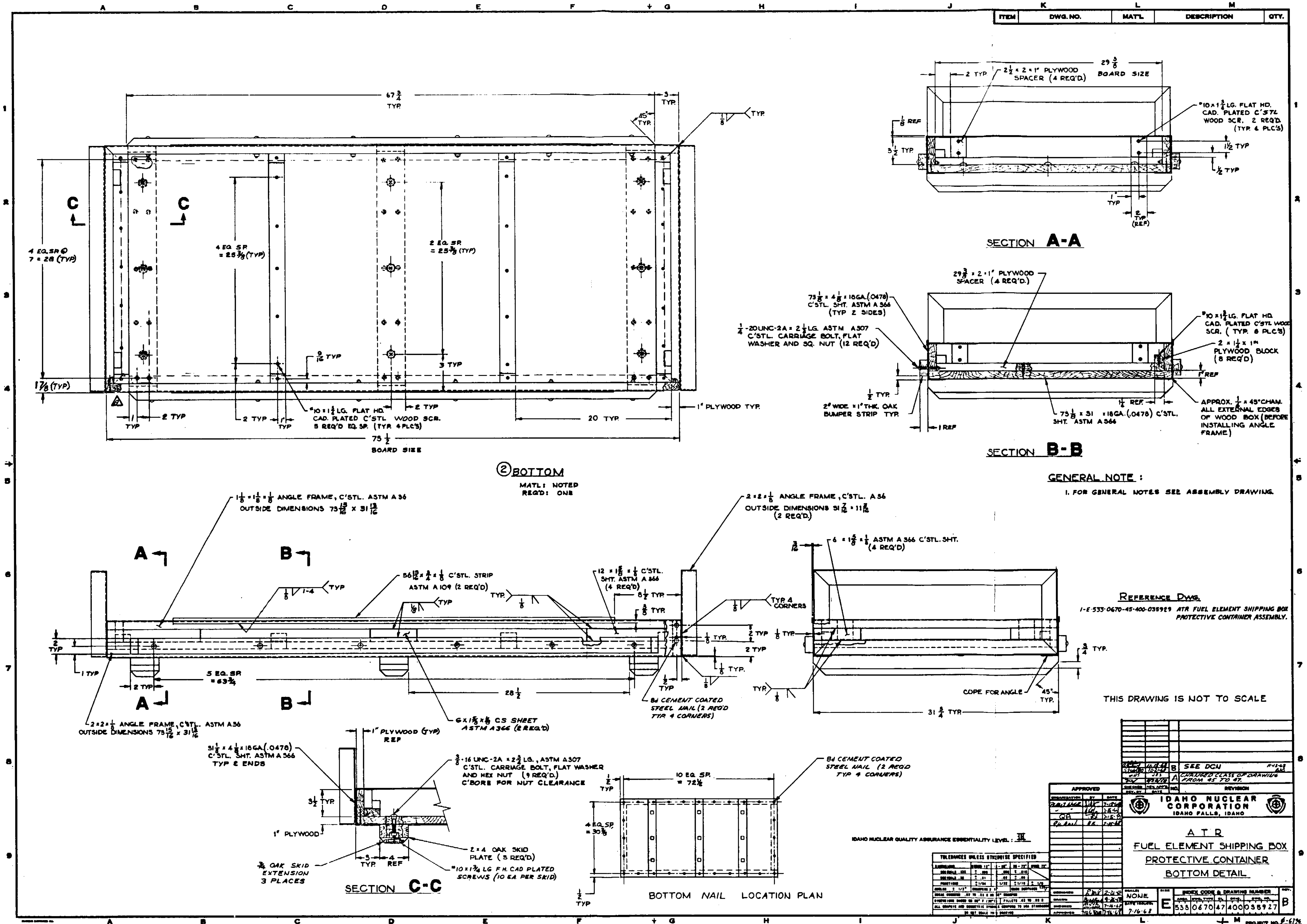
It is shown in Chapter 5.0 that an infinite array of ATR containers, loaded with the authorized contents in the most reactive fuel geometry and subjected to the most reactive water volume fraction, will pose no criticality problems. Since the drop, puncture, and fire tests do not alter the geometry of the storage compartment or melt the polyethylene and the cadmium, the final condition of water immersion will not cause criticality.

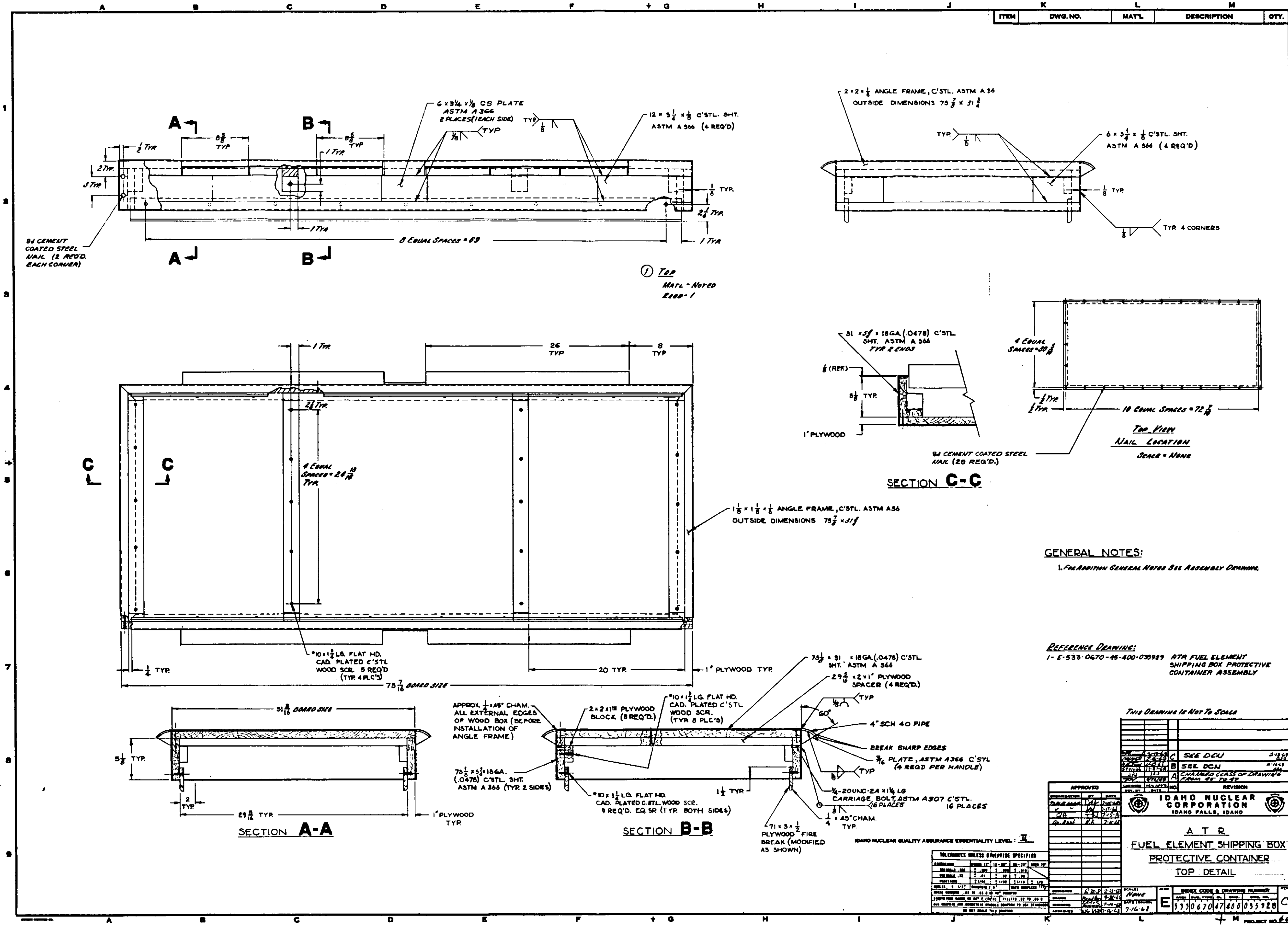
1.7.5 Summary and Conclusion

The hypothetical accident tests were not performed in sequence, however, it is noted that at the conclusion of the individual tests, no detrimental conditions existed which would have an effect on results of a sequential test.

The 30-foot free drop and puncture tests cause no damage to the inner container, slight deformation in the outer container, but no openings in the outer container. Therefore, thermal resistance, which has been shown to be adequate for the undamaged container, is not compromised. The final condition of water immersion poses no criticality problem, since the storage compartment and the cadmium remain intact (optimum moderation was assumed in the criticality analyses). It is concluded that the specified accident sequence will not cause criticality or decrease the calculated safety margin.

APPENDIX 1.8.1

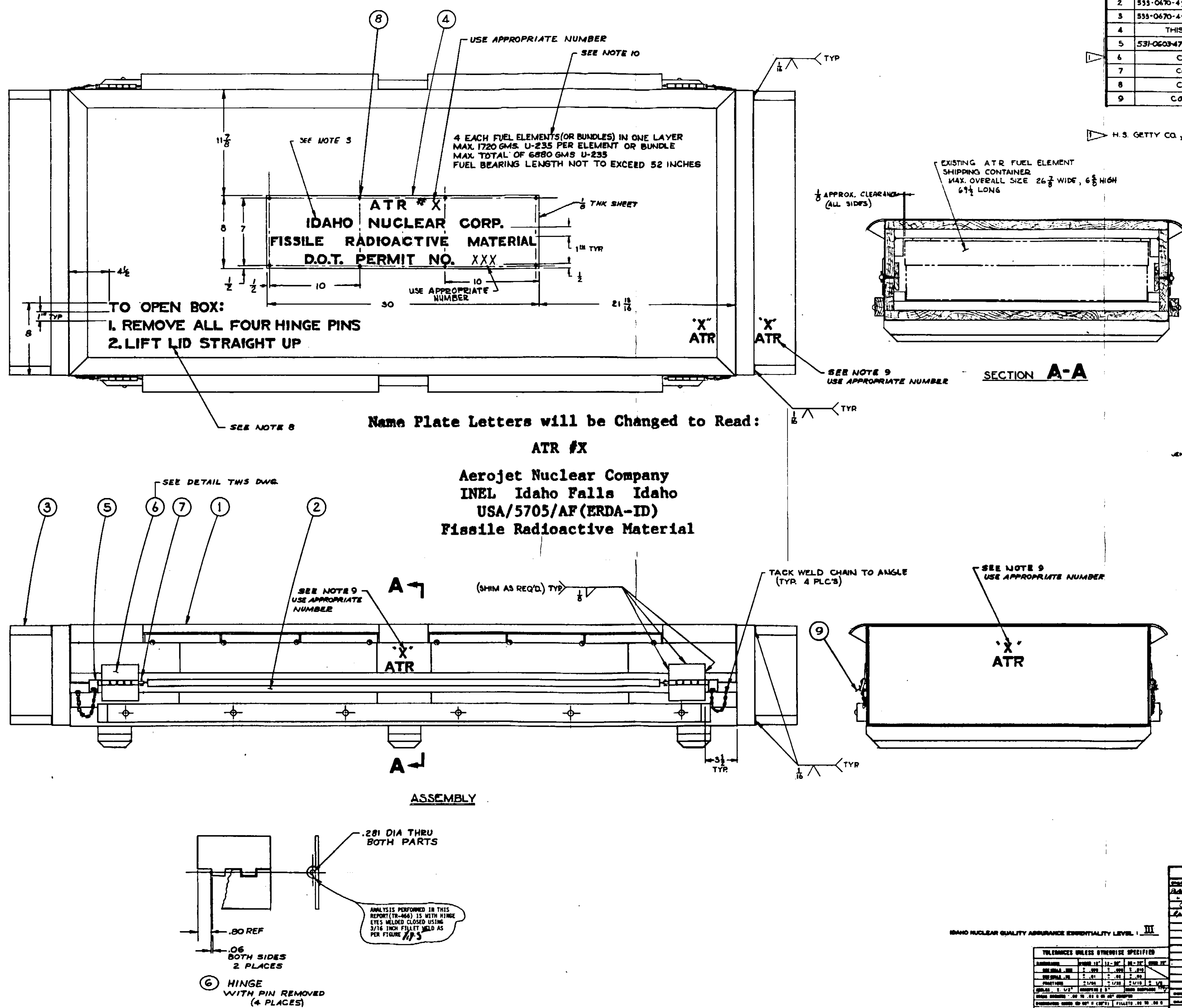

ITEM DWG. NO. MAT'L DESCRIPTION QTY.
SECTION A-A
SECTION B-B
GENERAL NOTE:
1. FOR GENERAL NOTES SEE ASSEMBLY DRAWING.
② BOTTOM
MATL: NOTED
REQ'D: ONE
REFERENCE DWG.
1-E-533-0670-45-400-038929 ATR FUEL ELEMENT SHIPPING BOX PROTECTIVE CONTAINER ASSEMBLY.
THIS DRAWING IS NOT TO SCALE
SECTION C-C
BOTTOM NAIL LOCATION PLAN
IDAHO NUCLEAR QUALITY ASSURANCE ESSENTIALITY LEVEL: III
IDAHO NUCLEAR CORPORATION
IDAHO FALLS, IDAHO
A T R
FUEL ELEMENT SHIPPING BOX
PROTECTIVE CONTAINER
BOTTOM DETAIL
B SEE DCN
A CHANGED CLASS OF DRAWING FROM 45 TO 47.
REVISION
APPROVED
TOLERANCES UNLESS OTHERWISE SPECIFIED
SCALE NONE
E 533 0670 47 400 038927 B



ITEM
DWG. NO.
MAT'L
DESCRIPTION
QTY.
6 x 3¼ x ⅛ CS PLATE ASTM A 366 2 PLACES (EACH SIDE)
12 x 3¼ x ⅛ C'STL. SHT. ASTM A 366 (4 REQ'D)
8d CEMENT COATED STEEL NAIL (2 REQ'D. EACH CORNER)
8 EQUAL SPACES = 69
① TOP
MAT'L - NOTED
REQD - 1
2 x 2 x ⅛ ANGLE FRAME, C'STL. ASTM A 36 OUTSIDE DIMENSIONS 75⅞ x 31¾
6 x 3¼ x ⅛ C'STL. SHT. ASTM A 366 (4 REQ'D)
TYP 4 CORNERS
31 x 5⅜ x 18GA.(.0478) C'STL SHT. ASTM A 366 TYP 2 ENDS
1" PLYWOOD
SECTION C-C
4 EQUAL SPACES = 30
18 EQUAL SPACES = 72
8d CEMENT COATED STEEL NAIL (28 REQ'D.)
TOP VIEW NAIL LOCATION
SCALE = NONE
1⅛ x 1⅛ x ⅛ ANGLE FRAME, C'STL. ASTM A36 OUTSIDE DIMENSIONS 75⅞ x 31⅞
#10 x 1¼ LG. FLAT HD. CAD. PLATED C'STL WOOD SCR. 5 REQ'D (TYP. 4 PLC'S)
20 TYP.
1" PLYWOOD TYP.
75 7/16 BOARD SIZE
31 5/16 BOARD SIZE
29 5/16 TYP.
1" PLYWOOD TYP.
SECTION A-A
APPROX. 1/16 x 45° CHAM. ALL EXTERNAL EDGES OF WOOD BOX (BEFORE INSTALLATION OF ANGLE FRAME)
2 x 2 x 1⅝ PLYWOOD BLOCK (8 REQ'D.)
#10 x 1¼ LG. FLAT HD. CAD. PLATED C'STL WOOD SCR. (TYP. 8 PLC'S)
75⅞ x 31 x 18GA.(.0478) C'STL SHT. ASTM A 366
29 3/16 x 2 x 1" PLYWOOD SPACER (4 REQ'D.)
4" SCH 40 PIPE
BREAK SHARP EDGES
3/16 PLATE, ASTM A366 C'STL (4 REQ'D PER HANDLE)
75½ x 5⅜ x 18GA. (.0478) C'STL. SHT. ASTM A 366 (TYP. 2 SIDES)
#10 x 1½ LG. FLAT HD. CAD. PLATED C.STL. WOOD SCR. 9 REQ'D. EQ. SP. (TYP. BOTH SIDES)
¼-20UNC-2A x 1¼ LG CARRIAGE BOLT, ASTM A307 C'STL. 16 PLACES
¼ x 45° CHAM. TYP.
71 x 3 x ½ PLYWOOD FIRE BREAK (MODIFIED AS SHOWN)
SECTION B-B
GENERAL NOTES:
1. FOR ADDITION GENERAL NOTES SEE ASSEMBLY DRAWING
REFERENCE DRAWING:
1 - E-533-0670-45-400-035929 ATR FUEL ELEMENT SHIPPING BOX PROTECTIVE CONTAINER ASSEMBLY
THIS DRAWING IS NOT TO SCALE
C SEE DCN
B SEE DCN
A CHANGED CLASS OF DRAWING FROM 45 TO 47
REVISION
APPROVED
IDAHO NUCLEAR CORPORATION
IDAHO FALLS, IDAHO
IDAHO NUCLEAR QUALITY ASSURANCE ESSENTIALITY LEVEL: III
A T R
FUEL ELEMENT SHIPPING BOX
PROTECTIVE CONTAINER
TOP DETAIL
SCALE: NONE
DATE ISSUED: 7-16-68
E 533 0670 47 400 035928 C

ITEM	DWG. NO.	MAT'L	DESCRIPTION	QTY.
1	533-0670-45-400-035928	—	TOP	1
2	533-0670-45-400-035927	—	BOTTOM	1
3	533-0670-45-400-035932	—	SHOCK ABSORBER	2
4	THIS DWG.	ASTM B 209 ALLOY 6061-T6 AL	NAME PLATE	1
5	531-060347-400-011951	C'STL.	HINGE PIN	4
6 (1)	COML.	C'STL.	HINGE, # 2501-E76-4 x 4 WITHOUT SCR. HOLES	4
7	COML.	C'STL.	$\frac{1}{16}$ DIA. COTTER PIN	4
8	COML.	C'STL.	#10 x 1" LG. FLT. HD. WOOD SCR.	8
9	COML.	C'STL	COTTER PIN-5/32 DIA x 3/4 LG.	9

(1) H. S. GETTY CO., PHILA., PA. (ORDER WITHOUT HOLES)



GENERAL NOTES

1. INTERPRET THIS DRAWING PER MIL-D-1000 FORM 2.
2. SPECIFICATION CALLOUTS ARE PER LATEST REVISION.
3. ENGRAVE 1" HIGH X 1/8" WIDE X .030 DEEP BLOCK LETTERING AS SHOWN AND FILL WITH BLACK EPOXY ENAMEL.
4. PRIME ALL EXTERIOR CARBON STL. SURFACES WITH ONE COAT. IRON OXIDE, FED. SPEC. TT-P-636. PRIME ALL EXTERIOR WOOD SURFACES WITH ONE COAT EXTERIOR, WOOD, PRIMER, FED. SPEC. TT-P-25. PAINT ALL EXTERIOR SURFACES 2 COATS OF FED. SPEC. NO. TT-E-529, GRAY SEMI GLOSS, FED. COLOR NO. 26251.
5. ALL WOOD JOINTS SHALL BE BONDED WITH ADHESIVE CASINE-TYPE, WATER RESISTANT, PER FED. SPEC. MMM-125.
6. WOOD SCREWS SHALL COMPLY WITH FED. SPEC. FF-S-111.
7. ALL PLYWOOD SHALL BE FIR, EXTERIOR, A-A GRADE AND FIRE RETARDANT TREATED PER MIL-L-19140.
8. PAINT LETTERS IN 1 HIGH CHARACTERS, USING SILK SCREEN PROCESS, WITH ONE COAT OF FED. SPEC. TT-E-[illegible] WHITE ENAMEL WITH YELLOW TINT G. S. A. CAT. NO. [illegible] YELLOW NO. 1.
9. PAINT LETTERS IN 1" HIGH CHARACTERS WITH ONE COAT OF FED. SPEC. TT-E-529 BLACK SEMI-GLOSS ENAMEL FED. COLOR NO. 17038.
10. STENCIL LETTERS IN 1/4" HIGH CHARACTERS, USING SILK SCREEN PROCESS, ONE COAT OF FED. SPEC. TT-E-529 , BLACK SEMI-GLOSS ENAMEL FED. COLOR NO. 1.038.

THIS DRAWING IS NOT TO SCALE

NO.	REVISION
C	SEE DCN
B	SEE DCN
A	CHANGED CLASS OF DRAWING FROM 45 TO 47.

IDAHO NUCLEAR QUALITY ASSURANCE ESSENTIALITY LEVEL : III

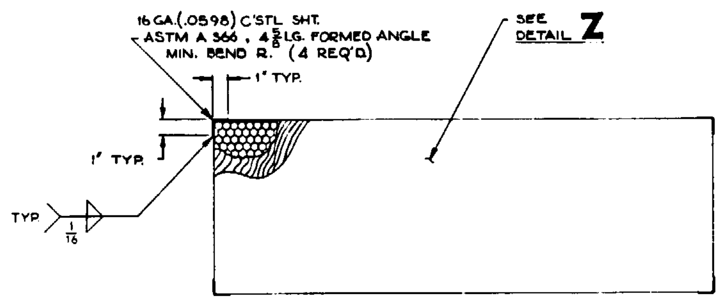
IDAHO NUCLEAR CORPORATION
IDAHO FALLS, IDAHO

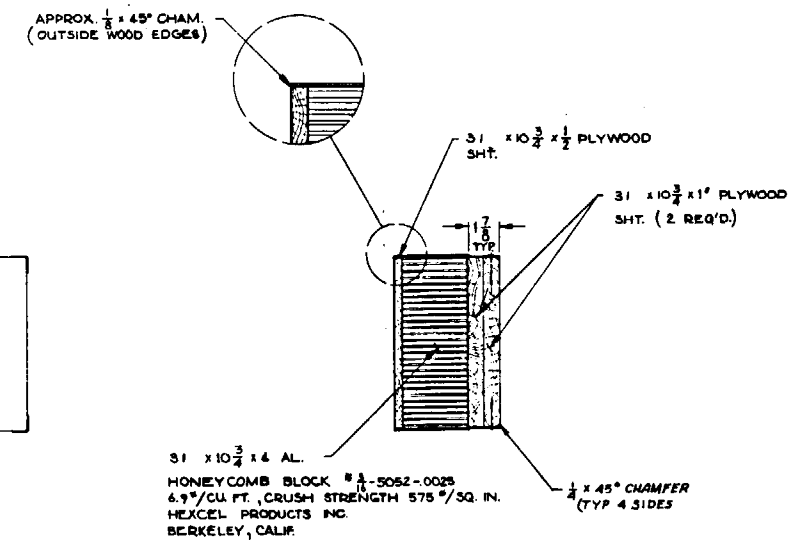
A T R
FUEL ELEMENT SHIPPING BOX
PROTECTIVE CONTAINER
ASSEMBLY

SCALE: NONE SIZE: E
INDEX CODE & DRAWING NUMBER: 533 0670 47 400 035929 REV. C

PROJECT NO. F-475

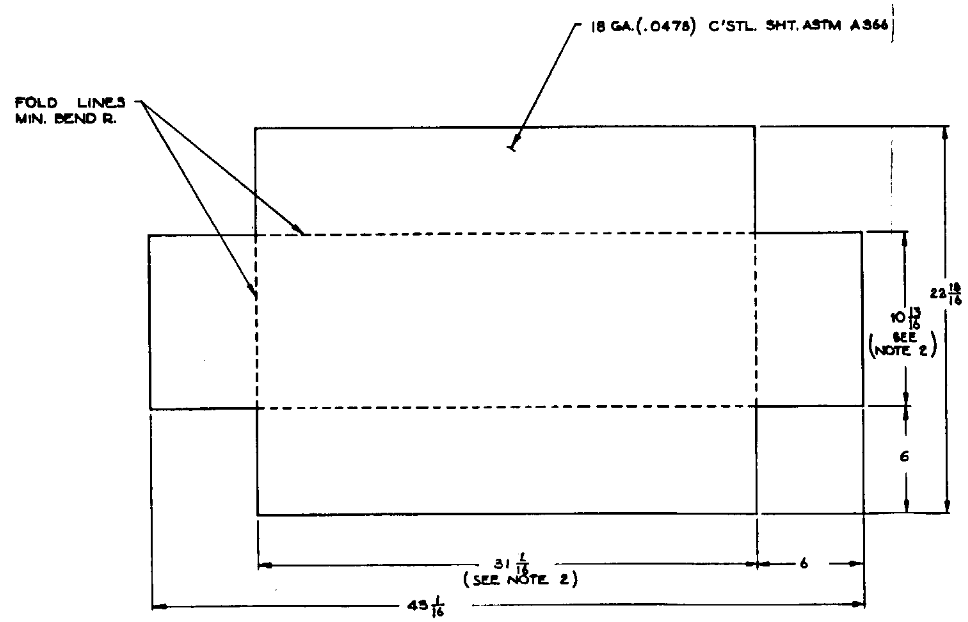
ITEM	DWG. NO.	MAT'L	DESCRIPTION	QTY.





③ SHOCK ABSORBER

MAT'L - NOTED
RE'QD - 2



DETAIL Z

BLANK DEVELOPMENT

GENERAL NOTES:

1. FOR ADDITIONAL NOTES SEE ASSEMBLY DRAWING.

2. DIMENSIONS TO BE INSIDE DIMENSION OF BOX AFTER BENDS.

REFERENCE DRAWINGS:

1-E-533-0670-45-400-035929 ATR FUEL ELEMENT SHIPPING BOX PROTECTIVE CONTAINER ASSEMBLY.

THIS DWG. IS NOT TO SCALE

REV. BY	DATE	NO.	REVISION
		A	CHANGED CLASS OF DRAWING FROM 45 TO 47

IDAHO NUCLEAR QUALITY ASSURANCE ESSENTIALITY LEVEL : II

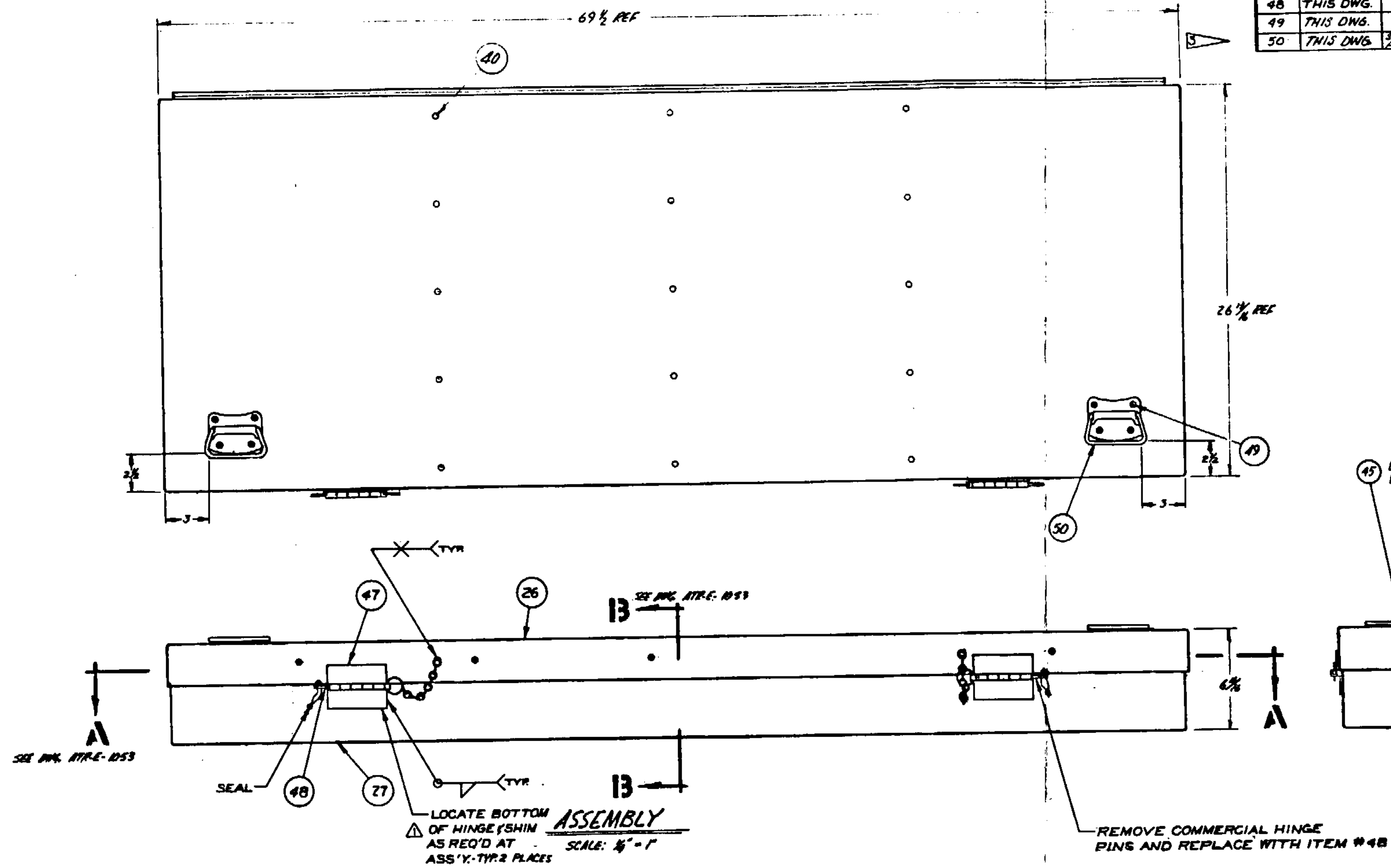
IDAHO NUCLEAR CORPORATION
IDAHO FALLS, IDAHO

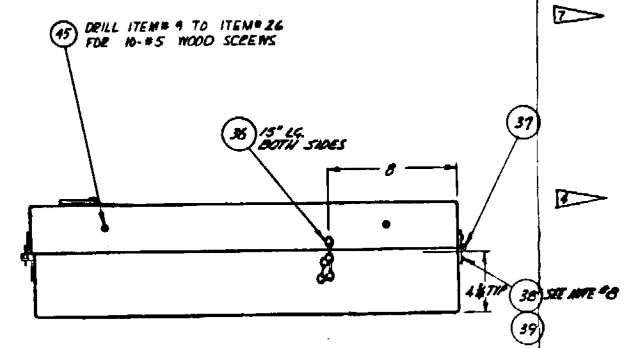
A T R
FUEL ELEMENT SHIPPING BOX
PROTECTIVE CONTAINER
SHOCK ABSORBER DETAIL

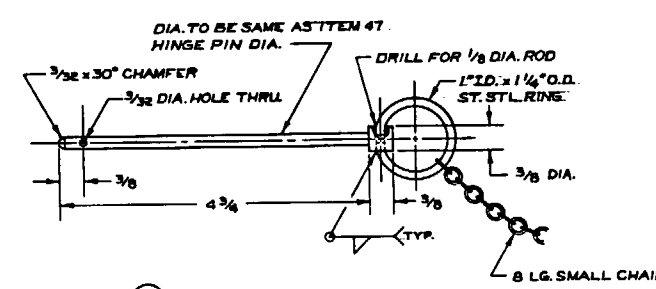
SCALE: NONE | SIZE: E | INDEX CODE & DRAWING NUMBER: 533 0670 47 400 085932 | REV. A

PROJECT NO. 6-6796

ITEM	DWG. NO.	MAT'L	DESCRIPTION	QTY.
46	REMOVED			
47	COMM.	STL.	3x4 FULL SURFACE HINGE HEAVY DUTY	2
48	THIS DWG.	STL.	HINGE PIN	2
49	THIS DWG.	STL.	#10 x 1" LG. F.H. BOLT W/NUT & WASHER	8
50	THIS DWG.	STL. ZINC PLATED	MODEL 1205, SIZE NO. 3½	2







48 HINGE PIN
MAT'L: 18-8 ST. STL.
No. REQ'D: 2
SCALE: 1" = 1"

ITEM	DWG. NO.	MAT'L	DESCRIPTION	QTY.
1	REMOVED			
2	ATR-E-1054	¾" FIR PLYWD.	BOTTOM STIFFENER	1
3	ATR-E-1054		END STIFFENER - BOTTOM	2
4	ATR-E-1054	¾" FIR PLYWD	END STIFFENER - LID	2
5	ATR-E-1054	FIR	BLOCK	2
6	ATR-E-1055	¾" FIR PLYWD.	TOP STIFFENER	1
7	ATR-E-1055		SIDE STIFFENER - BOTTOM	1
8	ATR-E-1055		" " "	1
9	ATR-E-1055		" " - LID	1
10	ATR-E-1055	¾" FIR PLYWD	" " "	1
11	REMOVED			
12	ATR-E-1056	FIR	SPACER	3
13	ATR-E-1056	FIR	"	2
14	ATR-E-1056	½" FIR PLYWD	MIDDLE SPACER	3
15	ATR-E-1056	½" FIR PLYWD	OUTSIDE SPACER	2
16	ATR-E-1056	HIGH DENSITY POLYETHYLENE	POLYETHYLENE SPACER - TOP	1
17	ATR-E-1056	HIGH DENSITY POLYETHYLENE	" " - BOTTOM	1
18	ATR-E-1056	.020 THK. CADMIUM	CADMIUM SHEET - TOP	1
19	ATR-E-1066		" " - BOTTOM	1
20	ATR-E-1056	.020 THK. CADMIUM	" " - SIDE	2
21	ATR-E-1057	SPONGE RUBBER	CUSHION	3
22	ATR-E-1057	SPONGE RUBBER	"	2
23	ATR-E-1057	RUBBER	"	2
24	ATR-E-1057	SPONGE RUBBER	"	8
25	REMOVED			
26	ATR-E-1057	16 GA. STL.	STEEL LID	1
27	ATR-E-1058	16 GA. STL.	STEEL BOX	1
28	ATR-E-1058	RUBBER	CUSHION	8
29	REMOVED			
30	REMOVED			
31	REMOVED			
32	REMOVED			
33	REMOVED			
34	REMOVED			
35	REMOVED			
36	COMM.	STL.	CHAIN - #6 TWIST LINK MACHINE	2
37	COMM.	STL.	CONTINUOUS HINGE	1
38	COMM.	STL.	#5 R.H. SCREW	32
39	COMM.	STL.	#5 x 1" LG. R.H. BOLT W/NUT & WASHER	34
40	COMM.	STL.	#10 x 2" LG. F.H. BOLT W/NUT & WASHER	16
41	COMM.	STL.	¼ DIA. x 5¾ LG. CARR. BOLT	5
42	COMM.	STL.	¼ DIA. x 2¾ LG. CARR. BOLT	10
43	COMM.	STL.	#6 x ½ LG. SELF TAPPING SCREW-BINDING HD.	18
44	COMM	STL.	1/4" x 4 1/2" LG. FL. HD. BOLT W/NUT & WASHER	10
45	COMM	STL.	#5 x ¾" LG. FL. HD. WOOD SCREW	10

3 CHEST HANDLE - STANLEY HARDWARE, DIVISION OF STANLEY WORKS, 77 LAKE ST., NEW BRITAIN, CT

4 HINGE - McMASTER-CARR, CAT. NO. 64, P. 417, PART NO. M1F4, SIZE 2. PLAIN STL. OR EQUAL.

5 PLYWOOD - EDWARDS CO. INC. WOOD PRESERVING DIVISION 35 NEW MONTGOMERY ST., SAN FRANCISCO 5, CALIF., ATTENTION MR. E.L. CLEMMAN. 3/4" - 5 PLY - FIR PLYWOOD (NON-COMB.)

6 SPONGE RUBBER - ASTM D-1056-59T RO-10-CF ANY SOURCE

7 RUBBER - ATLANTIC INDIA RUBBER WORKS, INC. - 571 WEST POLK ST., CHICAGO 7, ILLINOIS, CLOSED CELLULAR RUBBER ½" THK.

GENERAL NOTES:

1. POLYETHYLENE TO BE COVERED ON ALL INTERIOR SURFACES WITH .020 THK. CADMIUM SHEET.
2. PRIME AND PAINT 2 COATS OF GRAY RUST-OLEUM (BOX EXTERIOR)
3. ALL RUBBER AND CADMIUM SHEET TO BE GLUED IN PLACE WITH 3M SUPER ADHESIVE (DO NOT SUBSTITUTE).
4. POLYETHYLENE TO BE HIGH DENSITY 0.95 GM/CC MIN.
5. RUBBER CUSHION ITEMS NUMBERED 21, 22, & 24 TO BE AIR FOAM TYPE RUBBER. ITEMS 23, 28 TO BE CLOSED CELLULAR RUBBER.
6. REMOVED
7. ALL ¾"-5 PLY-PLYWOOD IS TO BE NON-COMB. FIRE PROTECTED PLYWOOD WHICH CARRIES A UNDERWRITERS LABORATORIES INC. APPROVAL. ISSUE NO. G-101 FIRE HAZARD CLASSIFICATION - SEE 5
8. THE CONTINUOUS HINGE IS TO BE SECURED TO LID AND BOX BY ALTERNATING BOLTS (ITEMS #39) AND SCREWS (ITEM #38).
9. REMOVED
10. PAINT IN 1" HIGH LETTERS IN CENTER OF TOP "ATR X" USING APPROPRIATE BOX NUMBER.

REFERENCE DWGS:

ATR-E-1053 ATR FUEL ELEMENT SHIPPING CONTAINER SECTIONS.

INDEX CODE				
AREA	DWG. TYPE	CL.	GRL.	SERIAL
533	0670	47	706	035053

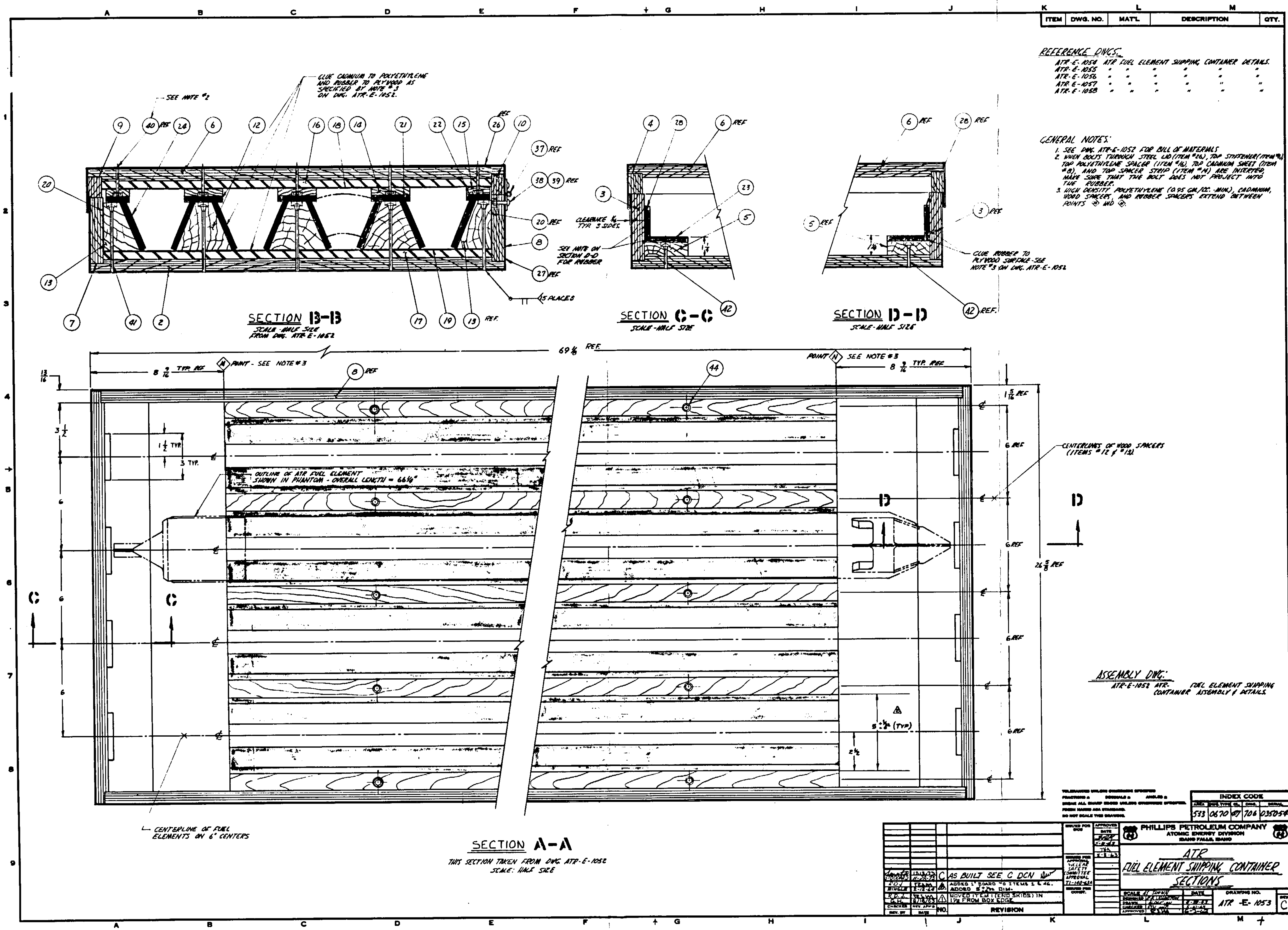
REV. BY	DATE	NO.	REVISION
	11-27-73	C	AS BUILT SEE C DCN
RDJ	3-13-64	B	ADDED 1" BOARD TO ITEMS 1 & 46
G.H.	8/16/63	1	ADDED ITEM #47 AND SHORTENED ITEM # 25 - RELOCATED ITEM #1
			RELOCATED ITEM #31, 16 7/8 WAS 12 7/8 ADDED B.E. PERMIT No. TO BOX & NOTE #9

ISSUED FOR APPROVAL NUCLEAR SAFETY COMMITTEE APPROVAL TI-190-63A

PHILLIPS PETROLEUM COMPANY
ATOMIC ENERGY DIVISION
IDAHO FALLS, IDAHO

ATR
FUEL ELEMENT SHIPPING CONTAINER
ASSEMBLY & DETAILS

SCALE AS SHOWN
DRAWING NO. ATR-E-1052
REV. C


REFERENCE DWGS.
ATR-E-1054 ATR FUEL ELEMENT SHIPPING CONTAINER DETAILS.
ATR-E-1055 " " " " " "
ATR-E-1056 " " " " " "
ATR-E-1057 " " " " " "
ATR-E-1058 " " " " " "
GENERAL NOTES:
1. SEE DWG. ATR-E-1052 FOR BILL OF MATERIALS
2. WHEN BOLTS THROUGH STEEL LID (ITEM #26), TOP STIFFENER (ITEM #), TOP POLYETHYLENE SPACER (ITEM #16), TOP CADMIUM SHEET (ITEM #8), AND TOP SPACER STRIP (ITEM #14) ARE INSERTED, MAKE SURE THAT THE BOLT DOES NOT PROJECT INTO THE RUBBER.
3. HIGH DENSITY POLYETHYLENE (0.95 GM/CC. MIN.), CADMIUM, WOOD SPACERS, AND RUBBER SPACERS EXTEND BETWEEN POINTS Ⓜ AND Ⓝ.
GLUE CADMIUM TO POLYETHYLENE AND RUBBER TO PLYWOOD AS SPECIFIED BY NOTE #3 ON DWG. ATR-E-1052.
SEE NOTE #2
15 PLACES
SECTION B-B
SCALE - HALF SIZE
FROM DWG. ATR-E-1052
CLEARANCE 1/8 TYP. 3 SIDES
SEE NOTE ON SECTION D-D FOR RUBBER
SECTION C-C
SCALE - HALF SIZE
GLUE RUBBER TO PLYWOOD SURFACE - SEE NOTE #3 ON DWG. ATR-E-1052
SECTION D-D
SCALE - HALF SIZE
69 1/8 REF.
POINT Ⓜ - SEE NOTE #3
POINT Ⓝ SEE NOTE #3
8 9/16 TYP. REF.
OUTLINE OF ATR FUEL ELEMENT SHOWN IN PHANTOM - OVERALL LENGTH = 66 1/4"
CENTERLINES OF WOOD SPACERS (ITEMS #12 & #13)
26 5/8 REF
5 1/2 (TYP)
CENTERLINE OF FUEL ELEMENTS ON 6" CENTERS
SECTION A-A
THIS SECTION TAKEN FROM DWG. ATR-E-1052
SCALE: HALF SIZE
ASSEMBLY DWG.
ATR-E-1052 ATR FUEL ELEMENT SHIPPING CONTAINER ASSEMBLY & DETAILS.
C AS BUILT SEE C DCN
ADDED 1" BOARD TO ITEMS 2 & 46. ADDED 5 1/2 DIM.
MOVED ITEM 1 (END SKIDS) IN 1 1/2 FROM BOX EDGE
REVISION
INDEX CODE
533 0670 07 706 035054
PHILLIPS PETROLEUM COMPANY
ATOMIC ENERGY DIVISION
IDAHO FALLS, IDAHO
ATR
FUEL ELEMENT SHIPPING CONTAINER
SECTIONS
ATR-E-1053 C

APPENDIX 1.8.2

Impact Calculations for ATR Protective Container

by

D. A. Tobias

March 1968

BY D. ICBAS DATE .... SUBJECT ETR - MTR - ATR FUEL ELEMENT PROTECTIVE PACKAGES SHEET NO. 24 OF 40

CHKD. BY ...... DATE .... JOB NO. PE62-39-IRA

INASMUCH AS THE ATR FUEL ELEMENT PACKAGE HAS THE GREATEST WEIGHT, A SUITABLE ABSORBER MATERIAL WILL BE SELECTED FOR IT AND THE REMAINING PACKAGES. COST IS CONSIDERABLY REDUCED THROUGH QUANTITY.

$W_{ATR} = 853$ lb $\qquad N = 43.935$ ft/sec

$\qquad g = 32.17$ ft/sec^2

$m = W/g = 853/32.17 = 26.515$ lb sec^2/ft

$KE = \frac{1}{2} m N^2 = (.5)(26.515)(43.935)^2$

$KE = (13.2575)(1930.289) = \underline{25587.35 \text{ ft-lb}}$

$A = (31.25)(11) = \underline{343.75 \text{ in}^2}$

ASSUME F_{CR} = $\underline{575 \text{ lb/in}^2 - 3/16 - 5052 - .0025 \quad 6.9 \text{ lb/ft}^3}$

$\underline{\text{NO FACING MATERIAL}}$

$KE = F_{CR} A S$

$$S = \frac{KE}{F_{CR} A} = \frac{25.58735 \times 10^3}{(575)(3.4375 \times 10^2)} = \frac{25.58735 \times 10^3}{19.7656 \times 10^4}$$

$S = .1294$ ft $= 1.553$ inches

MATERIAL HAS A 70% STROKE EFFICIENCY

$\therefore t_c = 1.553/.7 = $ __2.218 inches MINIMUM THICKNESS FOR DIRECT IMPACT__

@ $\angle 45°$ $t_c = 2.218/.70 = 3.169$ inches $\qquad$ .7% STRENGTH @ $\angle 45°$

ASSUME 20% t FOR OVERTRAVEL

$t = 3.169 + .634 = $ __3.803 MINIMUM THICKNESS FOR $\angle 45°$ IMPACT__

DH

LET $t = 4.0$ inches FOR ATR FUEL ELEMENT PACKAGE ABSORBER.

KE = WGS

$G = KE/WS = 25.5873 \times 10^3 / (853)(.1294) = \underline{231.8\ g's}$ AVERAGE

$G_{PEAK} = g_{AVE} + 20\% \cdot g_{AVE} = 231.8 + 46.4 = \underline{278.2\ g's}$

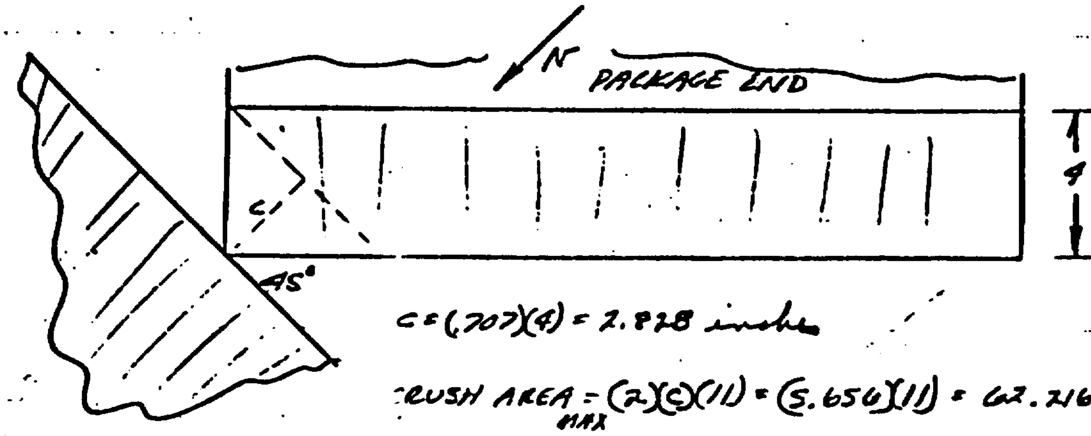
PEAK CRUSHING g LEVEL WILL APPROXIMATE 280 g's FROM HONEYCOMB. G LEVEL WILL BE SLIGHTLY HIGHER DUE TO STIFFNESS OF SHOCK ABSORBER COVER. TO PREVENT HIGH POINT LOADING ON THE END OF PACKAGE, SUCH AS A 40 inch DROP ON A 6" DIA PROJECTION, INSTALL A 1/2 inch PLYWOOD PLATE ON END OF ABSORBER. THE PLATE WILL DISTRIBUTE THE LOAD TO THE ABSORBER MORE EVENLY.

THE PACKAGE IS PROTECTED ADEQUATELY FOR DIRECT END IMPACTS ON A FLAT SURFACE OR ROUND PROJECTION.

INVESTIGATE PACKAGE ABSORBER REQUIREMENTS TO ABSORB KINETIC ENERGY IF PACKAGE EDGE LANDS ON A HARD SURFACE. THE END PLATE IS REQUIRED IN THIS ATTITUDE, AS WILL BE SHOWN IN THE FOLLOWING SKETCH AND SUBSEQUENT CALCULATIONS.
CONSIDER END WITHOUT PLATE ON ABSORBER TO ILLUSTRATE THE EFFECTIVENESS OF THE END PLATE.

OAR.

BY D. TOBIAS DATE ______ SUBJECT ETR - MTR - ATR SHEET NO. 26 OF 40
CHKD. BY ______ DATE ______ FUEL ELEMENT PROTECTIVE PACKAGES JOB NO. DE 67-39-TEA



$c = (.707)(4) = 2.828$ inches

CRUSH AREA$_{MAX}$ = $(2)(c)(11) = (5.656)(11) = 62.216$ in^2

AVERAGE AREA = 31.108 in^2

FOR DIRECT END IMPACT, 2.218 inches IS MINIMUM t REQUIRED TO STOP LOAD @ A CERTAIN G LEVEL.

$V = (343.75)(2.218) = 762.437$ in^3 VOLUME OF MATERIAL REQUIRED TO STOP LOAD

$V_\Delta = \frac{1}{2} b h w$ $\quad w = 11$ inches

$b = h$

$\therefore V_\Delta = \frac{1}{2} b^2 w$

MATERIAL HAS 70% STRENGTH @ 45° TO PLANE OF TUBE

$\therefore .7 V_\Delta = \frac{1}{2} b^2 w$ REQUIRED FOR LOAD @ 45°

$V'_\Delta = 762.437/.7 = 1089.19$ in^3

$V'_\Delta = \frac{1}{2} b^2 w$

DW

$$\therefore \; t = \sqrt{\frac{2V_a'}{w}} = \sqrt{\frac{(2)(1089.19)}{(11)}} = \sqrt{\frac{2178.39}{11}}$$

$t =$ 14.07 inches MINIMUM t REQUIRED TO STOP LOAD @ ∠45° WITHOUT END PLATE

THIS THICKNESS WOULD BE PROHIBITIVE IN COST TO INSTALL ON ALL CONTAINER PACKAGES. IN ADDITION, THE CONTAINER PACKAGES CANNOT BE MINIMAL SIZE IF ABSORBER MATERIAL IS INSTALLED ON SIDE AREAS.

INVESTIGATE EFFECT ON PACKAGE IF DROPPED @ ∠45° ON 1 inches OF ABSORBER.

$$KE = F_{cr} A S$$

$$KE = (575)(62.216)(1.414/12)$$

$$KE = (35.774 \times 10^3)(.1178) = 4{,}215.5 \text{ ft-lb}$$

ENERGY ABSORBED.

$$KE_{RESIDUAL} = 25{,}587.35 - 4{,}215.5 = 21{,}371.85 \text{ ft-lb}$$

RESIDUAL ENERGY

ABSORBER IS 16.48% EFFECTIVE AT THIS IMPACT ANGLE.

$$F = mv/t$$

VELOCITY HAS BEEN REDUCED AND MUST BE RECALCULATED

$$KE = F_{cr} A S = WGS$$

DJ

$G = KE / WS$

$G = 4215.5 / (853)(.1178) = \dfrac{42.155 \times 10^2}{10.048 \times 10^1}$

$G = 41.95$ g's

$G = a/g$

$\therefore a = Gg = (41.95)(32.17) = \underline{1349.53}$ ft/sec²

$V^2 - V_0^2 = 2as$ $\qquad V_0 = 43.935$ ft/sec

$2as = (2)(1349.53)(.1178) = 317.968$ ft²/sec²

$V^2 = V_0^2 - 2as = 1930.284 - 317.968$

$V = \sqrt{1612.316} = \underline{40.15 \text{ ft/sec}}$ VELOCITY OF PACKAGE @ IMPACT

CALCULATE PRIMARY STRESS WAVE INTERVAL

$V = 19.899 \times 10^4$ in/sec

$t = 2L/V = (2)(78) / 19.899 \times 10^4$

$\underline{t = .784 \times 10^{-3} \text{ sec}}$ THEORETICAL TIME FOR WAVE REFLECTION

$Ft = mV$

$F = mV/t = \dfrac{(26.515)(40.15)}{7.84 \times 10^{-4}}$

$F = 106458 \times 10^2 / 7.84 \times 10^{-4} = \underline{1.3578 \times 10^6 \text{ lb}}$

OK

$F = W/g\, a$ $\qquad \frac{a}{g} = G$

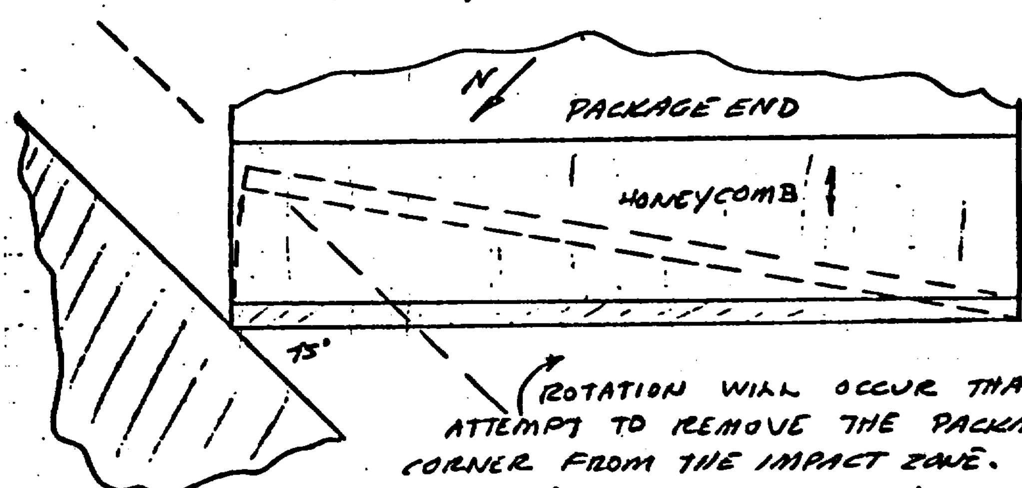
$F = W G$

$G = F/W = 13.578 \times 10^5 / 8.53 \times 10^2$

$G = 1591.7$ g's AVERAGE FORCE LEVEL

$G_{PEAK} = (1592)(2) = \underline{3184 \text{ g's PEAK FORCE LEVEL}}$
PROBABLE @ 195° IMPACT

AS CALCULATED, THIS SHOCK LEVEL IS QUITE HIGH AND WOULD CAUSE CONSIDERABLE DAMAGE TO THE PACKAGE. THE END PLATE INSTALLED ON THE EXTERIOR OF THE ABSORBER WILL CAUSE PROPER ATTENUATION OF THE SHOCK IMPULSE AS SHOWN BELOW:



ROTATION WILL OCCUR THAT WILL ATTEMPT TO REMOVE THE PACKAGE CORNER FROM THE IMPACT ZONE.

WHETHER A 45° IMPACT OCCURS ON A CORNER OR EDGE, HALF OF THE HONEYCOMB ABSORBER WILL BE CRUSHED IN A DIRECTION ⊥ TO THE CELL WALLS.

$V = \frac{1}{2} t A$, COMPRESSION STROKE = 2.8 inches

DH

BY D. TOBIAS DATE .... SUBJECT ETR - MTR - ATR FUEL ELEMENT PROTECTIVE PACKAGES SHEET NO. 30 OF 40

CHKD. BY ...... DATE .... JOB NO. BC-67-39-TRA

$V = \frac{1}{2} t \ell w = (.5)(2.8)(31.25)(11)$

$V = 481.25$ inches^3

$t = V/A = 481.25/343.75 =$ 1.4 inches AVERAGE CRUSH DISTANCE S

$S = 1.4/12 = .11666$ ft

$KE = F_{cr} A S$

$KE = (575)(343.75)(.11666)$

$KE = (19.765 \times 10^4)(1.1666 \times 10^{-1}) =$ 23,059 ft-lbs OF ENERGY ABSORBED

$KE_{RESIDUAL} = 25{,}587 - 23{,}059 =$ 2,528 ft-lbs OF RESIDUAL ENERGY

THIS RESIDUAL ENERGY REPRESENTS A DROP FROM A HEIGHT OF 2.96 ft (35.5 inches), WHICH THE PACKAGE CAN EASILY WITHSTAND.

ABSORBER IS 90.12 % EFFECTIVE IN REDUCTION OF DESTRUCTIVE KE.

VELOCITY HAS BEEN REDUCED AND MUST BE RECALCULATED.

$G = KE/ws = \frac{23\,059}{(853)(.11666)} = \frac{23.059 \times 10^3}{9.9511 \times 10^1}$

$G = 231.8$ g's DECELERATION FORCE LEVEL

$\therefore a = Gg = (231.8)(32.17) =$ 7457 ft/sec^2

DLT

$$V^2 - V_0^2 = 2as \qquad V_0 = 43.935 \text{ ft/sec}$$

$$2as = (2)(7457)(.11666) = 1739.87 \text{ ft}^2/\text{sec}^2$$

$$V^2 = V_0^2 - 2as = 1930.284 - 1739.87$$

$$V = \sqrt{190.414} = \underline{13.80 \text{ ft/sec}}$$

$$F = mV/t = (26.515)(13.8)/7.84\times10^{-4}$$

$$F = 36.591\times10^1/7.84\times10^{-4} = 4.667\times10^5 \text{ lbs}$$

$$F = \frac{W}{g}a = WG$$

$$G = F/W = 4.667\times10^5/8.53\times10^2 = \underline{547 \text{ g's AVERAGE FORCE LEVEL}}$$

G_{PEAK} = 1094 g's PEAK FORCE LEVEL TO INSTANTEOUSLY ABSORB 2,528 ft-lbs OF KINETIC ENERGY.

AS CALCULATED, THE SHOCK ABSORPTION SYSTEM IS ADEQUATE FOR ALL END IMPACT PROBIBLITIES.

APPENDIX 1.8.3

HANDLE LIFTING CALCULATIONS

Lid Lifting Handles - The weight (W) of the container and contents is 850 lbs, and the required load to be supported by the lid lifting handles is P = 3W = 3 x 850 lbs = 2550 lbs. If the lid lifting handles were to be used for supporting three times the weight of the container, the hinges which attach the lid to the bottom of the container would then be loaded with three times the weight of the container minus three times the weight of the lid. The required load on the hinges will be assumed to be the same as on the handles, 2550 lbs. Refer to Figure 1.7 for sketch of lid lifting handles.

There are four handles to support the required load of 2550 lbs. Each handle must support a load of:

$$P/4 = \frac{2550 \text{ lbs}}{4} = 637.5 \text{ lbs}$$

A conservative analysis can be made by considering a length of the pipe section between two of the vertical plates as a beam supported at two fixed ends with a concentrated load in the middle; then by considering that only one of the vertical plates carries the entire load on one handle as a cantilever beam with the load increasing uniformly from 0 at the fixed end to a maximum at the free end. See Figures 1.8 and 1.9.

The following calculations were made for this plate, and for the welds attaching the plate to the box, and the pipe section to the plate.

For a beam with fixed ends and concentrated center load, the maximum moment is given by:

$$M = \frac{P\ell}{8}$$

where P = the load on the beam

ℓ = the length of the beam

$$M = \frac{637.5 \text{ lb} \cdot 8.625 \text{ in}}{8}$$

$$M = 687.3 \text{ in} \cdot \text{lb}$$

The bending stress, σ, is given by $\sigma = \frac{Mc}{I}$

where c = the distance from the neutral axis

I = the moment of inertial

To determine I, we must first determine the position of two neutral axis. Referring to Figure 1.10, we can say:

$$\bar{y} = \frac{\int y\,dA}{\int dA}$$

$$= \frac{6}{\pi(r_o^2 - r_i^2)} \int_{r_i}^{r_o} \int_{\pi/6}^{\pi/2} r(\sin\theta) r \, d\theta \, dr$$

$$= \frac{6}{\pi(r_o^2 - r_i^2)} \int_{r_i}^{r_o} r^2 \left[-\cos\theta \right]_{\pi/6}^{\pi/2} dr$$

$$= \frac{6}{\pi(r_o^2 - r_i^2)} \int_{r_i}^{r_o} r^2 \left(-0 + \frac{\sqrt{3}}{2} \right) dr$$

$$= \frac{3\sqrt{3}}{\pi(r_o^2 - r_i^2)} \frac{1}{3} (r_o^3 - r_i^3)$$

$$= \frac{\sqrt{3}\,(r_o^3 - r_i^3)}{\pi(r_o^2 - r_i^2)}$$

$$= \frac{\sqrt{3}\,(2.25^3 - 2.013^3)}{\pi\,(2.25^2 - 2.013^2)}$$

$$\bar{y} = 1.765 \text{ in}$$

$$c_t = 2.25 \text{ in} - \bar{y} = 0.485 \text{ in}$$

$$c_b = \bar{y} - 2.013 \text{ in} \cdot \sin 30^{o} = 0.758 \text{ in}$$

The moment of inertia about the xx-axis, Figure 1.10, is:

$$I_{xx} = y^2 dA = \int_{r_i}^{r_o} \int_{\pi/6}^{\pi/2} (r \sin\theta)^2 \, r \, d\theta \, dr$$

$$= \int_{r_i}^{r_o} r^3 \left[\frac{\theta}{2} - \frac{\sin 2\theta}{4} \right]_{\pi/6}^{\pi/2} dr$$

$$= \left(\frac{\pi}{4} - \cancel{\frac{\sin \pi}{4}}^{\,0} - \frac{\pi}{12} + \frac{\sin \frac{\pi}{3}}{4} \right) \left[\frac{r^4}{4} \right]_{r_i}^{r_o}$$

$$= \left(\frac{\pi}{6} + \frac{\sqrt{3}}{8} \right) \left(\frac{2.25^4 - 2.013^4}{4} \right)$$

$$I_{xx} = 1.704$$

The moment of inertia about the neutral axis, Figure 1.10, is:

$$I_{NA} = I_{xx} - A\bar{y}^2$$

$$= 1.704 \quad - \frac{\pi(2.25^2 - 2.013^2)}{6} \; 1.765^2$$

$$I_{NA} = 0.0567 \quad in^4$$

The stresses at the extreme fibers are:

$$\sigma = \frac{Mc}{I}$$

$$\sigma_t = \frac{687.3 \text{ in} \cdot \text{lb} \cdot 0.485 \text{ in}}{0.0567 \text{ in}^4}$$

$$\sigma_t = 5880 \quad \text{lb}/\text{in}^2$$

and $$\sigma_b = \frac{687.3 \text{ in} \cdot \text{lb} \cdot 0.758 \text{ in}}{0.0567 \text{ in}^4}$$

$$\sigma_b = 9184 \quad \text{lb}/\text{in}^2$$

The minimum yield strength of the steel is 25,000 lb/in^2 > σ.

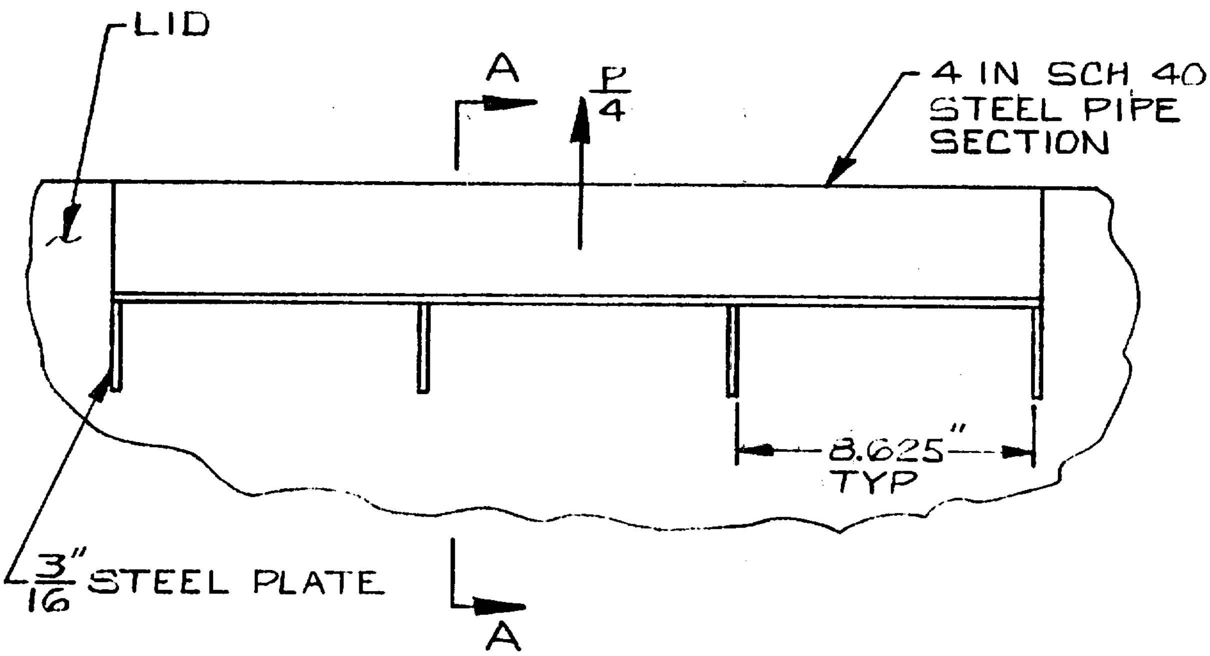
Thus, the maximum bending stress in the pipe section is much less than the yield strength of the material, even if the pipe section is considered to be supported only at its ends.

A cantilever beam loaded, as shown in Figure 1.9, has a maximum load, w_m, at the free end.

$$w_m = \frac{2P}{\ell}$$

where P = the total load on the beam

ℓ = the length of the beam



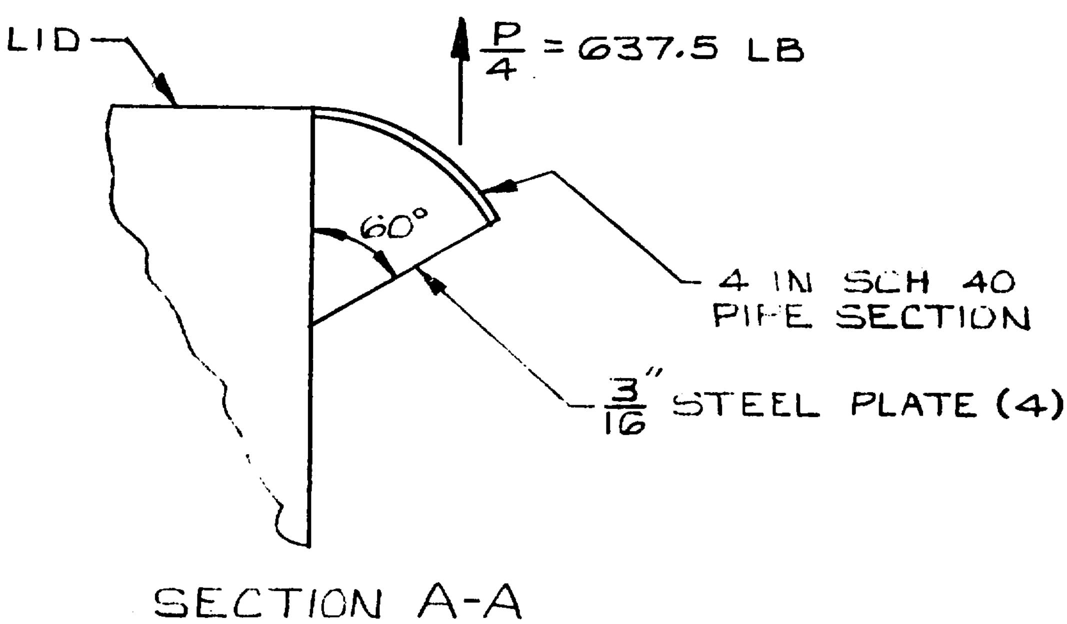


Figure 1.7 Lid Lifting Handles

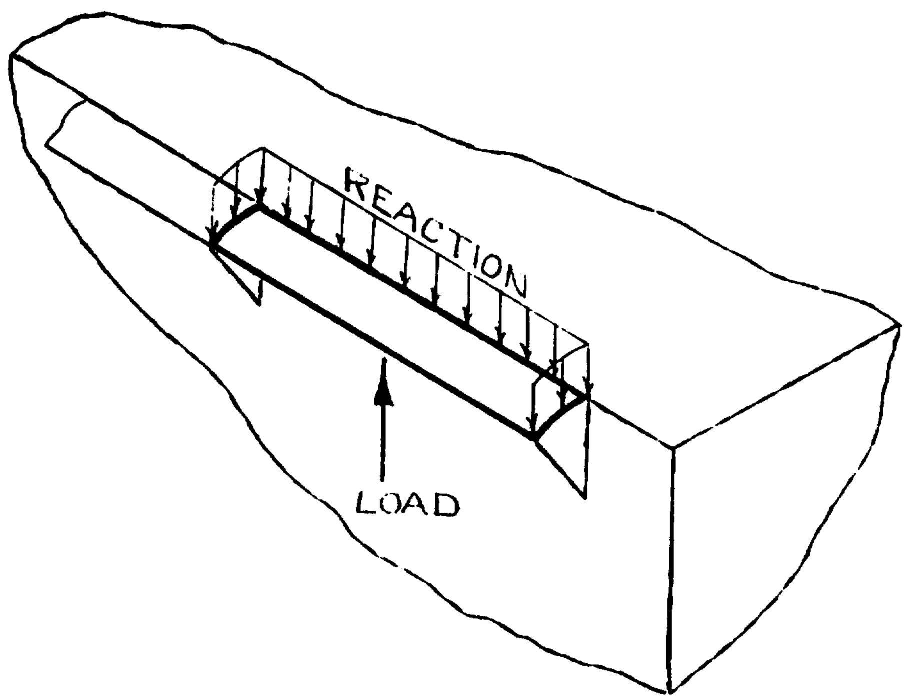


Figure 1.8 Length of Pipe Section of a Lid Lifting Handle Modeled as a Flat Plate, Simply Supported on Three Sides.

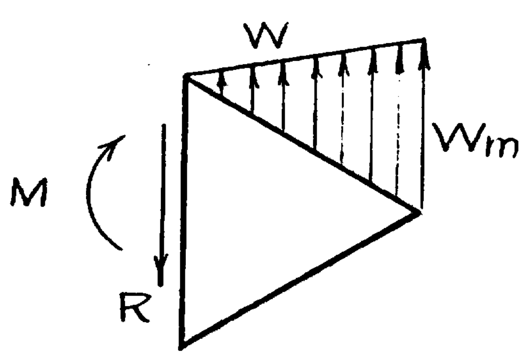


Figure 1.9 3/16 in. Gusset Modeled as a Cantilevered Beam with Load, w, Increasing Linearly from 0 at the Fixed End to a Maximum, w_m at the Free End.

For the vertical plate,

$$\ell = \left(\frac{4.5 \text{ in}}{2} - 0.237 \text{ in}\right) \sin 60^\circ$$

$$\ell = 1.74 \text{ in}$$

$$P = 637.5 \text{ lb}$$

$$w_m = \frac{2 \cdot 637.5 \text{ lb}}{1.74 \text{ in}}$$

$$w_m = 732 \text{ lb}/\text{in}$$

The load at any point from x = 0 to x = ℓ is expressed by

$$w = \frac{w_m x}{\ell}$$

$$w = \frac{732 \text{ lb}/\text{in} \cdot x}{1.74 \text{ in}}$$

$$w = 420 \frac{\text{lb}}{\text{in}^2} \cdot x$$

The shear at any point, x, on the beam is

$$V = \int_\ell^x w dx = \int_\ell^x 420 \frac{\text{lb}}{\text{in}^2} x dx$$

$$= 420 \text{ lb}/\text{in}^2 \int_\ell^x x dx$$

$$= 420 \text{ lb}/\text{in}^2 (x^2 - \ell^2)/2$$

$$V = 210 \text{ lb}/\text{in}^2 (x^2 - 3.04 \text{ in}^2)$$

The bending moment at any point, x, on the beam is

$$M = \int_\ell^x V dx = \int_\ell^x 210 \text{ lb}/\text{in}^2 (x^2 - 3.04 \text{ in}^2) dx$$

$$= 210 \text{ lb}/\text{in}^2 \int_\ell^x (x^2 - 3.04 \text{ in}^2) dx$$

$$= 210 \text{ lb}/\text{in}^2 (1/3\, x^3 - 3.04 \text{ in}^2 x - 1/3 \ell^3 + 3.04 \text{ in}^2 \ell)$$

$$= 210 \text{ lb}/\text{in}^2 \left(1/3\, x^3 - 3.04 \text{ in}^2 x - \frac{1.74^3 \text{in}^3}{3} + 3.04 \text{ in}^2 \cdot 1.74 \text{in}\right)$$

$$M = 741 \text{ in} \cdot \text{lb} + 210 \frac{\text{lb}}{\text{in}^2} (1/3\, x^3 - 3.04 \text{ in}^2 x)$$

The maximum shear stress in a beam of rectangular cross section is[2]

$$\tau = \frac{3V}{2A} = \frac{3V}{2bh}$$

where b is the width of the beam = 0.1875 in,

h is the height of the beam,

$$h = (2.013^2 \text{ in}^2 - x^2)^{1/2} - x\cot 60^\circ \text{ (see Figure 1.11)}$$

Substituting for V, b and h,

$$\tau = \frac{3 \cdot 210 \text{ lb /in}^2 (x^2 - 3.04 \text{ in}^2)}{2 \cdot 0.1875 \text{ in } [(2.013^2 \text{ in}^2 - x^2)^{1/2} - x\cot 60^\circ]}$$

This reduces to

$$\tau = -1260 \text{ lt /in}^3 \ [(2.013^2 \text{ in}^2 - x^2)^{1/2} + \frac{x}{\sqrt{3}}]$$

The derivative of τ is 0 when τ is a maximum

$$\frac{d\tau}{dx} = -1260 \ \frac{\text{lb}}{\text{in}^3} [(1/2) \ (2.013^2 \text{ in}^2 - x^2)^{-1/2} \ (-2x) + \frac{1}{\sqrt{3}}]$$

$$0 = -1260 \ \frac{\text{lb}}{\text{in}^3} [\frac{-2x}{2(2.013^2 \text{ in}^2 - x^2)^{1/2}} + \frac{1}{\sqrt{3}}]$$

$$0 = \frac{1}{\sqrt{3}} - \frac{x}{(2.013^2 \text{ in}^2 - x^2)^{1/2}}$$

$$x = \frac{(2.013^2 \text{ in}^2 - x^2)^{1/2}}{\sqrt{3}}$$

$$x = 1.006 \text{ in}$$

$$\tau_{1.006} = -1260 \ \frac{\text{lb}}{\text{in}^3} [\ (2.013^2 \text{ in}^2 - 1.006^2 \text{ in}^2)^{1/2} + \frac{1.006 \text{ in}}{\sqrt{3}}]$$

$$|\tau_{1.006}| = 2929 \text{ lb /in}^2$$

is the maximum shear stress in the 3/16 in vertical plates. This is much lower than the minimum shear strength of the material,

$S_{sy} = 0.5\ S_y \geq 12{,}500\ \text{lb}/\text{in}^2$

The maximum bending stress is(3)

$$\sigma = \frac{Mc}{I}$$

where M is the moment,

c is half the height = $\frac{h}{2}$,

I is the moment of inertia = $\frac{bh^3}{12}$,

Substitutuing for M, c, and I

$$\sigma = \frac{12\ [741\ \text{in} \cdot \text{lb} + 210\ \text{lb}/\text{in}^2\ (1/3\ x^3 - 3.04\ \text{in}^2\ x)]h}{2\ bh^3}$$

$$\sigma = \frac{6[741\ \text{in} \cdot \text{lb} + 210\ \text{lb}/\text{in}^2\ (1/3\ x^3 - 3.04\ \text{in}^2\ x)]}{0.1875\ \text{in} \cdot [(2.013^2\ \text{in}^2 - x^2)^{1/2} - \frac{x}{\sqrt{3}}]^2}$$

$$\sigma = 32[\frac{741 \cdot \text{lb} + 210\ \text{lb}/\text{in}^3\ (1/3\ x^3 - 3.04\ \text{in}^2\ x)}{2.013^2\ \text{in}^2 - \frac{2x^2}{3} - \frac{2x}{\sqrt{3}}\ (2.013^2\ \text{in}^2 - x^2)^{1/2}}$$

At $x = 0$,

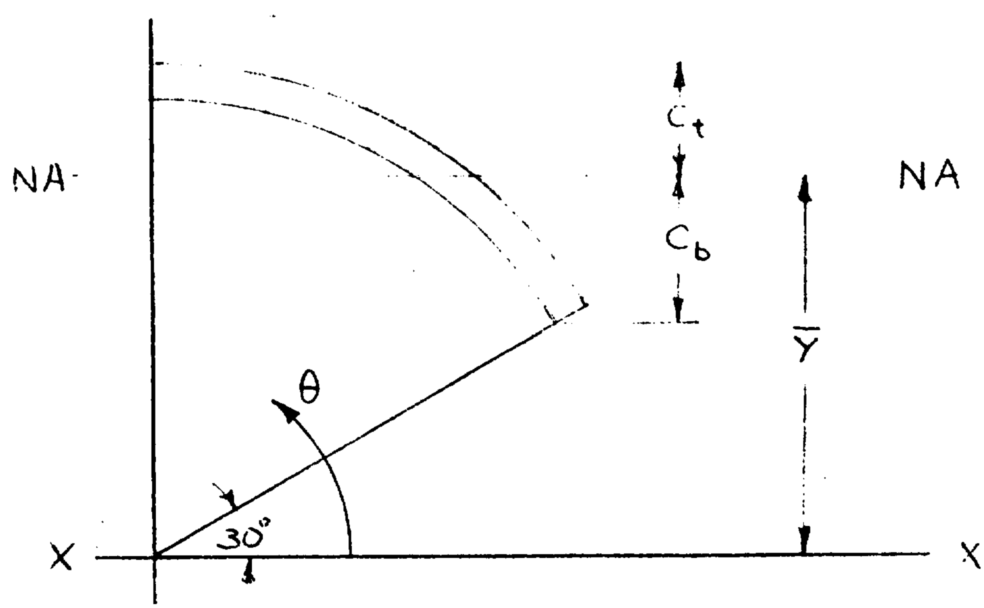


Figure 1.10 Neutral axis of pipe section.

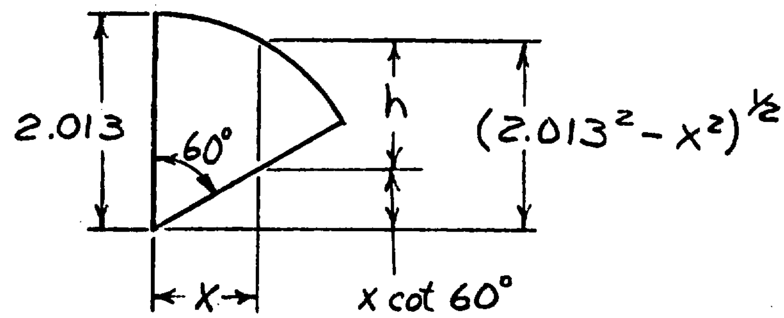


Figure 1.11 Height, h, of 3/16 in. Gusset Plate at any Distance, x, from side of Lid.

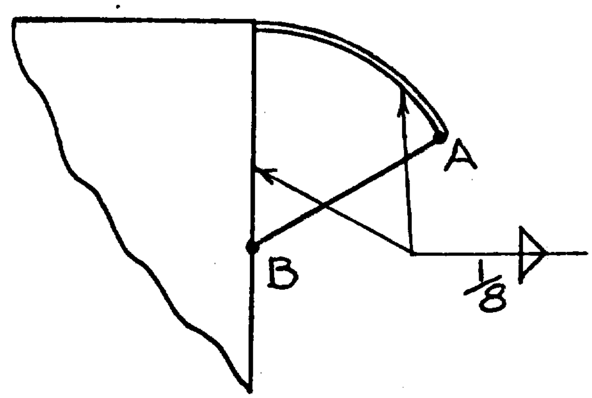


Figure 1.12 Welds between Pipe Section, 3/16 in. Plate and Lid.

$$\sigma_o = 32 \cdot \frac{741 \cdot \text{lb}}{2.013^2 \text{ in}^2}$$

$$\sigma_o = 5851 \text{ lb /in}^2$$

If $0 < x < 1.74$, then,

$$1/3\ x^3 - 3.04 \text{ in}^2\ x < 0$$

and $\sigma(x) < \sigma(0)$

The maximum bending stress is then 5851 lb/in^2 and is much less than the minimum yield strength of the steel, 25,000 lb/in^2.

Finally, the welded joints must be considered. There are two such joints as shown in Figure 1.12. The joint between the pipe section and the vertical plate is most highly stressed at point A,

$$w_A = 732 \text{ lb/in}$$

(See loading of vertical plate.)

The joint between the vertical plate and the side of the container is most highly stressed at point B,

$$w_B = 5851 \text{ lb/in}^2 \cdot 0.1875 \text{ in}$$

$$w_B = 1097 \text{ lb/in}$$

The maximum shear stress in any of the welds will be at point B on both sides of the plate (i.e., there are two welds to take the load). The shear stress at point B is(4),

$$\tau = \frac{F}{\sqrt{2}h\ell}$$

where $\frac{F}{\ell} = w$, h is the leg size.

Substituting,

$$\tau = \frac{1097 \text{ lb/in}}{\sqrt{2} \cdot 0.125 \text{ in}}$$

$$\tau = 6206 \text{ lb/in}^2$$

Again, the maximum shear stress is much less than the minimum shear strength, 12,500 lb/in^2.

In the three possible modes of failure of the handles, the maximum stresses under the prescribed load are much smaller than the corresponding strength of the materials. It can be safely concluded that the lid lifting handles will not yield.

A failure of the lid lifting handles under an excessive load would have no effect on the containment properties of the box as the handles are attached to the outer box lid and not required for package integrity. Actual containment of the contents is accomplished with the inner box. Changes in shielding properties due to a handle failure is of no consequence since shielding is not a required property of the packaging.

If the lid lifting handles are loaded with three times the weight of the ATR fuel shipping container, the hinges which hold the lid to the bottom of the container will also be loaded with three times the weight of the container minus the lid. The standards require that the resulting stresses in the hinges be less than the yield strengths of the materials. A conservative analysis can be made by assuming the load on the hinges is 2550 lbs. Failure of the hinges might occur by shear of the pins or by straightening of the hinges.

Consider the possibility of shearing the pins. There are four hinges and, as can be seen in Figure 1.13, each would have to shear in four places. The load at each position of shearing would be 1/16 of the total load. The pins are 0.25 inch diameter.

$$P - 2550\ \text{lb}/16 = 159.4\ \text{lb}$$

The area of shear is:

$$A = \frac{\pi d^2}{4}$$

$$= \frac{\pi(0.25)^2\ \text{in}^2}{4}$$

$$A = 0.0491\ \text{in}^2$$

The shear stress is:

$$\tau = \frac{P}{A}$$

$$= \frac{159.4\ \text{lb}}{0.0491\ \text{in}^2}$$

$$\tau = 3246\ \text{lb/in}^2$$

The tensile yield strength of the pin is $S_y = 45{,}000\ \text{lb/in}^2$. The shear strength is $S_{sy} = 0.5$, $S_y = 22{,}500\ \text{lb/in}^2 >> \tau$. Thus, the pins will not shear under the given load.

Finally, consider the possibility of failure of the hinges by straightening. The effective length of the upper half of the hinge, shown in Figure 1.13, 2 x 0.875 in = 1.75 in, is less than the effective length of the lower half, 3 x 0.75 in = 2.25 in. The upper half will clearly fail first. Since there are four hinges, there is a total effective length of 4 x 1.75 in = 7 in.

The hinge is loaded as shown in the cross section view in Figure 1.14. It is clear that R = P and M = (0.281 in + 0.125 in) P/2. The inset shows the loading on that element of the hinge which is at the interface between the straight portion and the curved portion of the hinge, i.e., where straightening will occur. It is similar to an element of a beam of height, h = 0.125 in, and width, b = 7 in, under combined tension and bending. The maximum stress will occur at point A where the bending stress and tensile stress reinforce each other,

$$\sigma = \frac{Mc}{I} + \frac{P}{hb}$$

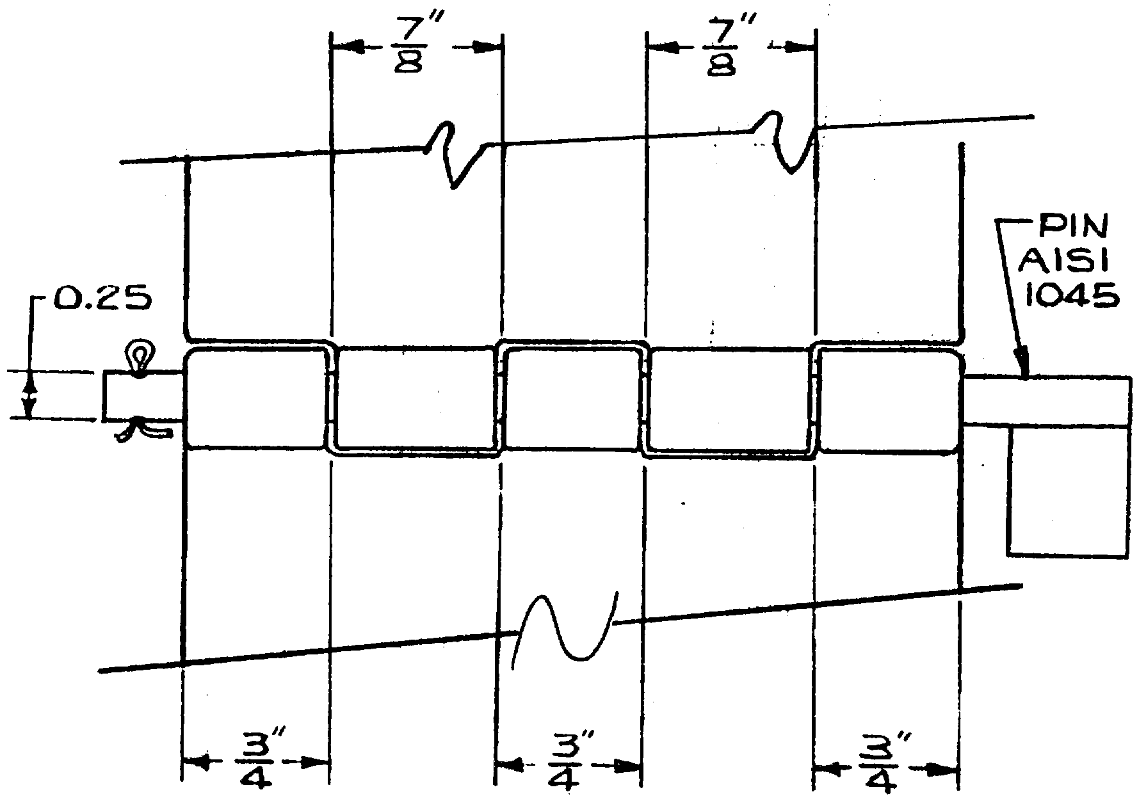


Figure 1.13 Hinge Used as Latch for Securing Lid to Body of Container.

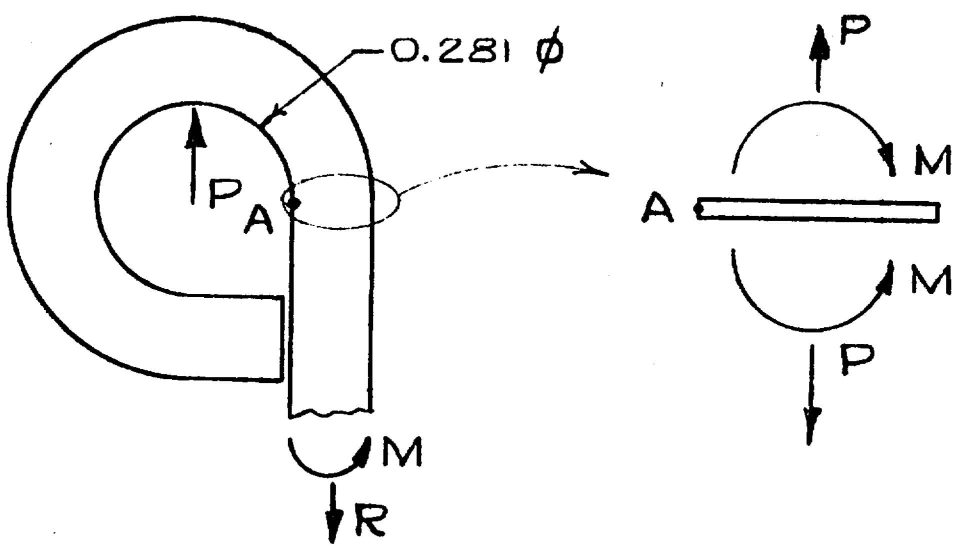


Figure 1.14 Load on Eye of Hinge.

where $c = \frac{0.125 \text{ in}}{2}$

$$I = \frac{bh^3}{12}$$

Substituting,

$$\sigma = \frac{(0.281 \text{ in} + 0.125 \text{ in})P \cdot 0.125 \text{ in} \cdot 12}{2 \cdot 2 \cdot bh^3} + \frac{P}{bh}$$

$$= \frac{0.406 \text{ in} \cdot 2550 \text{ lb} \cdot 0.125 \text{ in} \cdot 12}{2 \cdot 2 \cdot 7 \text{ in} \cdot 0.125^3 \text{ in}^3} + \frac{2550 \text{ lb}}{0.125 \text{ in} \cdot 7 \text{ in}}$$

$$\sigma = 31311 \text{ lb/in}^2$$

The hinges are steel with a minimum yield strength, $S_y = 25.000 \text{ lb/in}^2 < \sigma$. Thus it can be seen that the hinges, in this model, are not satisfactory. Each of the five eyes on each of the four hinges have been welded closed as shown in Fig. 1.15.

Welding the eyes closed as shown results in a large decrease in the bending moment at point A in Fig. 1.14. Even if only a 25% decrease is assumed, the stress at point A will be

$$\sigma = \frac{0.75 \text{ Mc}}{I} + \frac{P}{hb}$$

$$= \frac{0.75 \cdot 0.406 \text{ in} \cdot 2550 \text{ lb} \cdot 0.125 \text{ in} \cdot 12}{2 \cdot 2 \cdot 7 \text{ in} \cdot 0.125^3 \text{ in}^3} + \frac{2550 \text{ lb}}{0.125 \text{ in} \cdot 7 \text{ in}}$$

$$\sigma = 24212 \frac{\text{lb}}{\text{in}^2} < S_y$$

Now it should be noted that there are two safety factors here. First, the actual load on the hinges will be less than 2550 lbf by an amount equal to three times the weight of the lid, which is unknown but certainly significant. Second, the actual reduction in the bending moment will be more on the order of 75% instead of 25%. Thus it can be concluded that, the hinges with eyes welded closed will not yield due to loading the lid lifting handles with three times the weight of a container.

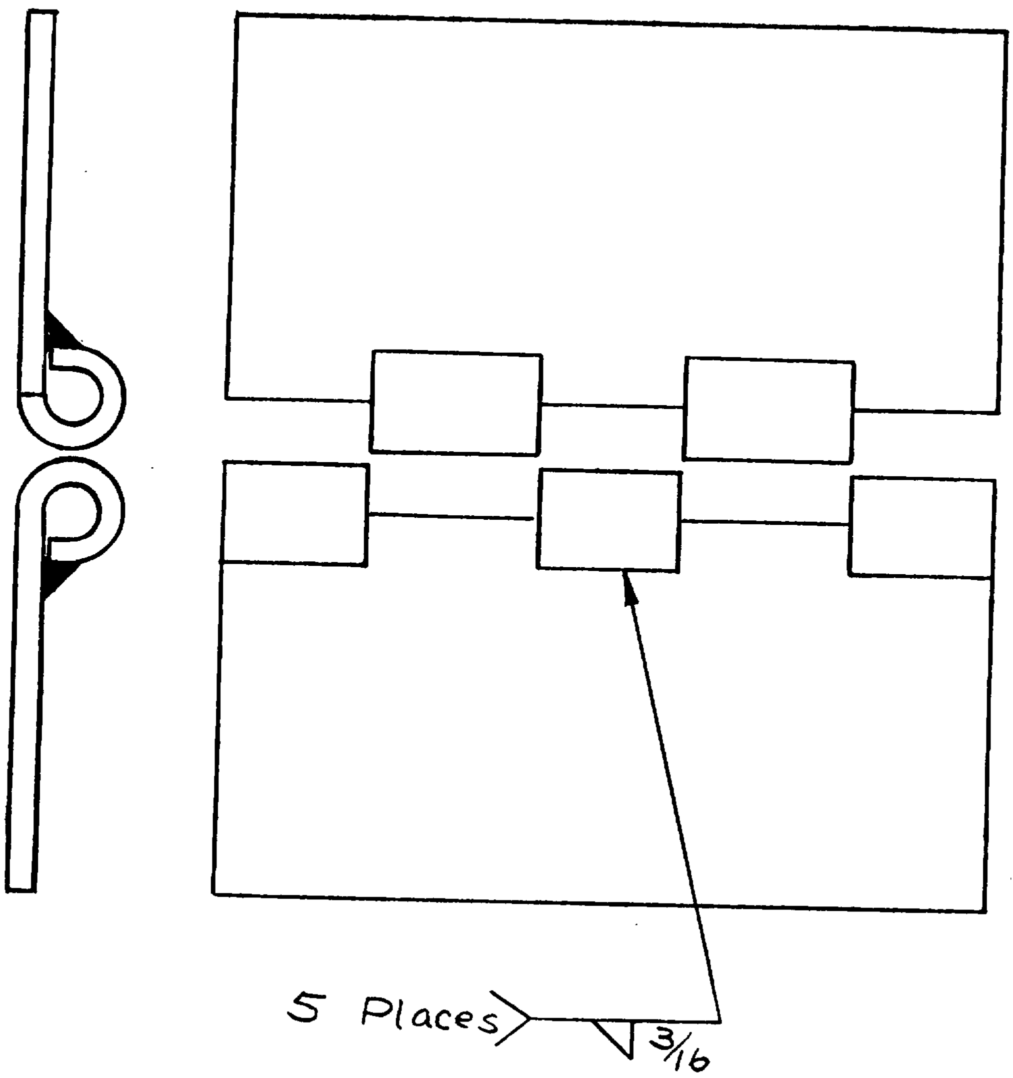


Figure 1.15 Lid Securing Hinges with Eyes Welded Closed.

APPENDIX 1.8.4

REFERENCES

(1) Theodore Baumeister, Mark's Mechanical Engineer's Handbook, McGraw-Hill Book Company, New York, 1958, Table 6.6.

(2) J. E. Shigley, Mechanical Engineering Design, McGraw-Hill Book Company, New York, 1972, p. 58

(3) Ibid., p. 53

(4) Ibid., p. 339

(5) L. B. Shappert, "Cask Designer's Guide", USAEC Report, ORNL-NSIC-68, Oak Ridge National Laboratory, 1970

(6) C. D. Hodgman, Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio, 1958, p. 2956

(7) A. J. Chapman, Heat Transfer, The MacMillan Company, New York, 1960, p. 270-276

(8) Ibid., Table A.7

2.0 THERMAL EVALUATION

2.1 Discussion

The thermal design features of the package include the use of fire retardant plywood in the construction of both the inner container and the outer container. The outer container has the added feature of a one-half inch exterior fir, fire retardant plywood fire break mounted inside the top that extends into the bottom of the container. This fire break protects the inner container at the exposed connection where the top fits to the bottom of the container. The fire breaks are installed only on the long sides of the container as the shock absorbers serve as fire breaks for this connection at the container ends. Both the inner container and outer container are sheathed in steel sheet which is fire resistant and also protects the plywood from the weather, so that there is an insignificant loss of fire retardant materials.

Fire tests conducted on inner containers of the same construction as the ATR inner container showed that additional protection was required to prevent the melting of cadmium sheet (melting point is 610°F). The outer container uses similar design and was assumed to offer the same thermal resistance as the inner container in the fire test. Actually, the outer container will offer considerably more thermal resistance because of its continuous welded steel sheathing seams. The analysis results show that when the ATR container is subjected to the thermal conditions of the hypothetical accident, the cadmium temperature will not exceed 263°F and the polyethylene will not exceed 306°F. The container contents will obviously remain undamaged.

The container has no coolant or mechanical cooling devices and they are not required, since heat generation is limited to 0.1 watt (Section 0.3).

2.2 Summary of Thermal Properties of Materials

The sources of data for thermal properties of materials (as they are used in the thermal analysis) are referenced in Appendix 1.8.4. The thermal properties of materials used in the thermal analysis for hypothetical accident conditions are discussed in Section 2.5.

2.3 Technical Specifications of Components

All specifications, codes, and standards known to be applicable to the components of the package are listed on the drawings and are listed in Section 1.3.

2.4 Thermal Evaluation for Normal Conditions of Transport

The regulations require that the package withstand direct sunlight at an ambient temperature, Ta = 130°F, in still air.

A recommended solar heat load of 144 $Btu/ft^2 \cdot hr$ was used[5]. The maximum temperatures at different points must be determined for those conditions.

If the top, one side, and one end are exposed to the sunlight, the exposed area will be (see Figure 2.1):

$$A = A_t + A_s + A_e$$

$$= 88 \text{ in} \cdot 32 \text{ in} + 88 \text{ in} \cdot 11 \text{ in} + 32 \text{ in} \cdot 11 \text{ in}$$

$$= 19.56 \text{ ft}^2 + 6.72 \text{ ft}^2 + 2.44 \text{ ft}^2$$

$$A = 28.72 \text{ ft}^2$$

This is greater than the actual projected area normal to the sunlight, and so will give a conservative figure for the maximum temperatures of the container.

The container is painted with gray paint which has an absorptivity for solar radiation, $\alpha = 0.75$, and an emissivity at low temperatures, $\epsilon = 0.95$[6]. The total solar heat absorbed by the container is:

$$q_s = \alpha \, A \cdot 144 \text{ Btu/hr} \cdot \text{ft}^2$$

$$= 0.75 \cdot 28.72 \text{ ft}^2 \cdot 144 \text{ Btu/hr} \cdot \text{ft}^2$$

$$q_s = 3102 \text{ Btu/hr}$$

At equilibrium, the three sunlit surfaces will be at approximately a uniform temperature, T_s, with all other parts of the container and contents at a somewhat lower, nonuniform temperature (considering that there is no significant internal heat generation). Convection and radiation (thermal) from the container will balance the solar heat input.

$$q_r + q_c = q_s$$

The values of q_r and q_c depend on the temperature, T_s,

$$q_r = \sigma_s \, A \, \epsilon \, (T_s^4 - T_a^4)$$

$$q_c = h_v \, (A_s + A_e) \, \Delta T + h_h \cdot A_t \, \Delta T$$

where q_r is radiative heat transfer,

q_c is convective heat transfer,

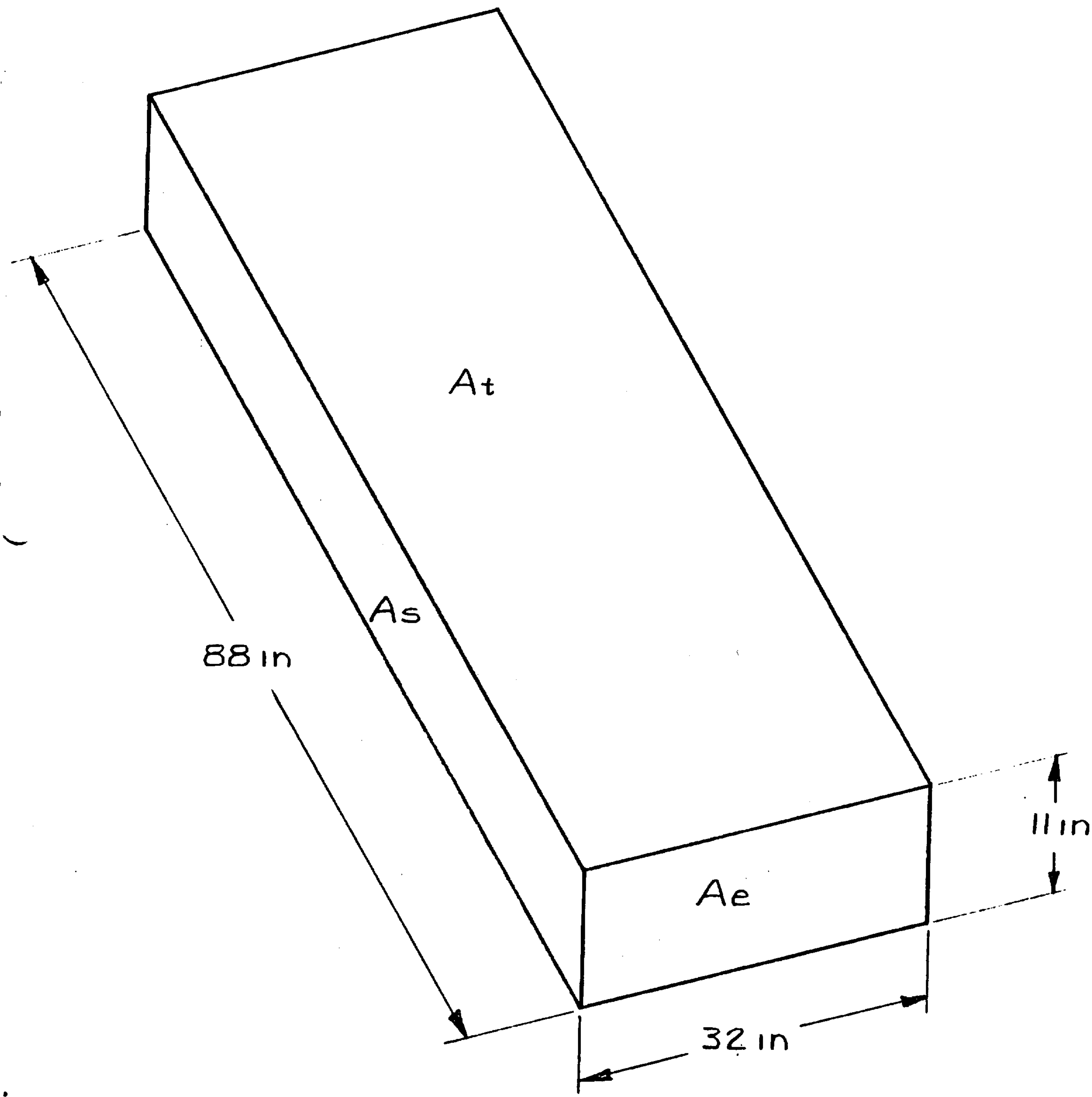


Figure 2.1 ATR Container Showing Heat Transfer Areas

$\sigma_s = 0.174 \cdot 10^{-8} \frac{Btu}{hr\ ft^2 R^4}$ is the Stefan-Boltzmann Constant,

h_v is the convection coefficient for a flat vertical surface,

h_h is the convection coefficient for a flat horizontal surface,

$\Delta T = T_s - T_a$.

The convection coefficient for a flat surface is [7]

$$H = N_{NU} \cdot \frac{k}{\ell}$$

where N_{NU} is the Nusselt number,

k is the fluid conductivity,

ℓ is the characteristic length of the surface.

The Nusselt number is a function of the Grashof and Prandtl numbers[7]

$$N_{NU} = C\ (N_{GR} \cdot N_{PR})^m$$

where C and m are constants whose values depend on $N_{GR} \cdot N_{PR}$

$$N_{GR} = (\Delta T \cdot \beta) \left(\frac{\ell^3 \rho^2 g}{\mu^2}\right) \quad \text{(Ref. 9)}$$

and where $\beta = \frac{1}{T_a}$ is the fluid coefficient of expansion,

μ is the fluid viscosity at temperature $\frac{T_a + T_s}{2}$,

ρ is the fluid density at temperature $\frac{T_a + T_s}{2}$,

g is the acceleration of gravity.

The solution of the above equations is a trial and error process starting with an assumption for the value of T_s. The correct value of T_s is that which balances the heat transfer equation, $q_r + q_c = q_s$.

If a value of T_s = 180F = 640R is tried the radiative heat transfer is:

$$q_r = 0.174 \cdot 10^{-8} \frac{Btu}{hr \cdot ft^2 \cdot R^4} \cdot 28.72\ ft^2 \cdot 0.95(640^4 R^4 - 590^4 R^4)$$

$$q_r = 2212\ Btu/hr$$

The temperature at which fluid properties are evaluated is:

$$\frac{T_a + T_s}{2} = \frac{130F + 180F}{2} = 155F$$

$\Delta T = 50R$

The fluid properties at 155F are (8)

$$\rho = 0.06454 \frac{lbm}{ft^3}$$

$$k = 0.01700 \frac{Btu}{hr \cdot ft \cdot F}$$

$$\mu = 0.04929 \frac{lbm}{ft \cdot hr}$$

$N_{PR} = 0.6985$

The characteristic length of the vertical surface is

$\ell = 11$ in $= 11/12$ ft. Thus,

$$N_{GR} = \left(\frac{50R}{590R}\right)\left(\frac{11}{12}\,ft\right)^3 \left(0.06454 \frac{lbm}{ft^3}\right)^2 (32.2\ ft/sec^2)\left(3600 \frac{sec}{hr}\right)^2 / \left(0.04929 \frac{lbm}{ft\ hr}\right)^2$$

$$N_{GR} = 4.670 \cdot 10^7$$

$$N_{GR} \cdot N_{PR} = 4.670 \cdot 10^7 \cdot 0.6985 = 3.262 \cdot 10^7$$

For a vertical surface, (9)

$C = 0.59$

$m = 1/4$

Solving for N_{NU} and h_v ,

$$N_{NU} = 0.59\ (3.262 \cdot 10^7)^{1/4}$$

$$N_{NU} = 44.59$$

$$h_v = 44.59 \frac{0.01700 \frac{Btu}{hr \cdot ft \cdot F}}{\frac{11}{12}\,ft}$$

$$h_v = 0.8269 \frac{Btu}{hr \cdot ft^2 \cdot F}$$

Similarly for the horizontal surface,

$$\ell = 32 \text{ in} = \frac{32}{12} \text{ ft}$$

$$N_{GR} = 1.1498 \cdot 10^9$$

$$N_{GR} \cdot N_{PR} = 8.031 \cdot 10^8$$

The values for C and m for a horizontal surface are(7)

$$C = 0.14$$

$$m = 1/3$$

Again, solving for N_{NU} and h_h ,

$$N_{NU} = 130.1$$

$$h_h = 0.8296 \frac{\text{Btu}}{\text{hr} \cdot \text{ft}^2 \cdot \text{F}}$$

Finally, solving for q_c ,

$$q_c = 0.8269 \frac{\text{Btu}}{\text{hr ft}^2 \text{ F}} (6.72 \text{ ft}^2 + 2.44 \text{ ft}^2) 50\text{F} + 0.8296 \frac{\text{Btu}}{\text{hr ft}^2 \text{ F}} \cdot 19.56 \text{ ft}^2 \cdot 50\text{F}$$

$$q_c = 1190 \frac{\text{Btu}}{\text{hr}}$$

Thus $$q_r + q_c = 3402 \frac{\text{Btu}}{\text{hr}} > 3102 \frac{\text{Btu}}{\text{hr}} = q_s$$

Therefore, the temperature of the sunlit surfaces would actually be less than 180°F. All other points within the container would also be less than 180°F. This temperature does not exceed the maximum safe operating temperature of any of the materials of the container or its contents. Neither would this temperature cause a pressure rise within the container since it is not sealed to air. It can be safely concluded that the ATR container will withstand direct sunlight at an ambient temperature of 130°F with no detrimental effects.

2.5 Hypothetical Thermal Accident Evaluation

The package must withstand a 30-minute exposure to a thermal radiation environment of 1475°F following the drop and puncture test. The radiation environment will have an emissivity of 0.9 and the container on absorptivity of 0.8. As discussed in Sections 1.71 and 1.72, the drop and puncture test results in no damage which will effect the thermal resistance of the container; thus, the thermal analysis was performed on an undamaged ATR container.

The ability of the ATR container to meet the specification is based on data obtained from computer analysis. The accuracy of the computer program was verified by analyzing a MTR inner container and comparing the results of this analysis with thermocouple data obtained from subjecting the MTR inner container to a fire test, which imposed the Underwriter's Laboratory standard time-temperature curve (Figure 2.3). As can be seen in Figure 2.4, which shows both analytical and experimental results, the experimental data verified the analytical method and demonstrated that an outer container was needed. The similarity of materials and construction between various inner and outer containers made it unnecessary to experimentally verify the analytical data for all three shipping containers with their outer containers. Details of the MTR fuel element container fire test and a discussion of the analytical methods taken from original reports are given in the following sections. Sufficient detail is given to demonstrate the adequacy of this approach. However, specific details, other than the results, are not provided for the ATR container.

The thermal analysis was based on the premise that the drop and puncture accident conditions do not cause any openings or breaks in the container structure. Drop tests on the inner containers and analysis of the package verify this is the case for the continuous welded outer container, even though Figure 1.6 shows a small opening in a tack welded container.

2.5.1 MTR Container

An MTR fuel element inner container (without the outer container) loaded with dummy fuel elements was fire tested at the Underwriter's Laboratory on January 7, 1965.

Test furnace temperatures and internal container temperatures were measured with thermocouples. The container was placed in the chamber on a 30 inch by 30 inch by 20 inch concrete block, as shown in Figure 2.2. The temperatures recorded during the 60-minute fire essentially duplicated the standard time temperature curve (NFPA No. 251), Figure 2.3.

Fifteen thermocouples measured internal temperatures. Figure 2.4 shows the time progression of experimental temperatures for selected thermocouples, along with two analytically derived time temperature curves. Two thermocouples measured the two most severe temperatures at a location just inside the plywood external frame. The other plotted thermocouple measurements indicated the temperature of the top center fuel element. The curves pertaining to these temperatures are identified in Figure 2.4. As indicated by the temperature curves,

Figure 2.2 MTR Container After Fire Test At Underwriter's Laboratory

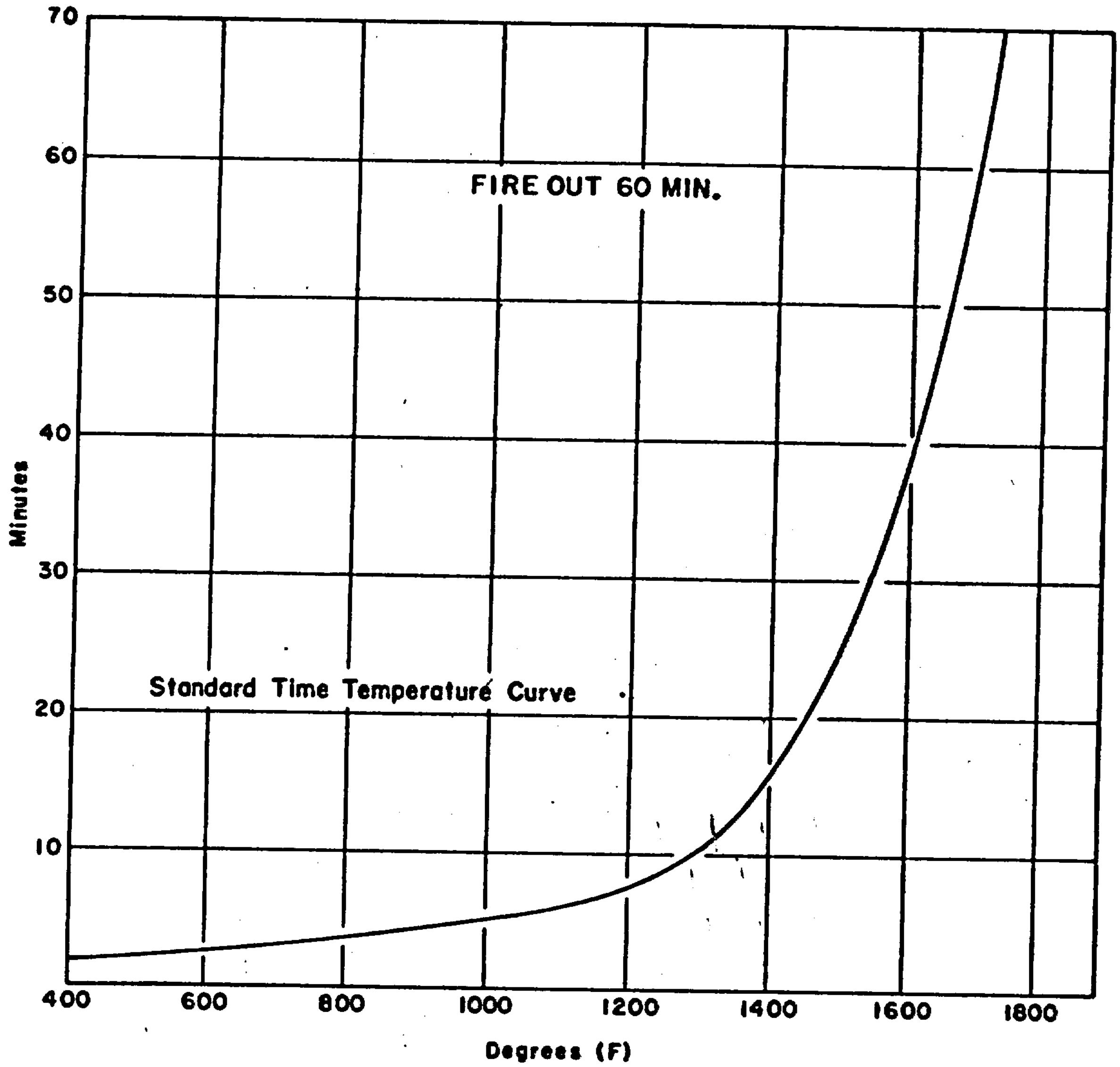


Figure 2.3 · Fire Endurance Test Curve

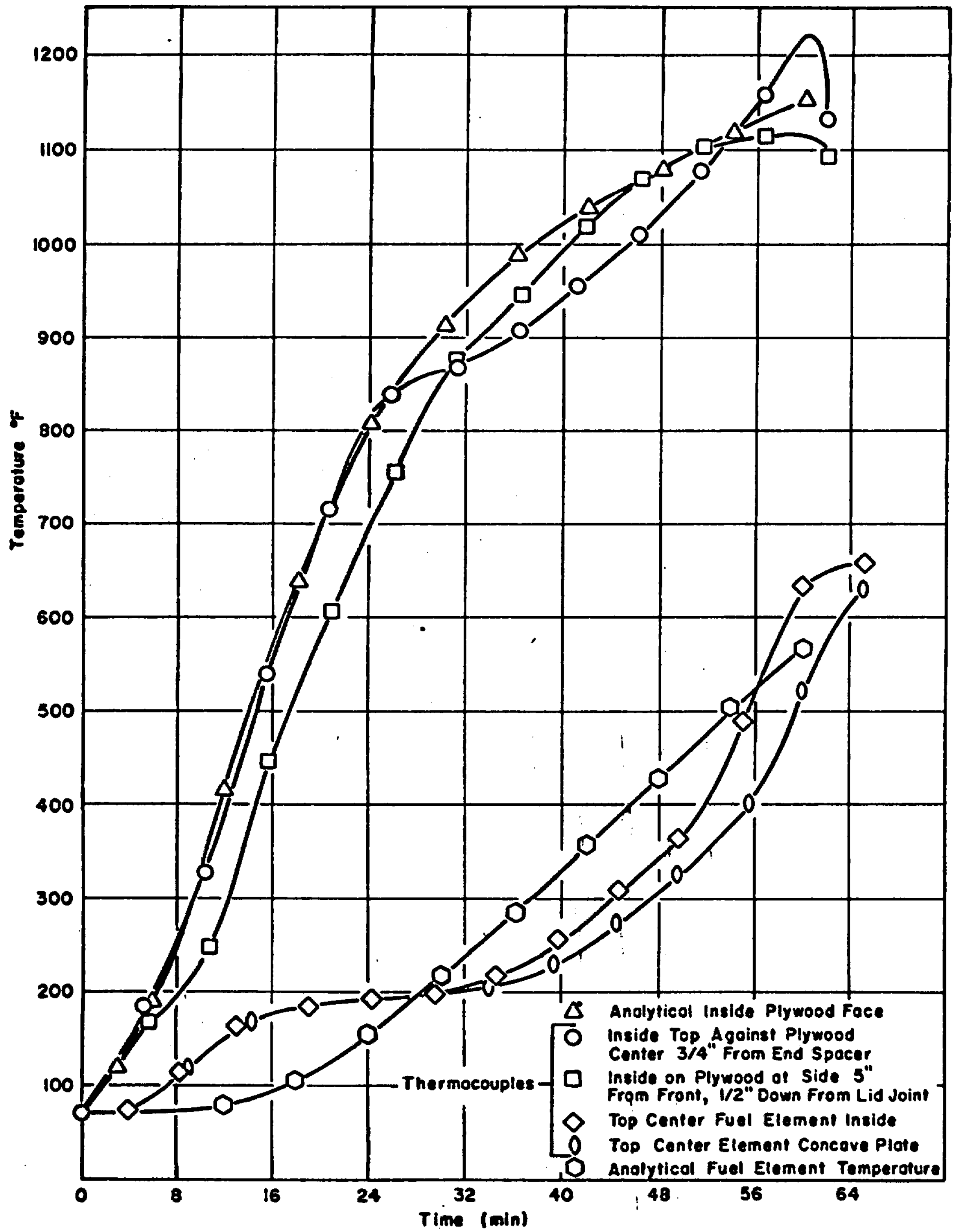


Figure 2.4 MTR Container Internal Temperature Curve

the analytically derived and actual measured temperatures are in good agreement. The highest recorded internal temperature was 1170°F, where the top layer of cadmium had completely melted but the center and lower layers * remained largely intact. It was concluded that a breakdown in effective insulation occurred when openings, caused by thermal expansion of the metal covering and unwelded areas in the metal sheathing, allowed charring of the plywood under the metal. It was further concluded that an outer protective container was needed and that continuous welding would provide greater protection than tack welding.

2.5.2 Analytical Methods

The actual fire test described in 2.5.1 is more severe than the hypothetical thermal accident specified in ERDA Manual Chapter 0529. The analytical method for the 0529 hypothetical thermal accident (a half-hour, 1475°F fire) is described below.

The Fortran IV Code HEAT 2, which describes unidirectional heat transfer by conduction through layers of several types of material with adjustable boundary conditions, was utilized. This code also allows for melting and will handle cylindrical, rectangular, and spherical geometry. Although the primary mode of heat transfer at the boundary was by radiation, a convection term was also included assuming a heat transfer coefficient of 2.0. Note that all models used in this and other codes (e.g., criticality) are not identical to each other or to the actual boxes. They are, in all cases, simplified but conservative models as compared to the actual boxes.

It was obvious that the thermal properties of the cold materials in the container would not describe the heat transfer mechanism in a mathematical model. The following factors would affect the heat transfer mechanism as thermal decomposition occurred in the container:

(1) Heats of combustion of components in the container.
(2) Thermal properties as a function of temperature.
(3) Changing dimensions of the materials upon combustion.
(4) Material changes as a result of combustion.
(5) Multi-dimensional heat transfer.

To compensate for these effects, the thermal diffusivity in the code was varied. This weighed thermal diffusivity value effectively measured the lumped effect of the above factors on heat transfer in the container by using the measured thermal behavior of the MTR box as a basis for thermal constants. By adjusting the thermal diffusivity

*MTR fuel element containers are of similar construction but are designed to accommodate 2 layers of fuel elements. Cadmium sheets are located above, between, and below the two layers of elements.

of the plywood in the external shell and the thermal diffusivity of the latex rubber surrounding the elements as functions of temperature, the measured experimental internal temperatures were simulated closely, as shown in Figure 2.4. The analytical method was adjusted to give temperatures slightly higher than the experimental results for a 54-minute elapsed time period to provide for a conservative analysis.

The developed thermal diffusivity of the plywood and latex was then used to describe the container reaction to the constant half-hour, 1475°F fire. The resulting internal container temperatures for one-half hour and one hour hypothetical fire conditions are compared in Figure 2.5. It is noted that temperatures were generally 180°F lower throughout the box after the half-hour, 1475°F fire than after the one-hour fire. It is also significant that if the constant temperature, half-hour fire were to be applied in the U.L. test described, the temperature of the top layer of cadmium would still rise above its melting point, thus verifying the need for an outer container.

2.5.3 MTR Container with Outer Container

An external enclosure was designed for the MTR container to insure that both outside layers of cadmium would remain intact during a fire.

The thermal analysis of the protective package considered the additional shell to offer the same thermal resistance (effective thermal diffusivity) as the shell on the original container. It will, in actuality, offer considerably more resistance because of the continuous welded steel sheathing seams.

A one-inch air gap between the outer shell and main container wall will be a region of radiative and convective heat transfer. A conservative equivalent thermal conductance was determined for the gap. Several conductivity values were assumed and applied on computer runs. The conductivity value used was that which effected the same heat transfer across the one-inch gap as calculated by hand using radiation and convection as the heat transfer medium between the two temperatures developed by the computer program using that conductivity value. (The code only allows conduction in a nonboundary region.) The assumed equivalent conductance throughout the fire was based on final, maximum value and is therefore conservative. It was assumed that the properties of the internal plywood shell would not change sufficiently to increase the heat transfer through that layer. Temperatures in this area, as indicated by the analytical results, would just reach the char point of wood. The thermal conductivity of charcoal is near that of wood.

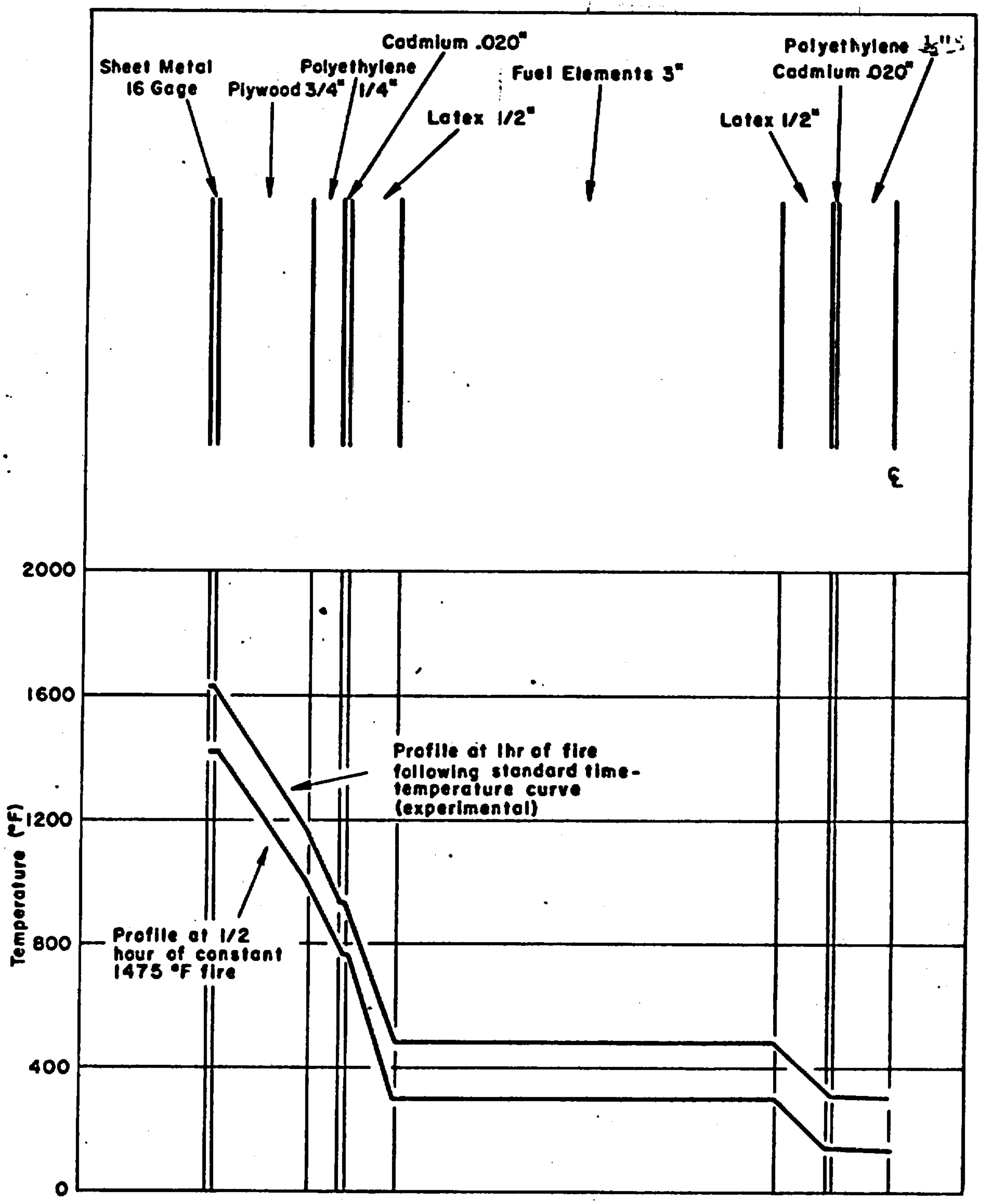


Figure 2.5 ETR Container Thermal Profile (No Protective Container)

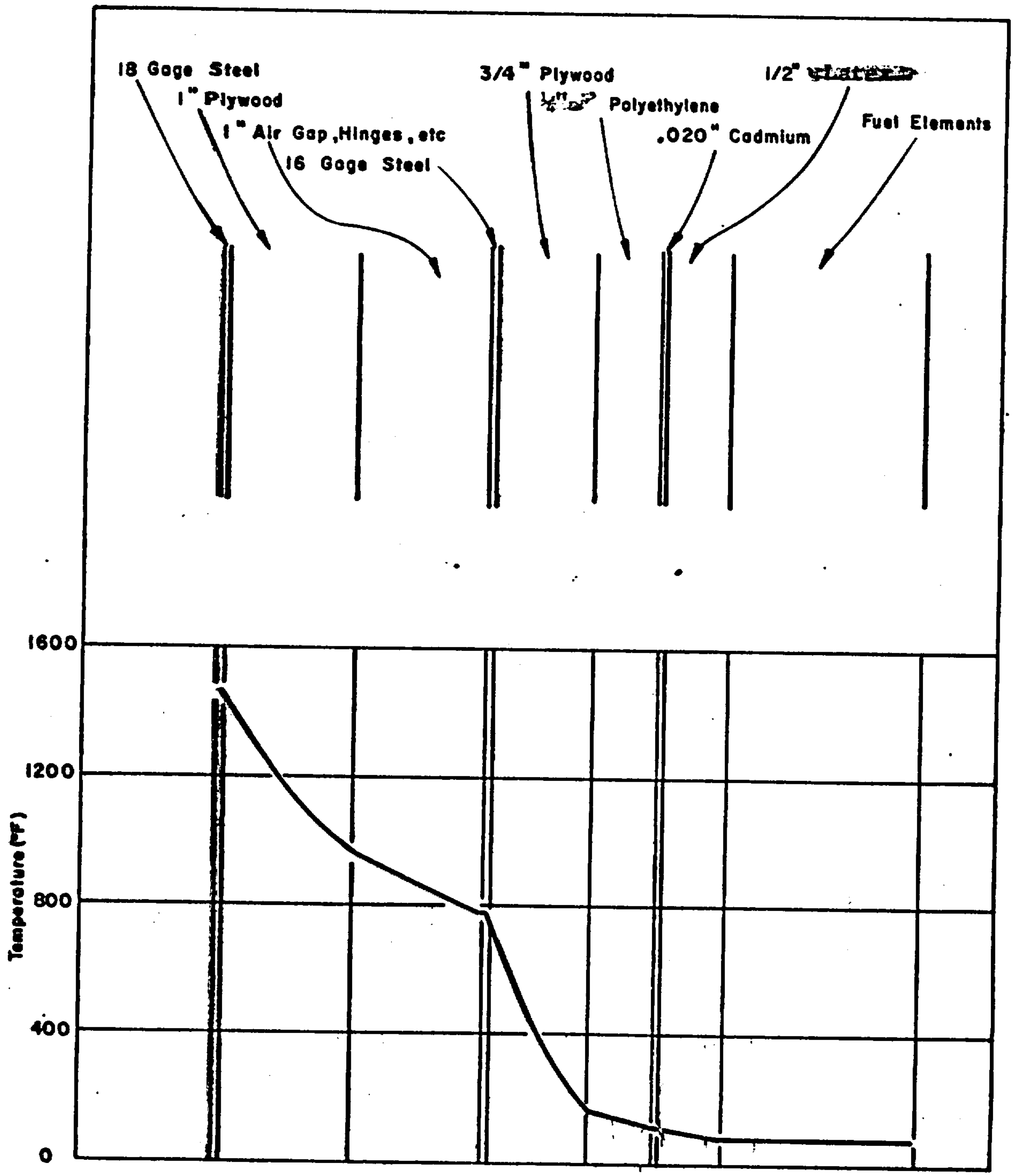


Figure 2.6 Thermal Profile of ETR Container with Protective Container

Results of the computer analysis indicate the maximum temperature reached by the cadmium was 170°F. This is well below 610°F melting point of cadmium and confirms a large margin of safety. The theoretical thermal profile of this protected container may be seen in Figure 2.6.

2.5.4 ATR Container

The same method, as described above, was used for the thermal analysis of the ATR container. The container internal geometry description, as modeled in the computer code, is shown in Figure 2.7. The container was given an initial uniform temperature of 130°F since this is the maximum temperature associated with normal conditions of transport (ERDA Appendix 0529). The container was then exposed, in the computer analysis, to a 1475°F fire for one-half hour, after which the environmental temperature was returned to 130°F. Internal temperatures were monitored until the temperature of the polyethylene, which is important for criticality, began to fall. Thermal profiles for the container are shown in Figure 2.7. One line on the figure shows the temperatures at the end of the one-half hour, 1475°F fire. The other line shows the temperatures at the time when the polyethylene temperatures peaked. Time-temperature plots of the polyethylene and the cadmium are shown in Figure 2.8.

The maximum temperature in the polyethylene is 306°F. At this temperature (which is well below the ignition temperature of polyethylene, 645°F*), the polyethylene will have softened somewhat, but it will not be liquid and will remain in its intended position, thus assuring that it will perform its intended function for prevention of nuclear criticality. The effect of temperatures in excess of 300°F on polyethylene was verified by a test documented in Appendix 2.6.1.

The maximum temperature shown for the cadmium is 263°F, with the temperature still rising slowly. However, the cadmium temperature cannot possibly exceed the temperature of the adjacent polyethylene which, at the end of the computer analysis, had fallen to 293°F. This is well below the 610°F melting point of cadmium, thus assuring a large margin of safety.

It is concluded that a one-half hour fire, followed by no cooling for three hours, will cause some charring of the plywood, but the basic structure of the container will not be changed. In addition, neither the polyethylene nor the cadmium will melt and the interior storage compartment will remain intact with no change. In particular, the fire will cause no changes in the exterior or

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* Polyethylene flash ignition temperature = 645°F and self ignition tempature = 660°F from Flamability Handbook for Plastics by Carlos Hilado , Technomics, Stanford, Conn.

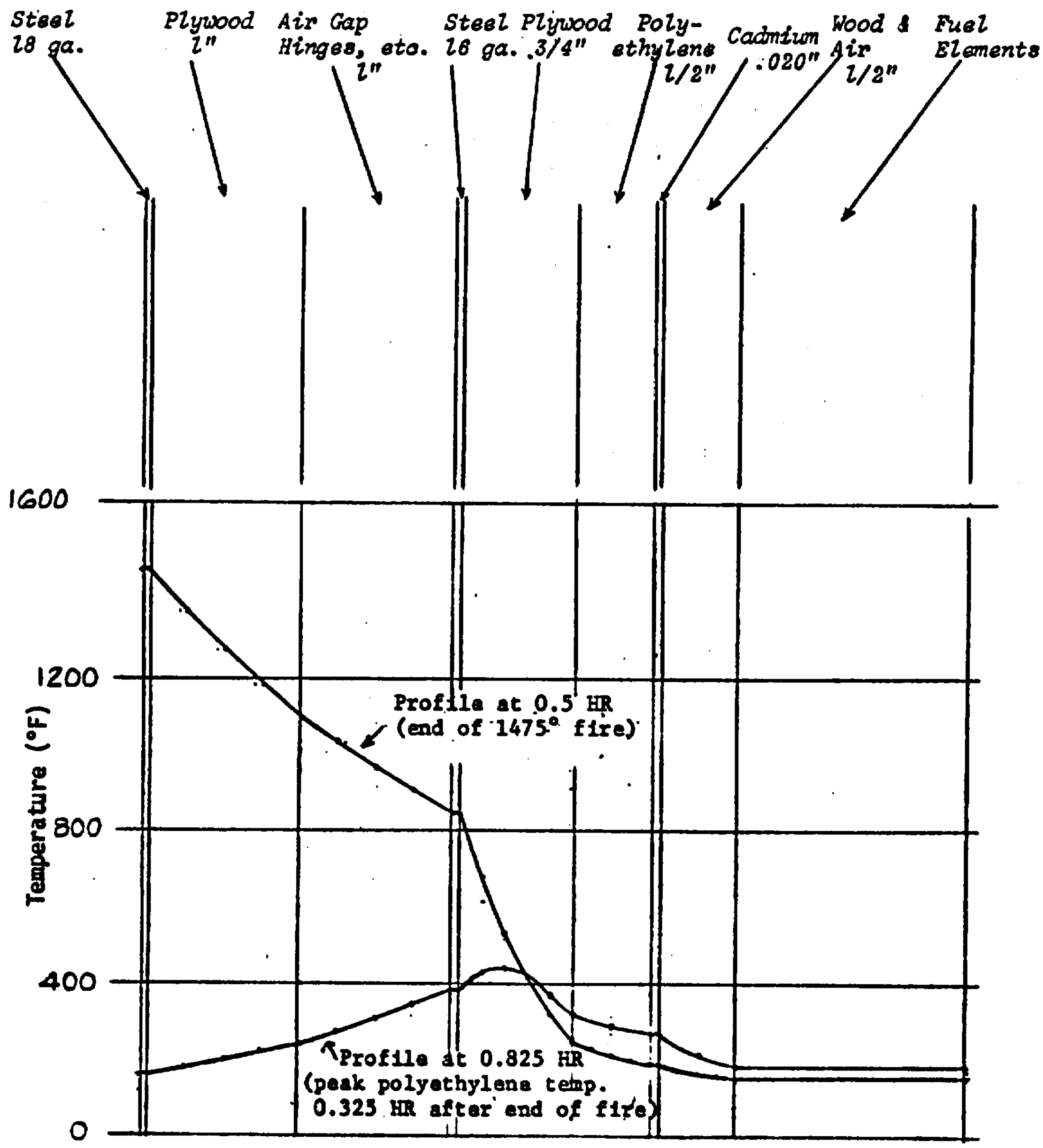

Figure 2.7 Thermal Profile of ATR Container with Protective Container

interior of the containers which will affect nuclear criticality or the container's ability to retain its contents. Thus, the ATR container will successfully withstand the thermal hypothetical accident condition.

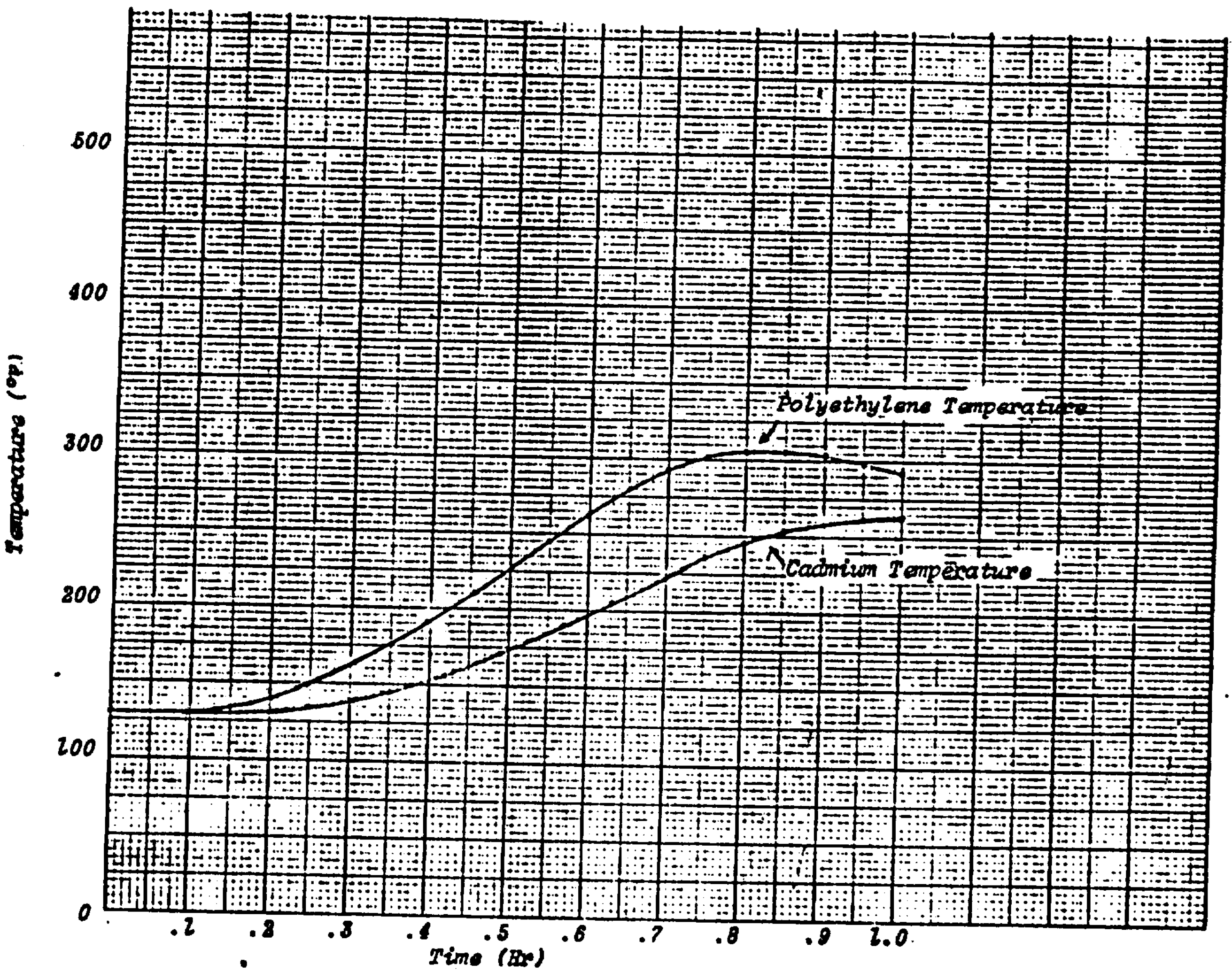

Figure 2.8 Time-Temperature Curves
for Polyethylene and Cadmium in the ATR Container

APPENDIX 2.6.1

THERMAL TEST ON POLYETHYLENE SHEET

PURPOSE: To observe high density polyethylene sheet when subjected to a temperature of 310°F and verify that the configuration of the polyethylene will not change significantly. Successful completion of the experiment would verify information obtained from polyethylene suppliers and establish that the polyethylene sheet used in the ATR Fuel Element Shipment Container would remain in place when subjected to a temperature of 306°F which would result from the 1475°F fire described in ERDA Appendix 0529 Annex 2.

TEST DESCRIPTION: The test was conducted at the Test Reactor Area, building MTR-667, Idaho National Engineering Laboratory on April 9, 1975. A specimen oven fitted with a thermometer to allow outside reading of inside oven temperature was used. Two specimens were selected for the test. The first was a 139.5 gram piece of one inch thick sheet having a measured density of 0.93 g/cc which places it in the medium density polyethylene class. The second specimen was a 90 gram piece of 1/2-inch sheet having a measured density of 0.95 g/cc which matches the polyethylene used in the ATR Fuel Element Shipping Containers. The two specimens were placed in the pre-heated oven at 310°F on a cylinder standing on end such that the ends of the polyethylene pieces had an overhang of about two inches. The polyethylene was inspected after 15 minutes, 30 minutes and 45 minutes. Observations are tabulated below.

At 15 minutes* - No observable change on either piece.

At 30 minutes* - No change observed on high density piece.

- Edges of 1" thick medium density piece were clear and rubbery, no deformation observed.

At 45 minutes* - Edges of high density piece showed slight clearing and rubbery with measured deformation at ends of 1/16 inch.

- Medium density piece showed increased clearing at ends and noticeable droop (1/8" at ends).

* Poloroid pictures taken and placed in Aerojet Nuclear Co., Plant Engineering Project File #85100-010,327 for record.

CONCLUSION: The test verifies that the high density polyethylene used in the ATR Fuel Element Shipping Container will remain in place when the container is subjected to the thermal condition of the hypothetical accident as described above.

Observers of the test were:

Aerojet Nuclear Personnel

L. L. Berry	- Safety
C. E. Friedrich	- Plant Engineering
L. W. Love	- TRA Operations
H. R. Orme	- Safety
R. L. Stevenson	- Safety
L. V. Wages	- Quality

ERDA-ID

L. E. Montoya - Test Reactors

3.0 CONTAINMENT

The specified containment boundary for the Fissile Class I, Type A quantity of material is the four compartments of the inner container in the 52-inch longitudinal region containing the cadmium. Methods to confine the material in this area are required when the contents are other than ATR fuel elements. The fissile material must additionally be contained in cladding or other containers which will prevent the spread of contamination.

Analyses in Chapter 1.0 and 2.0 of this document show that the inner container, when used inside the protective container, will endure all of the normal transport and hypothetical accident conditions without significant damage to the container. The analysis further indicates that no damage would occur to the contents and release of radioactive material is precluded.

4.0 SHIELDING

The ATR Fuel Element Shipping Container does not require shielding other than the neutron absorbing cadmium and polyethylene sheet which is used for criticality control. No other design features are specifically included for the purpose of radiation shielding.

Radiation levels at the surface of the outer container containing unirradiated fuel elements have been one or two mR/hr which are well below DOT regulation limits for Type A packages. In any event, Health Physics monitoring, required for all radioactive shipments, will assure that permissible radiation levels are not exceeded.

5.0 CRITICALITY EVALUATION

5.1 Introduction

The purpose of the evaluation is to demonstrate that the ATR Fuel Element Shipping Container has an adequate margin of safety below criticality when loaded with the maximum permitted quantity of fissile materials in the most reactive configuration, and subject to the maximum credible accident conditions. Normally, the container is used to ship assembled ATR fuel elements or "bundled" ATR fuel element plates.

The authorized limit is 12 kilograms, but not to exceed 700 grams in any one linear foot of U-235 in each of the four storage positions of each container. The fissile material must be confined to the 52-inch long section of the container containing the polyethylene-cadmium moderator-absorber. This limit provides flexibility in the use of the container, since any fissile material equal to or less than this limit is safe, regardless of the composition, provided the hydrogen atom density does not exceed that of water at 1 gm/cm^3.

5.2 Container Description

A description of the ATR Fuel Element Shipping Container is given in Section 0.2 of this document.

5.3 Criticality Control Parameters

5.3.1 Physical Control Parameters of the Container

The materials and geometry of the ATR Fuel Element Shipping Container are essential to criticality safety. No modifications in construction material and dimensions may be made to the containers without criticality evaluation, documentation, and approval.

5.3.2 Fissile Material Limits

The Fissile Class I material loading limits are those stated in Section 0.3 of this document.

5.3.3 Administrative Requirements

The administrative requirements are those stated in Section 0.4 of this document.

5.4 Inspection Requirements

The quality assurance and inspection requirements for the ATR Fuel Element Shipping Containers are those specified in Section 7.0 and 8.0 of this Safety Analysis Report.

5.5 Criticality Analysis

The calculational models used for analysis assumed an infinite array of shipping containers. One dimensional infinite slab geometry diffusion theory (DISNEL computer code) was used to perform parametric analysis to determine the most reactive fuel geometry and moderator conditions.

Figure 5.1 shows the infinite slab geometry model used for the diffusion theory parametric study, along with the material atom densities and dimensions, except for those in the fueled region of the model which were varied for the parametric study. A flooded condition assumed to be the most reactive was used in the initial models. Thus, the region between the inner and outer container is represented by a wood + water mixture with a water volume fraction of about 0.8. The material atom densities, H/U235 ratio, water volume fractions, and infinite slab thickness for the fueled region are given in Table 5-1, along with the results of each calculation. The fuel region thickness, given in Table 5-1, is one-half of that which would exist in an actual container, since the one dimensional infinite slab model is defined in the code with zero buckling in the infinite directions and zero neutron current at the inner and outer boundary, as indicated in Figure 5.1

By varying the water volume fraction and the thickness of the fueled region (Cases 1 through 7 of Table 5-1), it is shown that the most reactive geometry in the container is the fuel homogenized in water over the full length of the 4 inch x 6 inch cells at maximum water volume fraction. The fuel atom densities are equivalent to 1075 grams of U-235 (93% enrichment) homogenized in a cell 6 inches x 52 inches x 2 times the thickness indicated for each case in Table 5-1. Case 8 is the same geometry as Case 4 (i.e., the most reactive with the fuel homogenized over an entire cell volume), but for a higher U-235 loading (1075 grams x 1.75). Case 9 is the same as Case 8 except that water is eliminated from all regions outside the fuel region and shows an increase in reactivity.

Case 10 substituted graphite for water as a moderator in the fueled region. Otherwise, it is the same as Case 9 and demonstrates that in relatively thin fueled regions in a highly poisoned system, that water is the better moderator even in an infinite system. This is primarily due to the longer diffusion and slowing down lengths in graphite, which allows greater leakage to the external moderator-poison regions surrounding the relatively thin fuel region. This same conclusion is drawn for all other moderators which have a greater mass number than hydrogen (without additional calculations). Cases 1 through 9 thus demonstrate that the maximum possible content of water in the fuel region, but with no additional moderator or extraneous material outside the fuel region or between boxes, is the most reactive possible condition.

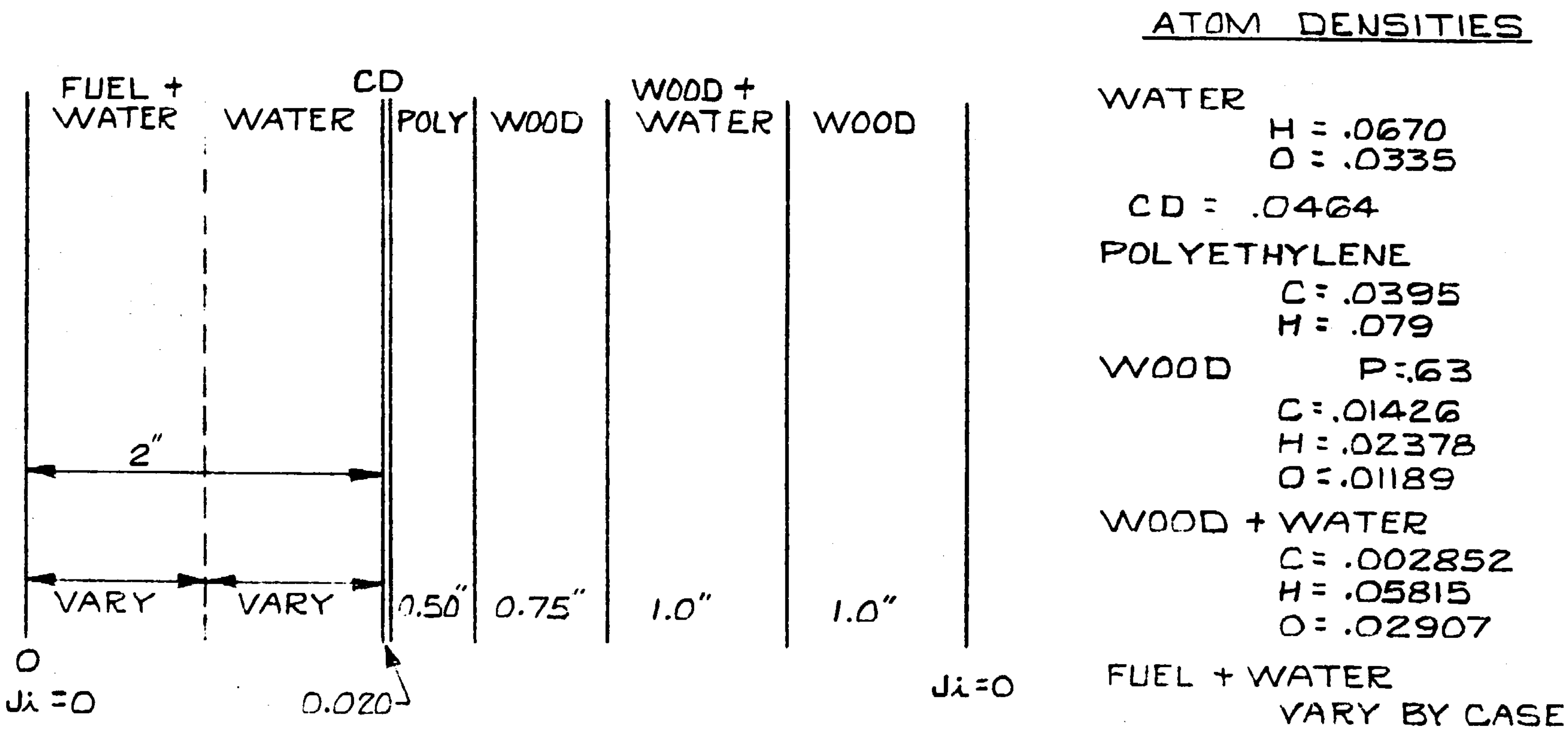

Figure 5-1 Infinite slab, infinite array geometry and materials model for ATR fuel shipping boxes.

TABLE 5-1

Fueled Region Parameters and Calculated Case Results For
Infinite Slab Geometry Diffusion Calculations of ATR Fuel Shipping Box

CASE	Fuel + Water Region 1/2-Thickness (inches)	Atom Density or Water V. F.			H/U-235	k_{inf}
1	2.0	(3)	U-235	1.347 -4	350.0	0.641
			U-238	1.001 -5		
		(2)	Water	0.7046		
2	2.0	(3)	U-235	1.347 -4	447.1	0.748
			U-238	1.001 -5		
		(2)	Water	0.90		
3	2.0	(3)	U-235	1.347 -4	481.85	0.778
			U-238	1.001 -5		
		(2)	Water	0.97		
4	2.0	(3)	U-235	1.347 -4	495.3	0.791
			U-238	1.001 -5		
		(1)	Water	0.9970		
5	1.5	(3)	U-235	1.796 -4	371.1	0.787
			U-238	1.335 -5		
		(1)	Water	0.9961		
6	1.0	(3)	U-235	2.694 -4	246.9	0.730
			U-238	2.003 -5		
		(1)	Water	0.9941		
7	0.5	(3)	U-235	5.389 -4	122.7	0.629
			U-238	4.005 -5		
		(1)	Water	0.9982		
8	2.0	(4)	U-235	2.357 -4	282.5	0.911
			U-238	1.752 -5		
		(1)	Water	0.9949		
9 (5)	2.0	(4)	U-235	2.357 -4	282.5	1.00
			U-238	1.752 -5		
		(1)	Water	0.9949		
10	2.0	(4)	U-235	2.357 -4		0.217
			U-238	1.752 -5		
		(6)	C	0.085		

(1) Maximum possible water volume fraction in fueled portion of cell.
(2) Partial water density in fueled portion of cell.
(3) 1075 grams U-235 in fueled portion of the cell.
(4) 1075 x 1.75 grams U-235 in fueled portion of cell.
(5) Low density aluminum substituted for the wood + water mixture to simulate a void between the inner and outer boxes.
(6) Graphite moderated fuel.

Once the most reactive geometry was obtained with DISNEL, the Monte Carlo Code, KENO, Version 5[1], with 16 group Hansen and Roach cross section library[2], was used to determine the infinite multiplication factor for the most reactive distribution and geometry. This code allows discrete geometrical representation of the shipping container. An infinite array of containers was simulated by representing a single container in the code and using spectral reflection of the neutrons on all six faces of the container.

The basic KENO model used is shown in Figure 5.2. The material atom densities shown in Figure 5.2 are for 3033 grams of U-235 loading in each of the four compartments (700 grams/linear foot). The following conservative factors are present in the model:

> Metal bolts and hinges present in the inner and outer containers were not modeled. The sponge rubber padding present in the container was not modeled - the exclusion of this material effectively increases the volume of the compartment, and thus the moderating ratio. The inner container is actually covered with 16 gage steel sheeting; this sheeting was modeled as 18 gage, this reduces the amount of steel - neutron poison, a conservative assumption.

KENO calculations were then performed to determine accurate multiplication values. The most reactive configuration having the maximum possible moderation in the fuel region with no extraneous material in the nonfuel regions was assumed with 3033 grams of U-235 loading in each of the four compartments (700 grams/linear foot). The calculated k_{inf} is 0.87 ± 0.02.

The analytical model assumes 4 inches of 0.02 inch cadmium sheet on each side of the 4-compartment storage region, whereas in actual fact, the cadmium sheet is only 3-1/8 inches high. This leaves a small neutron leakage path between the sides of the containers in an array. To demonstrate that this nonconservative factor is small, a second KENO run was made eliminating all of the cadmium on the sides. This increased k_{inf} from $0.87 \pm .02$ to $0.92 \pm .02$. The 7/8-inch leakage path would have a small effect compared to the 4-inch path so that the actual nonconservatism is of the order of one or two percent. Thus, the maximum k_{inf} for 700 grams of U-235 per linear foot is less than 0.90.

A third KENO calculation was run (with cadmium on the sides) to determine the safety margin in the 700 grams/linear foot limit. The enriched uranium loading was increased by 1.333 to 933 grams of U-235 per linear foot and resulted in a k_{inf} of $.93 \pm .03$. A linear extrapolation (which should be conservative since the moderating ratio is being reduced) indicates that criticality is reached in an infinite array with a fuel loading of approximately 1200 grams of U-235 per linear foot in each compartment.

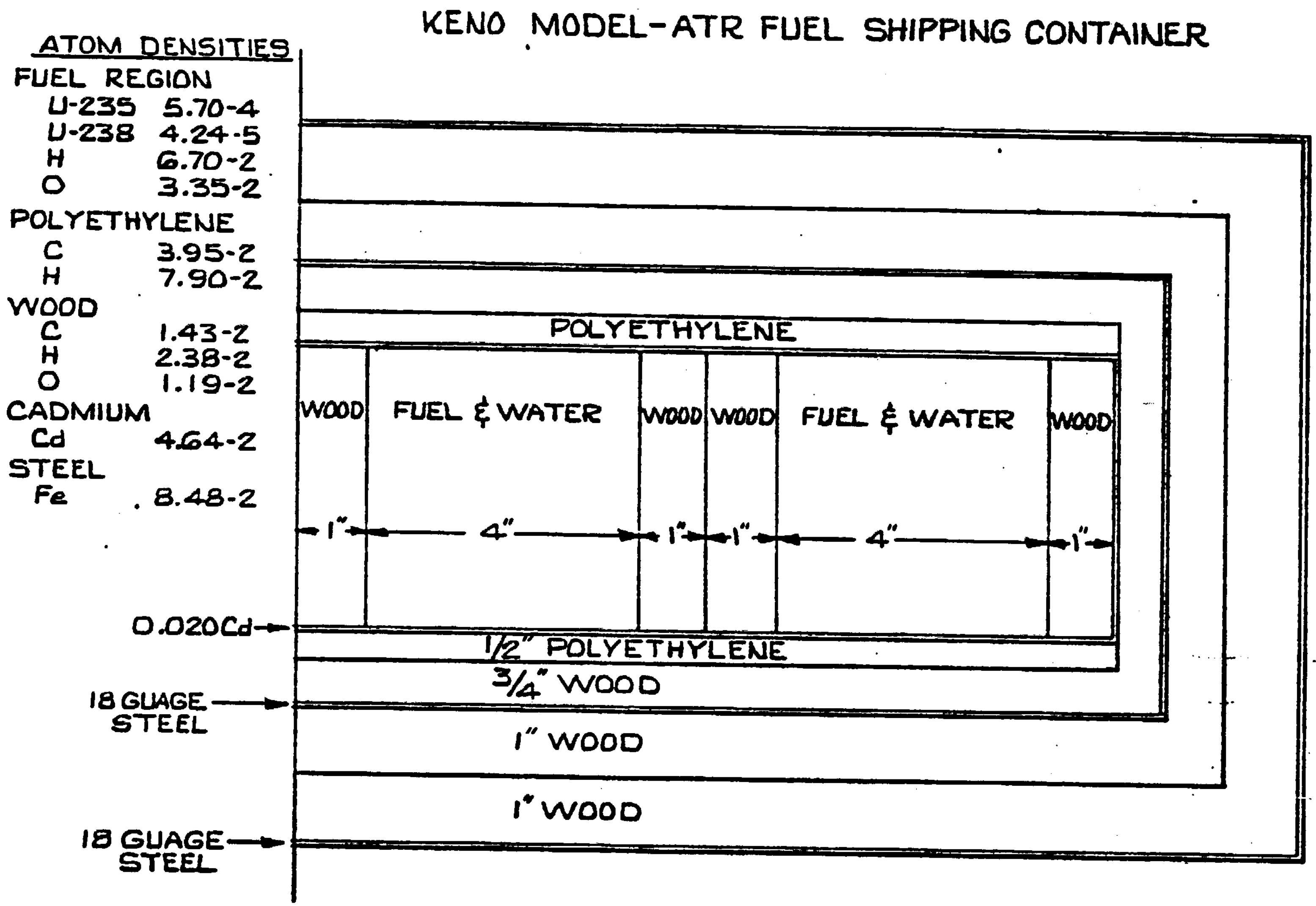

Figure 5.2 KENO Computer Code Model for ATR Fuel Shipping Container

5.6 Discussion

The infinite slab diffusion calculations cannot represent the actual container close enough to give accurate multiplication factors. Results are too conservative, giving such high multiplication factors that fissile loading limits would be unduly restrictive. Diffusion calculations can, however, be relied upon to show the direction of reactivity changes in parametric studies.

KENO can represent discretely the fuel container geometry, and the code accuracy has been validated for a number of different systems.(3) No validation is known to exist for highly poisoned systems, such as this study considers; however, there is no known reason why Monte Carlo methods should not give accurate results for this highly poisoned system. In addition, a conservative fissile limit for a container is chosen to provide an adequate safety margin while allowing for any unknown anomalies in the method of calculation.

As demonstrated, the most reactive condition for the ATR Fuel Element Shipping Container, within the limits specified, is fully enriched uranium homogenized with maximum possible volume fraction of water in the fuel region; additional material, such as water, in the nonfuel regions or interspersed between the boxes reduces reactivity. This is expected because the maximum possible H/U-235 moderating ratio of 495 in the fuel region for the parametric study (Case 4, Table 5-1) is near, but less than optimum for cylinders and slabs. In addition, the relatively thin fuel region bounded on two sides by cadmium sheets make hydrogen a most effective moderator. This was shown by Case 10 which resulted in a decrease in reactivity with a carbon moderator. The moderating ratio of 495, in the slab geometry model with wood spacers removed, is greater than the actual maximum possible moderating ratios as presented by the KENO model.

Conclusion: The only changes in materials or dimensions which can occur during a maximum credible accident would be a loss of moderating material from the fuel region or an increase of material outside of the fuel region. Both changes decrease the reactivity of an infinite array of containers.

Since the conditions of the hypothetical accident will not adversely affect the structural integrity of the container an infinite array of containers subjected to the accident and loaded with authorized contents as listed in Section 0.3 using the administrative controls listed in Section 0.4 will remain subcritical with optimum moderation. The ATR Fuel Element Shipping Container therefore meets the requirements specified for a Fissile Class I package.

5.7 Independent Criticality Safety Analysis

5.7.1 Introduction

The purpose of this evaluation is to independently verify the analysis of the primary criticality safety evaluation. The container description, criticality control parameters, and inspection requirement used are the same as those used in the primary evaluation.

5.7.2 Criticality Analysis

The KENO[1,3] computer code and the 16 group Hansen and Roach cross section[2] data was used. The model used to describe the ATR Fuel Element Shipping Container is shown in Figure 5.3. The atom densities used in the analysis are provided in Table 5-2. The following factors were used in modeling the container.

(1) In the model, the steel sheeting of the outer container and steel bolts used in the construction of the container were not included in the model. The presence of this additional steel would reduce reactivity; thus not including the material is a conservative approach.

(2) Metallic claddings or canning materials and the sponge rubber cushioning was not modeled.

(3) The fissile material was modeled as uranium 93% enriched in U-235 homogeneously dispersed with full density water. The uranium-water mixture was modeled as completely filling the volume of a 52-inch long storage position.

(4) The region between the wood of the outer protective container and the steel sheeting of the inner container was estimated to contain 20% wood by volume. This may be a slight nonconservative factor since it was determined that the addition of 20% water moderation in this region reduced reactivity of the container by approximately 1%.

(5) The triangular wood spacers between storage positions were modeled as rectangles of approximately equal cross sectional areas. The effect on reactivity of this change in geometry is considered negligible.

(6) As shown in drawing ATR-E-1053, the cadmium does not completely encompass the fuel region in that there is an approximately 3/4-inch wide, 52-inch long "slot" in the side corner. This slot was not modeled. As shown in Figure 5.3, the cadmium in the analytical model completely surrounds the fuel regions on four sides. The nonconservatism presented in modeling the narrow strip of cadmium in the corner of the container is small in magnitude by previously mentioned modeling conservatisms.

(7) The analysis was performed modeling an infinite array of containers, i.e., there is no leakage of neutron from the system.

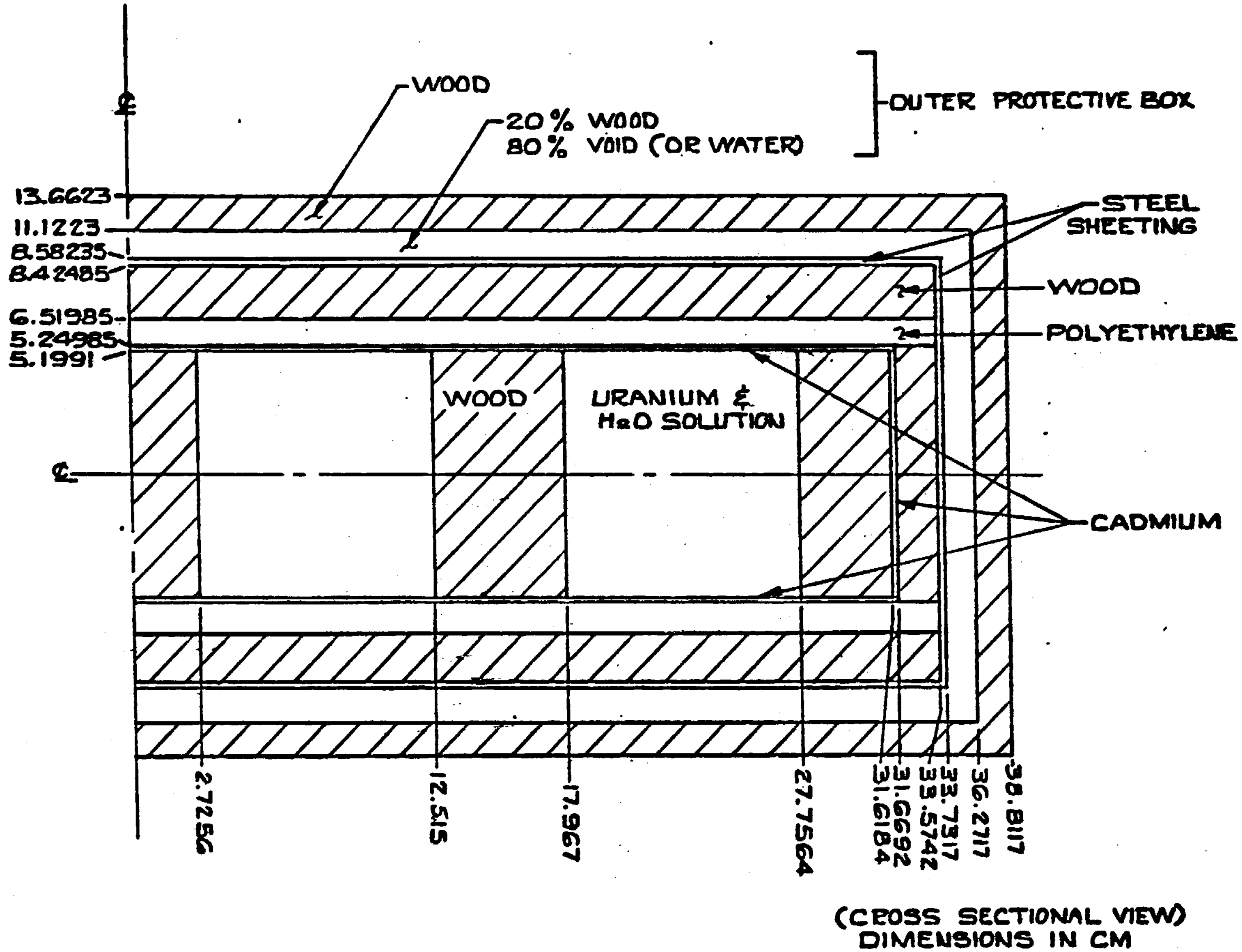

Figure 5-3 Computer Model
ATR Fuel Element Shipping Container

TABLE 5-2

Material Densities	Atoms x 10^{23} Per CC	
Wood .512 g/cc	C	.01142
	H	.01918
	O	.00951
Wood-void between boxes		
(A) 20% wood 80% void (Cases 1 and 2)	C	.002284
	H	.003836
	O	.001902
(B) 20% wood 20% H_2O 60% void	C	.002284
	O	.008592
	H	.017214
Polyethylene .95 g/cc	C	.04079
	H	.08158
Water	H	.06689
	O	.033445
Cadmium	Cd	.046337
	O	.0000001
Steel	Fe	.08289
	Ni	.00161
Fuel Region (uranium-water)		
Case 1 (Case A wood-void)	U-235	.0002669
1400 g U-235/position	U-238	.00001976
	H	.06689
	O	.033445
H:x ≈ 250		
Case 2 (Case A wood-void)	U-235	.000591
3100 g U-235/position	U-238	.000044
	H	.06689
	O	.033445
H:x ≈ 113		
Case 3 (Case B wood-water-void)	U-235	.000591
3100 g U-235/position	U-238	.000044
	H	.06689
	O	.033445
H:x ≈ 113		

(8) From Section 1.7 of this document, it is concluded that the sequence of hypothetical accident does not have significant adverse effects on the materials or dimensions of the ATR Fuel Element Shipping Container.

5.7.3 Results

These cases were modeled; they are listed below.

Case 1: 1400 g U-235 per position;
323 g U-235 per linear foot of storage position.
Infinite array K_{inf} .81 $\pm$ .01

Case 2: 3100 g U-235 per position:
715.4 g U-235 per linear foot of storage position.
Infinite array K_{inf} .91 $\pm$ .01

Case 3: 3100 g U-235 per position;
715.4 g U-235 per linear foot of storage position.
Infinite array with the addition of 20% water between the inner and outer containers K_{inf} .89 $\pm$ .01

Case 1 shows that a lower fuel loading and an increased hydrogen to uranium (H:R) is less reactive than the fully loaded Case 2.

Case 2 verifies that ATR Fuel Element Shipping Container meets the requirements of a Fissile Class I container in that, an infinite array of the containers loaded as specified in Section 0.3 will remain subcritical following the hypothetical accident.

Case 3 shows that the addition of moderating material between the inner and outer containers (as in flooding) reduces the reactivity of an infinite array of the containers.

Conclusion: The above cases verify the analysis and conclusion of the primary evaluation.

5.7.4 References

(1) KENO II Input (Version 5), CTC-5, KENO - A Multigroup Monte Carlo Criticality Program, by G. E. Whitesides and N. F. Cross, Union Carbide Corporation, 1969

(2) LAMS-2543, Six and Sixteen Group Cross Sections for Fast and Intermediate Critical Assemblies, by G. E. Hansen and W. H. Roach, LASL, 1961

(3) UC-46, Y-1858, Validation Checks of "Anisn" and "KENO" Codes by Correlation of Experimental Data, by G. R. Handley and G. M. Hopper, November 20, 1972

6.0 OPERATING PROCEDURES

Since the ATR container is routinely used for ATR fuel elements, the detailed loading and unloading procedures are given below. If other material is shipped, special instructions, depending upon the form and composition of the material, will be required. These include, but are not limited to, verification of compliance with authorized contents as specified in Section 0.3.

6.1 Procedure for Loading

Each container must first be inspected and discrepancies corrected before being selected for loading, as per Section 7.0 of this document. One container is loaded at a time using the following sequence:

(1) Assure that the container is to be loaded per the Certificate of Compliance and record this on the appropriate shipment documentation.

(2) Move container to loading area using fork lift under container.

(3) Remove the hinge pins from the outer container.

(4) Lift off outer container lid (this should be done manually).

(5) Pull hinge pins from inner container and raise the lid to the position shown in Figure 0.1 of this report.

(6) Load material into place in accordance with the Certificate of Compliance.

(7) Close lid after material has been loaded.

(8) Insert the 2 inner hinge pins and their cotter pins.

(9) Manually place the protective container lid on the assembly and install the 4 hinge pins. Install cotter pins in all 4 hinge pins and in two diagonally opposed pins install security seals. "Loaded" tags should be installed through the other two hinge pins.

(10) Conduct a radiation survey to determine compliance with Section 0.3.2, "Radioactivity Limits", and DOT contamination limits.

(11) Place the loaded containers on the shipping vehicle and position the containers using a fork lift under the containers.

(12) ATR fuel element containers are presently shipped in a "sole-use vehicle" which was specifically designed and approved to accommodate radioactive shipments.

This vehicle uses 9/16-inch steel cable attached to 1-inch tool steel tie-down rings, fastened through the trailer structural members which are reinforced. The tie-down rings are spaced on 24-inch centers along both sides for the length of the vehicle.

The fuel element shipping containers are stacked a maximum of four high in the vehicle with the long dimension of the container parallel or perpendicular to the length of the vehicle. A wood 2x4, the length of the container, is placed on top of the top containers, on the outside edge to protect the cable and to distribute the tie-down pressure along the length of the container.

When the containers are stacked parallel with the vehicle, a tie-down cable is passed over each end of the container through an opposing tie-down ring. The cable is then tightened. Three Crosby cable clips are then installed and tightened. When the containers are stacked with the long dimension perpendicular to the length of the vehicle, the tie-down is the same except that the tie-down cable forms an X over the containers. In either case tie-down rings must be selected such that the angle of the cables to the floor of the truck is as near 45° as possible.

6.2 Procedure for Unloading

One container is unloaded at a time in the following sequence.

(1) Conduct Health Physics survey to verify that the package is received in compliance with the radioactive material loading limits (Section 0.3.2) and DOT contamination limits.

(2) Move loaded container to unloading area using a fork lift under the container.

(3) Remove "loaded" tags and security seals from the four hinge pins and remove the hinge pins from the protective container.

(4) Manually lift off the outer container lid.

(5) Remove the hinge pins from the 2 inner container hinges.

(6) Open the box lid to the position shown in Figure 0.1 of this document and verify by visual inspection that contents of the container are as described on shipping documentation. If there are any discrepancies or if there are deviations from the Certificate of Compliance, notify the Safety Division and obtain approval to unload before proceeding.

(7) Remove the material from one position at a time to approved storage.

(8) After items have been removed, inspect the container for damage and make arrangements for repairs if required.

(9) Close inner container lid and insert hinge pins and their cotter pins.

(10) Manually install protective container lid on assembly and install the 4 hinge pins and their cotter pins.

(11) Transport empty container assembly using fork lift under the container to approved storage.

(12) Tag as "Empty".

6.3 Preparation of an Empty Package for Transport

An empty container to be shipped for later use for a return fuel shipment must be inspected and discrepancies corrected, as per Section 7.0 of this document.

7.0 ACCEPTANCE AND MAINTENANCE PROGRAM

7.1 Acceptance Tests

Original acceptance tests for the inner containers and the outer protective containers were made in the early and late 1960's, respectively. At that time, records of acceptance tests were not required as a part of safety documentation. As a result, these records have not been kept in an active file and are not readily available. However, it is known that dimensional and material inspections were performed against the specifications included in the drawings in Appendix 1.8.1, "Engineering Drawings of the ATR Shipping Box and Protective Container." Reverification of the thermal resistance of the fire retardant treated plywood is not considered necessary, since the plywood is sheathed in steel and is not open to the elements so that degradation is essentially zero.

Actual neutron reduction (transmission) measurements through the top, bottom, and sides of the container are required to verify the adequacy and presence of the cadmium. These measurement records are available on request. Containers not subjected to the measurements shall not be considered approved shipping containers in compliance with this document.

7.2 Maintenance Program

The maintenance program is performed as a result of and in conjunction with the Quality Assurance Inspection Maintenance Plan, which appears as Section 7.3 of this document.

Specifically, the program requires inspection of the outer container for damage, such as splitting, dimensional distortions, skid damage, and the inner container, to verify that sponge rubber is not deteriorating or missing, that cadmium and polyethylene sheets are in position on the lid and bottom, and that the latches, latch pins, and chains are in good condition. Visual inspection of the cadmium in the sides of the container is not considered necessary as its presence has been verified by neutron reduction measurements and its removal would require the disassembly of the container. If damage or other evidence indicates that mechanical or chemical degradation might have occurred to the cadmium in the sides of the containers the presence of cadmium will be verified by disassembly or neutron reduction measurements as appropriate.

The Inspection/Maintenance Plan for ATR Fuel Element Shipping Containers further provides that each container be inspected and that repair of discrepancies be completed and reinspected before reuse of the container.

7.3 Inspection/Maintenance Plan

7.3.1 Objective

Establish an Inspection/Maintenance Plan for maintaining ATR Fuel Element Shipping Containers in compliance with the approved drawings in Appendix 1.10.1.

7.3.2 Procedure

ANC Quality Division will perform inspections prior to reuse and following use of the container, and maintain an up-to-date permanent record file for each container which indicates inspection results, maintenance required, reinspection results following repairs, and acceptance for reuse.

These inspections are to be performed subsequent to receipt of container with fuel elements and prior to reuse.

An inspection record file is to be maintained current for each container number. The record file is to contain dates of each inspection, brief explanation of inspection results, status of follow-up for repairs, date and results of subsequent inspection following repairs, and inspectors indication as to acceptability for reuse. The following items shall be specifically inspected:

(1) Outer Container (Drawing 035929, Rev. C)

Visually examine for severe damage to the container, such as splitting, dimensional distortion, weld failure, and skid damage.

(2) Inner Container (Drawing ATR-E-1052, Rev. B)

Visually examine for the following:

(a) Verify sponge rubber is not deteriorating or missing (include lid).

(b) Verify cadmium and polyethylene sheet are not damaged and are on lid and bottom of box.

(c) Verify latch pins, latches, chains and welds are in good condition.

(d) Visually examine sides of box where spacer encloses cadmium to sides of box. Presence of cadmium in sides of container must be verified if degradation or absence of cadmium is indicated.

8.0 QUALITY ASSURANCE

The Aerojet Quality Assurance Program, regarding the shipping containers, is stated in Section 7.3, Inspection/Maintenance Plan, for ATR Fuel Element Shipping Containers.

This plan provides for specific inspection of the container after unloading and inspection following required repairs before reuse.

New ATR Fuel Element Shipping Containers constructed will require Quality Assurance in compliance with ERDA M-0529 Part III. Specific fabrication procedures, codes, standards, and specifications will be assigned as applicable to items not defined in construction of the original containers.

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